Exploring Physical Phenomena

Exploring Physical Phenomena

What happens when light from the Sun shines on the Earth?

EMILY VAN ZEE AND ELIZABETH GIRE

OREGON STATE UNIVERSITY
CORVALLIS, OR

Publication and on-going maintenance of this textbook is possible due to grant support from Oregon State University Ecampus.

Contents

Preface

Exploring Physical Phenomena: What happens when light from the Sun shines on the Earth?

This textbook is intended for use in laboratory-centered physics courses for prospective and practicing elementary and middle school teachers. By exploring physical phenomena in class, participants learn science in ways in which they are expected to teach science. The emphasis is upon questioning, predicting, exploring, observing, discussing, reading, and writing about what one thinks and why.

This textbook also is appropriate for use in general science courses that explore some of the physical phenomena underlying global climate change. In addition, organizations such as museums, youth groups, or senior citizen programs may find one or more units a feasible framework for offering extended science learning experiences to the public during workshops and/or special events. Some of the activities also could form the basis for on-going exhibits.

The text assumes that the participants will be working at tables in small groups rather than sitting in rows listening to lectures. However, the course has been adapted for remote learning. Most of the equipment involves everyday materials available in homes, schools, and offices. Regular bulb thermometers can be substituted for the digital temperature probes described in the text. Participants can use a cell phone app to measure reflectivity if they do not have light sensors. Those without access to motion detectors can use the graphs provided in the text to learn about the phenomena explored with these devices.

The level of mathematics required assumes proficiency in mathematics taught in K-8 classrooms. Also assumed is the willingness to strengthen some high school mathematics skills as needed. These include using the geometry of similar triangles, interpreting the heights and slopes of line graphs, and solving linear algebraic equations.

A. Unit Structure

Each unit follows the same structure:

- **Identifying resources** participants bring to the study of a topic from their prior experiences.
- **Developing central ideas** based on evidence from exploring physical phenomena with everyday equipment and materials.
- **Using these central ideas to explain intriguing physical phenomena**.
- **Developing mathematical representations** of the phenomena.
- **Using these mathematical representations to estimate a quantity of interest**.
- **Making connections to educational policy and the US *Next Generation Science Standards* (NGSS Lead States, 2013)**.

By central ideas, we mean understandings about physical phenomena that students develop while making sense of their observations. These ideas emerge from the students' discussions with one another as well as with the instructor. These central ideas also are powerful ideas because they form conceptual models useful in describing and explaining the phenomena explored. The units also develop expertise in generating and interpreting multiple representations of phenomena such as sketches, geometric figures, line graphs, and algebraic equations.

The theme for the course is: *What happens when light from the Sun shines on the Earth?* The first unit focuses on the nature of light phenomena. Students explore questions such as how light travels from a source, what affects the size and shape of shadows, how pinhole cameras work, how light reflects from both smooth and rough surfaces, and what happens when light shines through materials such as water and prisms? Students develop central ideas based on evidence from exploring these phenomena and use these understandings to think about what causes rainbows.

When light from the Sun shines on the Earth, things often get hot, so the second unit explores the nature of thermal phenomena. Why, for example, do some things feel hot or cold, how is energy conserved when mixing hot and cold water, and what happens when ice melts, liquid water warms, and then boils?

The third unit considers the influence of light and thermal phenomena on the water cycle and local weather. Students develop central ideas about forms of energy transfer such as radiation, reflection, absorption, conduction, and convection. They also explore properties of materials such as thermal conductivity and specific heat. They then use these ideas to explain weather phenomena. In particular, students develop explanations for why, after a sunny day at the beach, the sand is hot, water cool, and cloudy skies often occur along with sea breezes in the afternoon.

The fourth unit considers the influence of light and thermal phenomena on global climate (van Zee, Roberts, & Grobart, 2016). Questions include what happens to energy from the sun as it gets reflected or absorbed by the oceans, land forms, and atmosphere? What is the greenhouse effect and how does it modulate global temperatures? Students review websites presenting climate change indicators in the US, social issues, military issues, and ways to take action. They also review websites presenting local, state, national, and international efforts to understand and address concerns about changes in the global climate. As part of this unit, the students also explore motion to think about how to interpret graphical representations of changing phenomena– where something is, its position or current value; how that position or value is changing, its speed or rate of change; and how its speed is changing, its acceleration, where the 'it' may be a car speeding up but also could be the mass of melting glaciers all over the Earth.

The fifth unit extends throughout the course. On-going observations of the Sun and the Moon provide evidence for thinking about why day and night occur, why the Moon seems to have different shapes at different times, and why many places on the Earth experience different seasons at different times of year. Excerpts from writings by Galileo, Newton, and other scientists provide insights into the history of thoughts about the Earth's place in the Universe. Explorations throughout the course also provide contexts for reflecting upon the nature of science as well as upon the nature of science learning and teaching.

Each unit ends by making connections to educational policy, such as recommendations articulated in the US *Next Generation Science Standards* (NGSS Lead States, 2013). In particular, students reflect upon ways in which their explorations and developing understandings exemplify the science and engineering practices, crosscutting concepts, and disciplinary core ideas presented in this document.

B. Class Sessions

This textbook can support classroom-based, hybrid, and online courses. Our course meets twice a week for 2.5 hours each session for ten weeks. The supplementary materials may be used to extend instruction for a semester. Class sessions include documenting initial knowledge, exploring phenomena, recording progress during explorations, discussing interpretations, writing to solidify understandings, and closing by reflecting upon what learned and what one is still wondering.

1. Identifying Student Resources

Each unit begins with a diagnostic question to which students respond in order to document what they already know about some aspect of the phenomena they will be exploring. Some diagnostic questions require drawing and/or writing responses individually. Others involve small group conversations and brief presentations to the whole group. Responses to these diagnostic questions are not graded.

Diagnostic questions alert students to the context of upcoming explorations; they alert the instructor to prevalent ideas on which the students can build as well as to those that may need refining. Many initial ideas are reasonable within everyday circumstances rather than misconceptions that need to be corrected. The notion that a force is necessary to keep something moving, for example, is reasonable when thinking about everyday experiences in pushing objects along rough surfaces. Refining that notion involves considering the effect of different surfaces on the force needed; less force is needed to keep something moving at the same speed on smooth surfaces such as ice. If no friction with the surface and no air resistance occurs, no force is needed to keep something moving at the same speed in the same direction. Recognizing such conditions of applicability is an important aspect of learning physics. Instead of memorizing Newton's first law with a shrug as a counterintuitive abstraction impossible to believe, students can understand it as a sensible statement, that a moving object stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

Responding to diagnostic questions can activate *resources* from prior experiences that students can build upon in thinking about and exploring physical phenomena. The focus on reflecting upon one's own learning in this course also activates *epistemological resources*, from prior experiences that students can build upon in thinking about and exploring learning phenomena (Hammer & Elby, 2003). Students respond to some diagnostic questions again later in the course, compare their initial and current responses, and write about their learning processes with evidence drawn from their initial and current responses to support their claims. In an on-campus course, such diagnostic questions have been initially asked on handouts that students completed in class. The instructor collected, viewed, and stored the responses until returning them after students had completed handouts documenting their current understandings near the end of the course. In the remote learning setting, the students responded in class to ungraded surveys, both initially and near the end of the course. Both responses were accessed and stored electronically.

2. Exploring Phenomena

The units focus on doing and interpreting explorations of phenomena in class. Most equipment can be found in everyday settings such as kitchens, playrooms, and offices. Some activities and assignments assume students have access to a computer and to the Internet both inside and outside of class. Suggestions in the text reflect our setting of a classroom with tables at which small groups work together. Online students could collaborate in small groups via their course's electronic network or in breakout rooms. It would be best for interested individuals not enrolled in a course to explore phenomena with friends and/or family members rather than alone, but access to a variety of perspectives will be possible through reading the example student findings and interpretations.

The text presents the explorations as numbered ***Questions*** with bulleted statements that suggest what to do. These directions are not intended, however, to be handed out in class. The expectation instead is that the instructor will pose these general questions, provide the small groups with equipment needed, and offer some initial oral suggestions that the students see what they can find out by using the equipment to explore the phenomena. This open-ended format encourages active student engagement in designing explorations and interpreting findings.

This instructional approach assumes active engagement by the instructor and assistants as well. We recommend arranging for one or more graduates of the course to serve as learning assistants (LAs) for independent study credit or for stipends if department funding is available. Physics majors interested in teaching careers also have served as LAs for us as well as graduate students as teaching assistants (TAs). The instructor and such assistants circulate among the tables, listen in to what group members are saying, observe what the students are drawing or doing, and then ask a question or offer a comment only as needed to help a group to make progress. This process proved difficult in the remote learning setting as one cannot monitor what is happening across multiple groups while assisting one group. It is important to listen first to what is happening when joining a breakout room before intervening, or not.

A staff member may simply ask a small group "what are you doing?" to initiate a conversation that encourages students to clarify for themselves whether what they are doing and thinking makes sense in moving toward whatever is the goal. The staff member may follow up with "why are you doing that?" and/or "how is that helping you?" Such gentle guidance is essential for nudging groups along while also providing opportunities for students to design and undertake inquiries in ways that interest them. Alan Schoenfeld (1992) suggests asking these questions to help students avoid going down unproductive paths in solving mathematics problems. Such questions also can help students learn how to monitor their own progress eventually in designing, conducting, and interpreting explorations.

3. Recording Progress During Explorations

Keeping track of what one is doing and thinking is important. In our course, students use a template for a physics notebook page on which to record their notes during class. When students submit homework assignments, the instructor may ask them to submit these notebook pages as well, perhaps for a grade or just to get a sense of how students are doing. This textbook assumes students are using this physics notebook page but instructors may prefer to have other ways for students to document what they are doing and thinking in class.

The front and back of the recommended physics notebook page for students to use to keep track of what they are doing and thinking during explorations: **here** (docx) or **here** (pdf).

This shows the physics notebook page template with explanations of the various sections: **here** (docx) or **here** (pdf). Sections on the front of the physics notebook page include the *Topic* of the exploration, the students' initial ideas and plans *Before* starting their exploration, their observations and thoughts about what they are observing *During* their exploration, and relevant *Vocabulary*.

Example: Front of Physics Notebook Page

Topic: State the focus of the exploration: what question(s) are you asking?

Before column. Before starting your exploration, think about and discuss with your group members what you know already about this topic, how you plan to conduct the exploration and what you think you might find out. Record these initial ideas in the "Before" column. Draw pictures to represent your plans and predictions.

During column. During your exploration, record what is happening, what you observe, and what you are thinking about what you are observing. Include sketches of equipment and observations. Confirm or disconfirm predictions and describe some possible next steps.

Vocabulary. Note any words that are new and their definitions.

Sections on the back page refer to what happens after collecting data and recording these findings. These sections include *Central Ideas* that emerge from interpreting findings, the *Relevant Evidence* on which you are basing those ideas, the *Rationale* that justifies how the evidence supports the claims being made with these ideas, a *Reflection* about the exploration, and *What* you are *Still Wondering*.

Example: Back of Physics Notebook Page

After: **Central Ideas.** After your exploration, record any central ideas that have emerged from your observations and discussions.

After: Relevant Evidence. Also note the evidence on which you have based these ideas.

After: Rationale. State explicitly how the evidence is relevant and supports the claims you are making in stating the central ideas. Also explain why this result is important.

After: Reflection. Then write a reflection about whatever you want to remember about this experience – perhaps how what you learned connects to other experiences, how you learned what you learned, and what implications these findings might suggest for the next exploration or for teaching this topic in your own classroom.

After: Wonderings. In addition, briefly state what you are still wondering in this context.

Our students make copies of the template of the two-sided physics notebook page, punch holes in the copies, and use a 3-ring binder in which they store the notebook pages and handouts. They bring copies of the physics notebook page to class to use during explorations. Instructors may prefer to recommend other processes for documenting explorations in this course.

Entries on the physics notebook pages in class serve as notes for writing a coherent summary of **questions, initial thoughts and plans, findings, and interpretations** as a laboratory report after class. For the most effective learning experience, students complete explorations and summaries before reading the example student findings and interpretations included in the online text.

Adam Devitt designed these physics notebook pages when he was assisting in this course. He was a special education elementary school teacher enrolled in a graduate program in science education. He based his design of these physics notebook pages by analogy with "before, during, and after" reading strategies that enhance literacy learning (Devitt, 2010; Winegrad & Devitt, 2009). The pages have been slightly modified with the addition of a *Rationale* section and revision of some of the suggestions in the template with explanations of the various sections.

4. Discussing Interpretations of Findings

Initial discussions interpreting findings occur in the small groups. It is important, however, for the whole group to come to consensus on what the observations were and what these findings mean. There should be a clear articulation of one or more central ideas that emerge from the exploration, the evidence upon which the claims are based, and the rationale that discusses how the evidence supports the claims and why this result is important. This coming to a shared understanding about what happened and what one can infer from the findings can occur through small group presentations and/or instructor facilitated whole-group discussions.

Small group presentations maximize the involvement of individual students in developing interpretations and ways to present these interpretations to the whole group. Students need to plan and rehearse how every member of the group will contribute to what they are reporting about their findings and interpretations. If the small groups have been exploring the same phenomena in different ways, suggesting a different focus to different groups will help multiple small group presentations remain interesting and informative.

As small groups are working on their presentations, the instructor and assistants visit each group briefly to look at what the students are putting on a poster (large whiteboard) and to listen to what each student is planning to say. This way the instructor and assistants can help shape what the students choose to present and address any issues that need refining. The group members should include the process of resolving any such issues as part of their presentation.

Facilitating whole group discussions involves listening to what students say, welcoming contributions from a variety of individuals, and encouraging student/student interactions. One way to encourage student questioning is to paraphrase what someone just said and wait before saying anything more. Listening to statements puts students into a conversationally appropriate position to ask a question. If the instructor waits without responding to that question, another student may venture an answer, which may prompt yet another student to risk offering a contribution to the thinking (van Zee & Minstrell, 1997). Although time-consuming, such vigorous student/student discussions can create a meaningful context for students to make sense of their findings before leaving class.

It is important for the instructor to resist the temptation to present a quick coherent summary of what was to be learned. If this occurs frequently, students tend to wait for it and not engage as well in making their own sense of what has happened. The extent to which the instructor feels compelled to 'tell answers' likely will vary, however, with the time to the end of class, the importance of the current topic to later topics, the apparent engagement of the students, and everyone's patience. We believe that the more group members can generate their own ideas, resolve puzzles themselves, and develop coherent arguments supporting their claims, the more they will learn.

Fostering small group presentations and/or whole group conversation near the close of the students' explorations is an important step in helping to clarify and refine understandings. Such presentations and conversations also will help students develop the skills in argumentation advocated in the US *Next Generation Science Standards* (Lead States, 2013). The intent is for the students to be the ones who articulate emergent central ideas, state relevant evidence, and provide rationales to explain how that evidence supports the claims being made and why the result is important.

Similar interpretative processes occur during subsequent sessions when students use the central ideas developed previously in order to explain intriguing phenomena that they have just explored, to develop mathematical representations of the phenomena, and/or to use these mathematical representations to estimate a quantity of interest.

5. Writing to solidify understandings

Scheduling time near the end of class for students to write about what they have understood helps solidify understandings about the physical phenomena explored and the learning that occurred during the session. Sometimes this can be an open-ended opportunity to reflect on what seems most interesting and/or important to the students but often the instructor may choose to provide some structure such as a table to complete, a drawing to be made, or a prompt for a summary statement. Many of the optional handouts provide such structure. These efforts do not need to be collected nor graded. They are intended to be the beginnings for students to write a coherent summary prepared at home.

6. Reflecting Upon What Learned and What Still Wondering

At the close of class, members of each small group reflect together upon what they have just learned in class, write a brief statement of what was most interesting to them, and articulate a question that expresses what they are still wondering. They record these thoughts briefly on *exit tickets* that the small groups turn in as they leave class. In the remote learning setting, the students responded individually to ungraded surveys with the essay questions *What was most interesting about what you learned today* and *What are you still wondering*. This provided immediate feedback to the instructor, which was very helpful in becoming aware of issues that students might otherwise have not expressed.

If a member of each group reports orally to the whole group, students also hear what others have learned and are still wondering. These brief reflections often provide insights into what was puzzling and needs clarification, next steps that might not otherwise have been contemplated, and practical matters that need attention. Sometimes the students' questions get the whole class thinking about the next exploration! Although time-consuming, such oral as well as written reflections can foster a sense of community and enrich the wonderings as well as the understandings with which students leave the classroom.

This practice was inherited from Dr. John Layman, a physics professor who taught a similar physics course at the University of Maryland College Park. One of his graduates strongly recommended continuing this closing ceremony as she had found it very meaningful. Apparently some of our graduates feel this way as well as several have reported choosing to continue this practice with their own elementary students.

The instructor can indicate sections of the online text that are relevant to the explorations undertaken during that class and/or to some of the questions just raised.

Many of the students' questions will not be addressed in this course, however. It is important to acknowledge such questions as an aspect of doing science. Scientists frequently generate intriguing questions that they cannot immediately explore within their current research. Generating questions about whatever one is doing and thinking can become a helpful practice no matter in what field of endeavor one is engaged.

After class, we have posted the relevant sections of the text online. Earlier access to the text may inhibit student learning. We believe that students will learn more, as well as build confidence and competence in doing science, if they use the online text as a means for confirming understandings that they have already developed themselves through their explorations and discussions in class.

C. Assignments

As is typical in physics courses, assignments include solving a variety of word problems related to the physical phenomena explored in class. The students also report their ongoing observations of the Sun and the Moon on a weekly basis. These form the evidence later in the term for developing explanatory models of day and night, the phases of the Moon, and the Earth's seasons.

Assignments also emphasize integrating science and literacy learning, such as speaking clearly, listening closely, writing coherently, reading with comprehension, and creating and critiquing information provided through electronic media (van Zee et al., 2013a,b). As prospective teachers, our students create a children's book based on their explorations in class. They also make connections in each unit to the US *Next Generation Science Standards* (NGSS Lead States, 2013) adopted by many departments of education.

Suggested assignments also include engaging friends and family members in learning about the phenomena that students just explored in class (Crowl et al., 2013). Such assignments can enhance the students' confidence in teaching science as well as contribute to educating citizens about the nature of science as well as about the evidence underlying concerns about climate change. The students write reflections about what happened, what the learner(s) asked, said, did, and found, and what they learned about science learning and teaching. By posting these reflections on an electronic discussion board, they can learn from one another's experiences.

The students also reflect upon their learning processes, how they are making sense out of what they are learning each week, what aspects they want to remember, and what questions they still have. These reflections also are helpful for alerting the instructor to issues that need to be addressed and for suggesting ways to connect topics in the course to the students' interests.

Readings include articles by teachers reflecting upon exploring similar phenomena with their students as well as internet resources relevant to phenomena explored in class. The suggested *before*, *during*, and *after reading strategies* (Winegard and Devitt, 2009) are shown **here** (docx) or **here** (pdf).

The students access and critique internet resources relevant to university, state, national, and international efforts to address issues related to global climate change. They also explore websites presenting climate change indicators, social issues, military issues, and ways to take action. The expectation is that students will read enough to become aware of such resources and to find something interesting to report; they are not expected to read these materials in depth.

Students submit printed homework and reading assignments in class; some instructors prefer submission through an electronic platform (Canvas). Midterm and final examinations complete these formal assessments of students' learning. Currently the midterm is a 'sit down' affair during a class session where students can use their notebooks (but not their cell phones) for up to the full 2.5 hours of class if needed. The final currently involves preparing at home a file with responses to the questions and submitting this file online. Some of the questions include comparing students' responses on the same diagnostic questions early and late in the course and discussing how they learned what they learned based on the evidence provided by these responses.

D. Equipment

This course is laboratory-centered, which means every session involves some kind of exploration. Most of the equipment involves everyday materials found in homes, schools, and offices such as toilet and paper towel rolls, aluminum foil, wax paper, cardboard, flashlights, pots, hot plates, jars, plastic containers, etc. The Instructor's Guide includes a detailed list, or you can find it here. Access to the internet is assumed inside and outside of class. Usually at least one member of a small group has a computer laptop that can be brought to class. We use three digital probes:

1. A light probe (TI light probe, https://www.vernier.com/products/sensors/tilt-

bta/, $16 with Go-Link interface ($69).

2. A temperature probe (Go!Temp, http://www.vernier.com/products/sensors/temperature-sensors/go-temp/, $39).
3. A motion detector (Go!Motion, http://www.vernier.com/products/sensors/motion-detectors/go-mot/, $124).

Each group uses 1 light probe, 2 temperature probes, and 1 motion detector. If necessary, the instructor can use only one motion detector with the entire class. Regular bulb and tube thermometers can be used rather than the digital temperature probes. The students can use a cell phone app for measuring reflectivity rather than a light probe. The text also includes screen shots of the relevant graphs so that students without access to digital equipment can still think about the topics addressed. They will miss, however, the wonderful learning experiences these devises can provide.

E. Connection to US *Next Generation Science Standards*

This course addresses aspects of the following disciplinary core ideas, crosscutting concepts, and science and engineering practices suggested in the *Next Generation Science Standards* (Lead States, 2013) http://www.nextgenscience.org:

Relevant Disciplinary Core Ideas Addressed

Physical Sciences:
PS1A:Structure and Properties of Matter
PS2A:Forces and Motion
PS3A:Definitions of Energy
PS3B:Conservation of Energy and Energy Transfer
PS4A:Wave Properties
PS4B:Electromagnetic Radiation

Earth and Space Sciences:
ESS1B: Earth and the Solar System
ESS2D: Weather and Climate
ESS3D: Global Climate Change

Crosscutting Concepts

Patterns
Cause and effect
Scale proportion and quantity
Systems and systems models
Energy and matter, flows, cycles and conservation
Structure and function
Stability and change

Science and Engineering Practices

Asking questions and defining problems.
Developing and using models.
Planning and carrying out investigations.
Analyzing and interpreting data.
Using mathematics and computational thinking.
Constructing explanations and designing solutions.
Engaging in argument from evidence.
Obtaining, evaluating and communicating information.

At the close of each unit, the students write reflections about which of these dimensions of science learning they have been experiencing and how they might engage their own students in similar ways.

Acknowledgements

We deeply appreciate the encouragement of Professor Henri Jansen in the design and implementation of this course when he was chair of the Physics Department. Professor Kenneth Winegrad, a literacy faculty member in the College of Education, contributed many helpful insights to our endeavors to integrate science and literacy learning in this course. This open-source textbook includes work supported earlier by the National Science Foundation under Grant No. 0633752-DUE, *Integrating Physics and Literacy Learning in a Physics Course for Elementary and Middle School Teachers*. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the grantees and do not necessarily reflect the views of the National Science Foundation.

Two papers describe this effort to integrate science and literacy learning in a physics course for prospective teachers (van Zee, Jansen, Winegrad, Crowl, & Devitt (2013a, b). Another describes ways we later included global climate change issues (van Zee, Roberts,

& Grobart, 2016). Professor Winegrad and Adam Devitt, a graduate assistant who was an experienced elementary special education teacher, developed a handout describing before, during, and after reading strategies for use in the course (Winegrad & Devitt, 2009). Adam also created the before, during, and after design of the Physics Notebook Page in analogy to those reading strategies. In addition, he documented literacy activities he initiated in the course (Devitt, 2010). Michele Crowl, a graduate assistant who was a former science museum educator, invented the friends and family assignments (Crowl, Devitt, Jansen, van Zee, & Winegrad, 2013). Katie Kizer, an undergraduate peer instructor, created a website documenting the course at [http://sites.science.oregonstate.edu/physics/coursewikis/ph111/doku81aa.html?id=start .](http://sites.science.oregonstate.edu/physics/coursewikis/ph111/doku81aa.html?id=start)

Many of the suggested readings were written by teachers participating in NSF No. MDR-9155726, *Investigation of Questioning Processes during Conversations about Science*, Emily H. van Zee, PI, University of California-Berkeley; NSF No. 9986846, *Case Studies of Elementary Student Inquiry in Physical Science*, David Hammer, PI; Emily van Zee, co-PI, University of Maryland College Park; and a series of small grants from the Spencer Foundation under the Practitioner Research program, including *Fostering Teachers' Inquiries into Science Learning*, Emily H. van Zee, PI, University of Maryland, College Park. Participating teachers included Mary Bell (2006), Claire Bove (2007), Kathleen Hogan (2007), Christopher Horne (2007), Marletta Iwaysk (1997), Akiko Kurose (2000), Diantha Lay (2000), Jamie Mikeska (2006), Constance Nissley (2000), Jessica Phelan (2006), Deborah Roberts (1999, 2000, 2007), Patricia Roy (2006), Dorothy Simpson (1997), and Kathy Swire (2006).

With consent forms approved by the Oregon State University Institutional Review Board (IRB), we ask students for permission to video-record class sessions, to make copies of student writings and drawings, and to photograph artifacts such as large white boards that small groups create to present and discuss their findings. Students contributing their work to this open-source textbook in these and other ways include Nicole Acadio, Mackenzie Belden, Alexia Berg, Lauren Bickhaus, Rachael Brickson, Lindsay Carlton, Sierra Christianson, Erica Chelgren, Kirsten Clark, Nina Coleman, Natalia Cox, Maddison Cruz, Bridget Eby, Colleen Ellis, Kirby Erdman, Judith Ford, Nathalie Gaebe, Emma Grobart, Jorgan Hanson, Rebecca Huber, Justine Hynes, Tylyn Jones, Mikaela Kerr, Andrea Kenagy, Camryn Kimberly, Katie Kizer, Alison Latham-Ocampo, Emily Lemons, Jordan McCarty, Hannah Nealy, Paige Noonan, Natasha Ostertag-Hill, Andie Porta, Kortney Reddick, Zhanè Richardson, Shanna Roast, Sage Robertson, Kathryn Rodriggs, Erin Ross, Kaila Smith, Maggie Stewart, Joslyn Strickler, Danielle Taylor, Nathan Tran, Sarah Van Kessel, Courteney Vogt, Trinity Whitaker, and Stacey Zaback.

We have been very fortunate to have had excellent mentors and many opportunities to participate in and/or to learn about research and curriculum development projects while teaching and learning science with preschoolers, school children, undergraduates, graduate students, teachers, and the public, inside and outside of formal settings:

The first author, Emily van Zee, would like to thank Professor Gerald Holton for introducing her to the community of physicists who care about teaching when she worked for him as a research and editorial assistant during the early years of *Project Physics* (Holton, 2003; Rutherford, Holton, & Watson, 1971). She enjoyed learning not only about ways to engage students in exploring physical phenomena but also about historical, philosophical, and cultural aspects of the development of physics principles. The importance of providing access to such broader views underlies her inclusion of aspects of these perspectives in this *Exploring Physical Phenomena* open-source textbook.

Betty Roald, a talented elementary school teacher, welcomed the first author, as a stay-at-home Mom, to teach science to wiggly first grade students. The first author remembers sitting on the floor with the children around her while engaging them in explorations suggested in a book about how bodies work (Allison, 1976). Similar volunteer experiences with young children and older scouts in both formal and informal settings prompted her later support of a graduate assistant's initiative in inventing the friends and family assignments, now a regular part of our course (Crowl et al., 2013). The first author learned about the Moon from Leslie DeWater, a talented fifth grade teacher as well as master teacher in the University of Washington's physics programs for teachers.

The first author also would like to thank Professor Arnold Arons (1972, 1977) and Professor Lillian C. McDermott (1993, 2016) for changing the way she teaches. The first author joined the Physics 101-102, 103 staff at the University of Washington when it was the setting for the development of the *Physics by Inquiry* curriculum (McDermott, 1990; McDermott and the Physics Education Group, 1996; McDermott, Rosenquist, & van Zee, 1983). Earlier, as a new middle school science teacher, the first author had taught students in the way she had been taught, by telling them what she thought they should know. Here, however, she learned how to teach in a new way, by moving among small groups of students sitting at tables as they worked together exploring phenomena. She learned to listen closely to what the students were saying to one another, to intervene (or not) with a comment or question, and to answer a question with a question designed to help prompt the next step in thinking.

Petra Carrera, Rafael Escribano, Gabriel Florentino, Luanna Gomez, KimBerly Petitt, and Darrell Simms were particularly insightful about their learning processes as students and/or peer instructors in the Physics 101 series. The first author's experiences in teaching these courses motivated the inquiry-based pedagogical approach as well as some of the light, thermal and astronomy activities that she adapted while designing and teaching this physics course for prospective teachers. Also relevant was the emphasis on documenting and interpreting student learning, such as ways students used multiple representations, particularly those involving motion graphs (McDermott, Rosenquist, & van Zee, 1987). In addition, the first author became aware here of the extensive science curricular resources developed earlier with NSF support for use with elementary and middle school students (National Academy of Science, 1996).

With expert guidance from Professor Lee Beach (1990), the first author undertook studies of cognition and metacognition, particularly in exploring ways people use information while making decisions (van Zee, Palunchowski, & Beach, 1992). She also began studies of the ethnography of communication with Professor Gerry Philipsen (1994) about ways in which people talk thoughtfully with one another; she was particularly interested in the role of questioning during such discussions. These studies contributed to her interest in and awareness of many aspects of discourse that affect how students think and learn.

The first author enjoyed collaborating with a high school physics teacher, Jim Minstrell, in documenting and interpreting how he used questioning to guide student thinking (van Zee & Minstrell, 1997a,b). Her post-doctoral research focused upon *An Investigation of Questioning Processes during a Cognitive Approach to Physics Instruction* with support from the James S. McDonnell Foundation. We found that he asked questions to help students make their meanings clear, to consider various points of view in a neutral manner, and to monitor the discussion and their own thinking. He had developed a computer program, *Diagnoser*, based on facets of student knowledge that he had identified through research in his own classroom (Minstrell, 1988, 1992; Minstrell & Hunt, 1990). The students could work through a series of questions to diagnose their current thinking; then they could take next steps that the *Diagnoser* suggested based upon their responses. The diagnostic questions that begin each unit in this *Exploring Physical Phenomena* open-source textbook are a similar effort to alert the students and the instructor to students' initial ideas about a topic, both those useful for building deeper understandings as well as any needing refinement. The first author's experiences here deeply influenced her adoption of a positive instructional perspective of helping students to expand their areas of competence rather than screening student responses for misconceptions that need to be corrected.

As an instructor in an innovative combined program for future teachers and future researchers at the University of California, Berkeley (Lowery, Schoenfeld, & White, 1990), the first author modeled video recording her own class sessions to gather data for doing research on one's own teaching practices and students' learning (van Zee, 2000). She enjoyed learning more about cognitive science along with her students, particularly through many conversations with Claire Bove, Ming Chiu, Miriam Gamoran, Sean Hutcherson, Lawrence Muilenburg, Marcelle Siegel, and Erica Street as well as with teaching colleagues Stan Fukunaga, Don Hubbard, and Dan Zimmerman. She learned about causal models from Professor Barbara White (1993) and about ways to use computers as learning partners from Professor Marcia Linn(1991). She also learned from Professor Andy diSessa (1993) about phenomenological primitives (p-prims), or pieces of knowledge that students may use in generating responses when asked physics questions. This perspective contrasts with interpreting students' responses as revealing misconceptions firmly embedded in students' brains, wrong ideas that need to be elicited, confronted, and changed. In addition, she learned from Professor Alan Schoenfeld (1992) about metacognitive processes that help students stay aware of what they are doing and why. These perspectives underlie this course's emphasis on explorations to expand and refine the prospective teachers' understandings of physical phenomena.

With expert mentoring from Professors John Layman, Randy McGinnis, and Jim Fey, the first author taught courses on methods of teaching science for prospective elementary and middle school teachers as a faculty member in the Department of Curriculum and Instruction at the University of Maryland, College Park. She also appreciated the warm welcome by Professor Joe Redish to activities in the Department of Physics. She noticed a distinct difference in students who were graduates of Physics 115, a course that served as one of the development sites for the American Association of Physics Teachers' *Powerful Ideas in Physical Science* curriculum (American Association of Physics Teachers, 1995; Ukens, Hein, Johnson, & Layman, 2004). Rather than being bewildered by her inquiry-based instructional approach, Physics 115 graduates understood what to do and seemed to enjoy doing it, modeling for their classmates learning science by working together asking their own questions and exploring phenomena without detailed step-by-step directions. The first author enjoyed observing the Physics 115 course occasionally. She chose to adapt some light and thermal activities from this resource.

Collaboration with Professor David Hammer and a group of practicing elementary and middle school teachers broadened the first author's vision of what teaching science through inquiry can mean. Developed under NSF-9986846, *Case Studies of Elementary Student Inquiry in Physical Science* included engaging the teachers in learning physics during the summer as well as in documenting and interpreting their students' science thinking during the academic year (Hammer & van Zee, 2006). The emphasis was on recognizing and refining epistemological resources as well as initial science understandings (Hammer, 2000; Hammer & Elby, 2003). In teaching the physics course for prospective elementary and middle school teachers and preparing this open-source textbook, the first author drew on many of these experiences in the context of exploring light phenomena (van Zee, Hammer, Bell, Roy, & Peter, 2006).

Participating in the Carnegie Academy for the Scholarship of Teaching and Learning (Shulman, 2002) increased the first author's proficiency in video recording her own instructional practices and in writing interpretations of her students' thinking and learning. She also encouraged her students and graduates of her courses to document and interpret their own teaching practices and students' thinking and learning (van Zee, Lay & Roberts, 2003). This emphasis on focused reflection, based on evidence collected in class, underlies the extensive use of students' writing in preparation of this open source textbook.

The first author was invited to design this physics course for prospective elementary and middle school teachers after retiring from the University of Maryland and moving to Corvallis, Oregon. She deeply appreciates the welcome by Professors Larry Flick and Larry Enochs and the opportunity to collaborate with Rebekah Elliot, Nam Hwa Kang, and Janice Rosenberg in the Department of Science and Mathematics Education at Oregon State University. She learned a lot about teaching mathematics and using technology during a series of collaborations with Professor Maggie Niess.

The first author would like to thank Professor Fred Goldberg for his thoughtful encouragement as she grew more confident in teaching physics in interactive ways. The process of developing explanations in *Physics and Everyday Thinking* (Goldberg, Robinson, & Otero, 2007; Goldberg, Otero, & Robinson, 2010; Goldberg, Price, Robinson, Boyd-Harlow, & McKean, 2012) influenced the first author's design of assignments in this course. In starting to work on a physics problem, for example, students review the conceptual model they have developed for the relevant physical phenomenon before attending to the specific information provided. The *Physics and Everyday Thinking* curriculum's explicit emphasis on learning about learning as well as learning about physics also influenced our attention to engaging students in developing pedagogical as well as physical science understandings as integral to class activities, homework assignments, and examinations.

The second author, Elizabeth Gire, also enjoyed talking with Professor Goldberg about interactive engagement strategies while he was teaching a course for prospective teachers with the *Physics and Everyday Thinking* curriculum. In addition, she was mentored by Charles De Leone in teaching an adaptation of CLASP (*Collaborative Learning through Active Sense-Making in Physics*), a course that supports students in building understanding by making observations, working in small groups to generate ideas, presenting those ideas to the rest of the class, and whole class discussion of those ideas (Potter, Webb, Paul, West, Bowen, Weiss, & De Leone, 2014). During that time, she studied how students' success on physics problems correlated with their use of non-algebraic representations (graphs, diagrams, etc) to make sense of physical situations and to communicate their understanding (DeLeone and E. Gire, 2006). Since then, her teaching and research has focused both on how students engage in physics sensemaking and how they use different representations to make sense of physical systems (Gire, Nguyen, & Rebello, 2011; Gire & Price, 2015; Hahn, Emigh, Lenz, & Gire, 2017).

Now a physics faculty member at Oregon State University, the second author is the current instructor for our physics course for prospective teachers and has been enriching this effort to create the *Exploring Physical Phenomena* open-source textbook. Her research focuses upon ways in which to engage students in seeking coherence among different representations of physics knowledge. She and her colleagues are developing a set of hands-on, discovery-style, discussion-based classroom activities that use dry-erasable three-dimensional plastic surfaces to represent physical systems that depend on multiple variables (Gire, 2017; Gire, A. Wangberg & R. Wangberg, 2018).

The second author also is developing a physics course for majors that explicitly engages students in developing knowledge of sense-making strategies, metacognitive skills, and productive beliefs about the nature of doing physics as well as in increasing their awareness and appreciation of physics sense-making processes (Gire, Emigh, Hahn, and Lenz, 2018). Her explicit focus on such physics education research contributes to her positive pedagogical approach in meeting the needs of the prospective elementary and middle school teachers, many of whom seem to perceive themselves initially as reluctant science learners. She has introduced circle conversations, for example, in which the small groups gather to share their findings, sometimes through multiple iterations of thoughtful discussions, until they come to consensus on their interpretations of what they have observed.

Both authors have enjoyed collaborating with Professor Corinne Manogue in the physics department's on-going research and curriculum development in the context of upper division courses for physics majors, *Paradigms in Physics* (Gire, Kustusch, & Manogue, 2012; Gire & Manogue, 2011; Manogue, Cerny, Gire, Mountcastle, Price, & van Zee, 2010; Manogue, Gire, & Roundy, 2013; Manogue & Krane, 2003; van Zee & Manogue, 2010, 2018). These courses are unusual in their organization of the physics content studied as well as in their use of interactive engagement strategies in class. Although the level of mathematics and conceptual content in the course for prospective teachers is different, the emphasis on encouraging students to enjoy learning with and from one another is similar. We both have grown in pedagogical as well as physics knowledge through our participation in the *Paradigms in Physics* program.

We are deeply grateful to the colleagues who have educated and encouraged us. We also have greatly appreciated the care and thoughtful assistance from Stefanie Buck, Dianna Fisher, Kenya Hazell, Baylee Bullock, Derek Ostrom, and Mark Lane of OSU Open Educational Resources. Our families have been wonderfully supportive of this endeavor. However, any errors in these materials are our own. Please email us at Emily.vanZee@science.oregonstate.edu and/or giree@oregonstate.edu if you have suggestions for improving these materials.

References

L. Allison, *Blood and Guts: A Working Guide to Your Own Insides* (Brown Paper School Book for Young Readers, Little, Brown, Boston, 1976).

American Association of Physics Teachers. *Powerful Ideas in Physical Science* (AAPT,College Park, MD, 1995). https://www.aapt.org/Publications/pips.cfm

A. Arons, Anatomy of a physical science course for non-science students, Journal of College Science Teaching, **I**, 30-34 (April, 1972).

A. Arons, *The Various Language: An Inquiry Approach to the Physical Sciences* (Oxford University Press, New York, 1977).

L. R. Beach, *Image Theory: Decision Making in Personal and Organizational Contexts* (Wiley, Chichester, England, 1990).

M. Bell, Fifth and sixth graders discuss a dropped pendulum, in *Seeing the Science in Children's Thinking: Case Studies of Student Inquiry in Physical Science*, edited by D. Hammer and E. H. van Zee, (Heinemann, Portsmouth, NH, 2006), pp. 47-70.

C. Bove, Student teaching as collaboration, in *Teacher Research: Stories of Learning and Growing* edited by D. Roberts, C. Bove, and E. H. van Zee (National Science Teachers Association Press, Arlington, VA, 2007), pp. 72-86.

M. Crowl, A. Devitt, H. Jansen, E. H. van Zee and K. Winograd, Encouraging prospective teachers to engage friends and family in exploring physical phenomena, *Journal of Science Teacher Education*, **24(**1), 93-110 (2013). DOI 10.1007/s10972-012-9310-3

C. J. DeLeone and E. Gire, Is instructional emphasis on the use of non-mathematical representation worth the effort? *American Institute of Physics Conference Proceedings*, **818**, 45-48 (2006).

A. Devitt, *Integrating science and literacy with prospective teachers*, Master's project. Oregon State University (2010).

A. diSessa, Toward an epistemology of physics, Cognition and Instruction **10**(2-3), 105-225 (1993).

E. Gire. *Collaborative Research: Raising Physics to the Surface*, National Science FoundationGrant No. 1612480 (2017).

E. Gire, P. J. Emigh, K.T. Hahn, and M. K. Lenz, Making sense of physics sensemaking, *Forum on Education Newsletter*, *American Physical Society*, **94** (1), 9-11 (Fall, 2018). https://www.aps.org/units/fed/newsletters/fall2018/making-sense.cfmE

Gire, M. B. Kustusch, and C. A. Manogue, Supporting and sustaining the holistic development of students into practicing physicists, *2012 Physics Education Research Conference*, Philadelphia, PA, *AIP Conference Proceedings*, **1513**, 19-22 (2012).

E. Gire and C. Manogue, Making sense of quantum operators, eigenstates and quantum measurements, 2011 Physics Education Research Conference, Omaha, NE, *AIP Conference Proceedings*, **1413**, 195–198 (2011).

E. Gire, D. H. Nguyen, and N. S. Rebello, Characterizing students' use of graphs in introductory physics with a graphical analysis epistemic game, Proceedings of the National Association of Research in Science Teaching 2011 Annual Meeting, Orlando, FL, (2011).

E. Gire and E. Price, Structural features of algebraic quantum notations, *Physical Review Special Topics -Physics Education Research*, **11**, 020109 (2015).

E. Gire, A. Wangberg, and R. Wangberg, Multiple tools for visualizing equipotential surfaces: Optimizing for instructional goals, *Proceedings of the 2017 Physics Education Research Conference*,Cincinnati, OH, edited by L. Ding, A. Traxler, and Y. Cao, 140-143(2018), doi:10.1119/perc.2017.pr.030.

F. Goldberg, V. Otero, and S. Robinson, Design principles for effective physics instruction: A case from *Physics and Everyday Thinking*, *American Journal of Physics* **78** (12), 1265-1277 (2010).

F. Goldberg, E. Price, S. Robinson, D. Boyd-Harlow, and M. McKean, Developing the learning physical science curriculum: Adapting a small enrollment, laboratory and discussion based physical science course for large enrollments, *Physical Review Special Topics –Physics Education Research* **8**, 010121-1-24 (2012).

F. Goldberg, S. Robinson, and V. Otero, *Physics and Everyday Thinking* (It's about Time, Herff Jones Education Division, Armonk, NY, 2007).

K. T. Hahn, M. Lenz, P. J. Emigh, and E. Gire. Student sense-making on homework in a sophomore mechanics course, in *Proceedings of the 2017 Physics Education Research Conference*, Cincinnati, OH AIP *Conference Proceedings*, pp. 160–163, (2018).

D. Hammer, Student resources for learning introductory physics, *Physics Education Research, American Journal of Physics Supplement* **68**(7), S52-S59 (July 2000).

D. Hammer and A. Elby, Tapping students' epistemological resources, *Journal of the Learning Sciences*, **12**(1), 53-91(2003).

D. Hammer and E. H. van Zee (Eds.) *Seeing the Science in Children's Thinking: Case Studies of Student Inquiry in Physical Science*. (Heinemann, Portsmouth, NH, 2006)

R. Hawkins, Science beyond labeling, in *Inquiring into Inquiry Learning and Teaching in Science* edited by J. Minstrell and E. H. van Zee (American Association for the Advancement of Science, Washington, D.C, 2000), pp. 169-175. https://www.aaas.org/sites/default/files/s3fs-public/InquiryPart2.pdf

K. Hogan, How can playing with a motion detector help children learn to write clear sequential directions? in *Teacher Research: Stories of Learning and Growing* edited by D. Roberts, C. Bove, and E. van Zee, (National Science Teachers Association Press, Arlington, VA, 2007), pp. 2-9.

G. Holton, The *Project Physics Course*, then and now, *Science & Education*, **12**, 779-786 (2003).

C. Horne, Becoming a teacher researcher: Giving space, finding space, in *Teacher Research: Stories of Learning and Growing*, edited by D. Roberts, C. Bove, and E. van Zee, (National Science Teachers Association Press, Arlington, VA, 2007), pp. 100-109.

M. Iwasyk, Kids questioning kids: Experts' sharing, *Science and Children*, **35**(1), 42-46 (1997). Also in *Inquiring into Inquiry Learning and Teaching in Science* edited by J. Minstrell and E. H. van Zee (American Association for the Advancement of Science, Washington, D.C, 2000), pp. 130-138. https://www.aaas.org/sites/default/files/s3fs-public/InquiryPart2.pdf

A. Kurose, Eyes on science: Asking questions about the moon on the playground, in class, and at home, in *Inquiring into Inquiry Learning and Teaching in Science* edited by J. Minstrell and E. H. van Zee (American Association for the Advancement of Science, Washington, D.C, 2000),pp. 139-147. https://www.aaas.org/sites/default/files/s3fs-public/InquiryPart2.pdf

D. Lay, Science Inquiry Conference –a better way! in *Inquiring into Inquiry Learning and Teaching in Science* edited by J. Minstrelland E. H. van Zee (American Association for the Advancement of Science, Washington, D.C, 2000), pp. 164-168. https://www.aaas.org/sites/default/files/s3fs-public/InquiryPart2.pdf

M. Linn, The computer as learning partner: Can computer tools teach science? *This Year in School Science*, 31-39 (1991).

L. Lowery, A. Schoenfeld, and B. White, *Master's and Credential in Science and Mathematics Education (MACSME) Program*, (National ScienceFoundation TPE91–50028). University of California, Berkeley, Berkeley, CA, 1990).

J. Minstrell, *The Diagnoser Project*. (http://www.facetinnovations.com/daisy-public-website/fihome/resources/diagnoser.html; http://www.diagnoser.com).

J. Minstrell and E. Hunt, The development of a classroom based teaching system representing students' knowledge structures and their processing of instruction, Technical report to the James S. McDonnell Foundation. (Mercer Island School District and University of Washington, Mercer Island, WA, 1990).

National Academy of Science. Curriculum projects past and present, Chapter 5 in *Resources for Teaching Elementary School Science*. (The National Academies Press, Washington, D.C., 1996), pp. 122-129. https://doi.org/10.17226/4966.

NGSS Lead States. *Next Generation Science Standards: For States, By States*. (The National Academies Press, Washington, D.C., 2013).

C. Nissley, Giving children a chance to investigate according to their own interests, in *Inquiring into Inquiry Learning and Teaching in Science* edited by J. Minstrell and E. H. van Zee (American Association for the Advancement of Science, Washington, D.C, 2000), pp. 151-156. https://www.aaas.org/sites/default/files/s3fs-public/InquiryPart2.pdf

J. Phelan, Eighth graders discuss the rock cycle, in Seeing the Science in *Children's Thinking: Case Studies of Student Inquiry in Physical Science*, edited by D. Hammer and E. H. van Zee, (Heinemann, Portsmouth, NH, 2006) pp. 96-115.

G. Philipsen, The ethnography of speaking, in *The Encyclopedia of Language and Linguistics*, Vol. 3, edited by R. E. Asher and J. M. Y. Simpson (Pergamon, Oxford, 1994) pp. 1156-1160.

W. Potter, D. Webb, C. Paul, E. West, M. Bowen, B. Weiss, L. Coleman and C. De Leone, Sixteen years of collaborative learning through active sense-making in physics (CLASP) at UC Davis, *American Journal of Physics* **82**,153–63 (2014).

D. Roberts, The sky's the limit: Parents and first-grade students observe the sky, *Science and Children*, **37**(1), 33-37 (1999).

D. Roberts, Learning to teach science through inquiry: A new teacher's story, in *Inquiring into Inquiry Learning and Teaching in Science* edited by J. Minstrell and E. H. van Zee (American Association for the Advancement of Science, Washington, D.C., 2000), pp. 120-129. https://www.aaas.org/sites/default/files/s3fs-public/InquiryPart2.pdf

D. Roberts, Learning about motion: Fun for all!, in *Teacher Research: Stories of Learning* *and Growing* edited by D. Roberts, C. Bove, and E. van Zee, National Science Teachers Association Press, Arlington, VA, 2007), pp. 124-137.

S. Robertson, *Inquiring into Temperatur*e. (Oregon State University, Corvallis, OR, 2007).

P. Roy, Third graders discuss bubbles, in *Seeing the Science in Children's Thinking: Case Studies of Student Inquiry in Physical Science*, edited by D. Hammer and E. H. van Zee, (Heinemann, Portsmouth, NH, 2006) pp.116-133.

J. Rutherford, G. Holton, and F. Watson, *Project Physics*. (Holt, Rinehart & Winston, New York, 1970).

A. Schoenfeld, Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics, in *Handbook for Research on Mathematics Teaching and Learning* edited by D. Grouws (MacMillan, NewYork, 1992), pp. 334-370.

L. Shulman, Forward. in *Ethics of Inquiry*: Issues in the *Scholarship of Teaching and Learning* edited by Pat Hutchings (The Carnegie Foundation for the Advancement of Teaching, Menlo Park, CA, 2002) pp. v-viii.

D. Simpson, Collaborative conversations: Strategies for engaging students in productive dialogues, *The Science Teacher*, **64**(8), 40-43 (1997). Also in *Inquiring into Inquiry Learning and Teaching in Science* edited by J. Minstrell and E. H. van Zee (American Association for the Advancement of Science, Washington, D.C, 2000), pp. 176-183. https://www.aaas.org/sites/default/files/s3fs-public/InquiryPart2.pdf

K. Swire, Second graders discuss magnets, in *Seeing the Science in Children's Thinking: Case Studies of Student Inquiry in Physical Science*, edited by D. Hammer and E. H. van Zee, (Heinemann, Portsmouth, NH, 2006) pp.134-146.

L. Ukens, W. W. Hein, P. A. Johnson, and J. W. Layman, *Powerful Ideas in Physical Science*, *Journal of College Science Teaching*, **33**(7), 38-41 (2004).

E. H. van Zee, Analysis of a student-generated inquiry discussion, *International Journal of Science Education*, **22**, 115-142(2000).

E. H. van Zee, D. Hammer, M. Bell, P. Roy, and J. Peter, Learning and teaching science as inquiry: A case study of elementary school teachers' investigations of light, *Science Education*, **89**(6), 1007-1042 (2005).

E. H. van Zee, H. Jansen, K.Winograd, M.Crowl, A. Devitt, Fostering scientific thinking by prospective teachers in a course that integrates physics and literacy learning, *Journal of College Science Teaching*, **42**(5), 29–35 (2013a).

E. H. van Zee, H. Jansen, K. Winograd, M. Crowl, and A. Devitt, Integrating physics and literacy learning in a physics course for prospective elementary and middle school teachers, *Journal of Science Teacher Education*, **24**(3), 665-691 (2013b). DOI 10.1007/s10972-012-9323-y

E. H. van Zee, D. Lay and D. Roberts, Fostering collaborative inquiries by prospective and practicing elementary and middle school teachers, *Science Education*, 87, 588-612 (2003).

E.H. van Zee and C. A. Manogue, Documenting and interpreting ways to engage students in thinking like a physicist, 2010 Physics Education Research Conference, Portland, OR: *AIP Conference Proceedings*, **1289**, 61–64 (2010). Also: http://physics.oregonstate.edu/mathbook/P20/html/index.html accessed September 19, 2019.

E. H. van Zee and C. A. Manogue, A study of the development of the *Paradigms in Physics* Program. (Department of Physics, Oregon State University, Corvallis, OR (2018). http://physics.oregonstate.edu/mathbook/P20/html/

E. H. van Zee and J. Minstrell, Reflective discourse: Developing shared understandings in a high school physics classroom, *International Journal of Science Education*, **19**, 209-228 (1997a)

E. H.van Zee and J. Minstrell, Using questioning to guide student thinking, *The Journal of the Learning Sciences*, **6**, 229-271 (1997b).

E. H. van Zee, T. F.Paluchowski, and L. R. Beach, The effects of screening and task partitioning upon evaluations of decision options, J*ournal of Behavioral Decision Making*, **5**, 1-19(1992). Reprinted in Beach, L.R. (Ed.) (1998). *Image Theory: Theoretical and Empirical Foundations* (Erlbaum, Mahwah, NJ, 1998), pp. 61-72.

E. H. van Zee, D. Roberts, and E. Grobart, Ways to include global climate change in courses for prospective teachers, *Journal of College Science Teaching*, **45**(3), 28-33(2016).

B. White, Thinker tools: Causal models, conceptual change, and science education, *Cognition and Instruction*, **10** (1), 1-100 (1993).

K. Winegrad and A. Devitt, Suggested reading strategies. Oregon State University (2009).

About the Authors

Emily van Zee

Emily van Zee is a retired associate professor of science education at Oregon State University. She designed and taught this physics course for prospective elementary and middle school teachers. She also taught graduate courses in science education. Her research has included documenting and interpreting ways to engage students in "thinking like a physicist." She also has explored student and teacher questioning during conversations about science in pre-college classrooms. In addition, she has collaborated with K-12 teachers interested in inquiring into their own teaching practices and students' learning. She can be reached at *vanzeee at oregonstate.edu.*

Elizabeth Gire

Elizabeth Gire is an associate professor of physics at Oregon State University. She is the current instructor of this physics course for prospective elementary and middle school teachers. She also teaches physics courses for majors. Her research focuses upon ways in which to engage students in seeking coherence among different representations of physics knowledge. She also has designed and taught a course that explicitly engages students in developing knowledge of sense-making strategies, metacognitive skills, and productive beliefs about the nature of doing physics as well as in increasing their awareness and appreciation of physics sense-making processes. She can be reached at *giree at oregonstate.edu.*

UNIT 1: EXPLORING THE NATURE OF LIGHT PHENOMENA

Exploring Physical Phenomena: *What happens when light from the Sun shines on the Earth?*

Table of Content

Figures

Tables

I. Introduction

This course is intended for prospective and practicing elementary and middle school teachers. By exploring physical phenomena in class, you will learn science in ways in which you are expected to teach science in schools or in informal settings such as afterschool programs, youth group meetings, and museum workshops. This course also is appropriate for general science students and others interested in exploring some of the physical phenomena underlying global climate change.

The theme for the course is: *What happens when light from the Sun shines on the Earth?* The emphasis is on questioning, predicting, exploring, observing, discussing, reading, and writing about what one thinks and why. This first unit focuses on exploring the nature of light phenomena. Among the unit's many goals are two primary ones: to learn about light phenomena and to learn about ways to foster science learning for yourself and others such as your family, friends, and students.

What does it mean to "explore the nature of light phenomena"? You will be:

- ***identifying resources*** such as positive experiences you already have had in learning about light and
- ***developing central ideas based on evidence*** that you record while exploring everyday phenomena such as light and shadows.

By central ideas, we mean understandings about physical phenomena that emerge from your discussions with your group members as well as with the instructor. These also are powerful ideas because they form conceptual models useful in:

- ***explaining an intriguing phenomenon*** such as what happens when you look through a pinhole camera, something most find surprising, yet even children can understand.

After developing conceptual understandings of the relevant physics principles, you will be:

- ***developing mathematical representations*** of this phenomenon and using these when
- ***estimating a quantity of interest***, such as the diameter of the Sun.

Throughout the course you will be reflecting upon ways that are helping you learn science. In reflecting upon this learning process, you will be:

- ***making connections to educational policy***, such as the *Next Generation Science Standards* (NGSS Lead States, 2013). This document has been adopted by many departments of education as the science standards for grades K-12 in the United States.

Other light phenomena that you will be exploring during this unit include reflection, refraction, and dispersion. You will develop additional central ideas based upon these explorations; then use this expanded conceptual model for light to explain another intriguing but more complex phenomenon: rainbows.

Because K-8 curricula emphasize learning to read and write well, this course also models ways to integrate science and literacy learning. By literacy learning, we mean learning to speak clearly, listen closely, write coherently, read with comprehension, and create and critique media.

The main sections present questions with suggestions for exploring topics and for writing reflections about your findings. The text in gray font indicates that these are suggestions; you may think of better ways to explore the topic. You are encouraged to ask and explore your own questions about light phenomena as well as those posed here. Check with your instructor if you choose to devise an alternative approach.

Keeping track of what one is doing and thinking is important. This course uses a physics notebook page that can organize how you record your notes during class. This physics notebook page can help you remember your thoughts *before*, *during*, and *after* an exploration. An experienced elementary teacher, Adam Devittt, designed this physics notebook page to mirror the structure of *before*, *during*, and *after* reading strategies:

Before starting your exploration, think about and discuss with your group members what you know already about this topic, how you plan to conduct the exploration, and what you think you might find out.

During your exploration, record what is happening, what you are observing, and what you are thinking about what you are observing. Include sketches of equipment and observations. Note any words that are new and their definitions.

After your exploration, record any central ideas that have emerged from your observations and discussions. Also note the evidence on which you have based these ideas. State explicitly how the evidence is relevant and supports the claims you are making in stating the central ideas. Also explain why this result is important. Then write a reflection about whatever you want to remember about this experience. In addition, briefly state what you are still wondering in this context.

After class, use your physics notebook pages and any handouts to write a summary of your exploration and findings. Writing such a summary after every class is a good way to prepare for the midterm and final examinations.

Next, to be sure you have understood the physics involved, read this text and some examples of student work. The student authors first wrote drafts, received feedback for ways to enhance content and clarity, and submitted these final versions. Also read about some nuances to consider when explaining the phenomena explored.

You may also find helpful student reflections about teaching a friend or family member about what they had just learned in class, historical information about ways knowledge about the topic developed, and some relevant aspects of the nature of science in the context of the topic explored. These sections of the text may broaden your understanding of science and of science learning and teaching.

II. Identifying Student Resources

What do you already know about light? When did you learn this? Where were you? With whom? Why were you interested? How did this learning occur? These prior experiences in learning about light provide *resources* upon which you can draw in learning more about light in this course.

These "question words" –What? When? Where? Who? Why? and How? – represent an important aspect of science for which you are already expert in everyday life: asking questions. In this unit, you will explore questions that you and others generate about science learning in general and also about learning about light.

A. Learning about ways to foster science learning

Here is the first question:

Question 1.1 What have you learned about light at some time in your life, inside or outside of school, during an experience when you enjoyed the learning process?

> Equipment for each small group: Use a piece of chart paper, magic markers (all colors), and some masking tape if there is room on a nearby wall to display your work.

- What did you learn about light? How did you learn this? With whom were you learning? Where were you doing this learning? When did this happen? Why were you enjoying this learning process?

  Think about what you may have learned about light in a science class at school but also consider what you learned outside of school by playing with flashlights, looking in mirrors, swimming, wearing glasses, painting, seeing rainbows, sitting by campfires, growing plants, noticing the moon, watching a sunset, looking up at the stars…

If you are working with a group, share some of these learning experiences with one another.

- Choose one of these positive science learning experiences on which to focus. Draw a picture of yourself learning about light while enjoying the process. This course models integrating art and science so make a large vivid, colorful picture that will interest others.
- Note the age you were when you were learning this.
- While drawing a picture of yourself learning about light, think about why this experience had 'worked' for you. What had helped you learn about light in this instance?
- Add to your drawing words or phrases that convey some of the ways that this experience had helped you learn about light.
- If you are working with others, introduce yourselves by describing your positive experiences learning about light, the ages you were when you had these experiences, and some of the ways that these experiences had fostered your science learning.
- Based upon the evidence provided by this process, make a list of ways to help someone learn science in the context of learning about light.
- Make a claim about one way to foster such science learning. Support your claim with evidence drawn from the positive science learning experiences you and others reported.

After completing your exploration of ways to foster such science learning, look at an example of student work to see how others have thought about this process.

1. An example of student work identifying resources for fostering science learning

On the first day of class, for example, physics students in this course reflected upon their experiences in learning about light at some time in their lives, inside or outside of school, when they learned some science and enjoyed the process. Figure 1.1 shows some examples of positive science learning experiences that members of one group remembered and represented with drawings of ways in which they had learned about light.

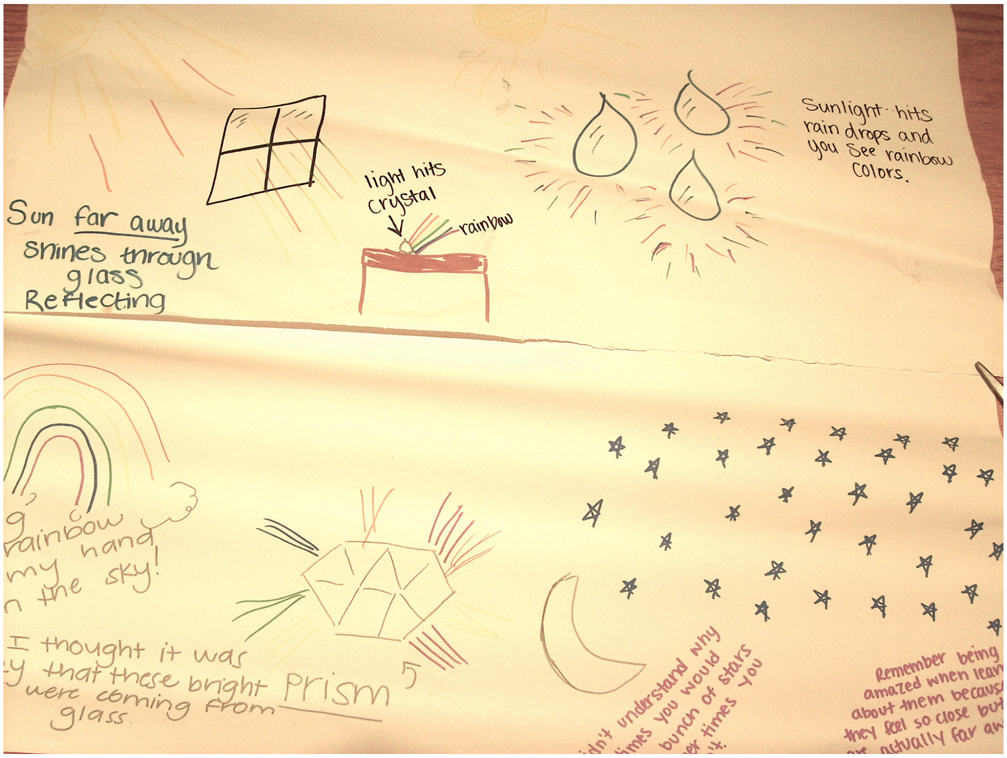


FIG 1.1 A *small group's drawings of enjoyable experiences learning about light.*

A student wrote about looking up at the stars, "didn't understand why sometimes you would see a bunch of stars and other times you wouldn't…Remember being amazed when learning about them because they feel so close but are actually far away." Another student wrote, "Exciting to see rainbow colors in my hand and not in the sky!…I thought it was crazy that these bright colors were coming from glass."

This array of experiences, drawn from multiple individuals, provides evidence upon which one can base claims. As shown in Fig. 1.2, students identified the following ways that had fostered their science learning: learning hands-on, access to books/resources, support from families, education, use of the environment: outdoor, camps, OMSI (Oregon Museum of Science and Industry), going to museums/planetarium, visual experiences, doing experiments, and asking questions.

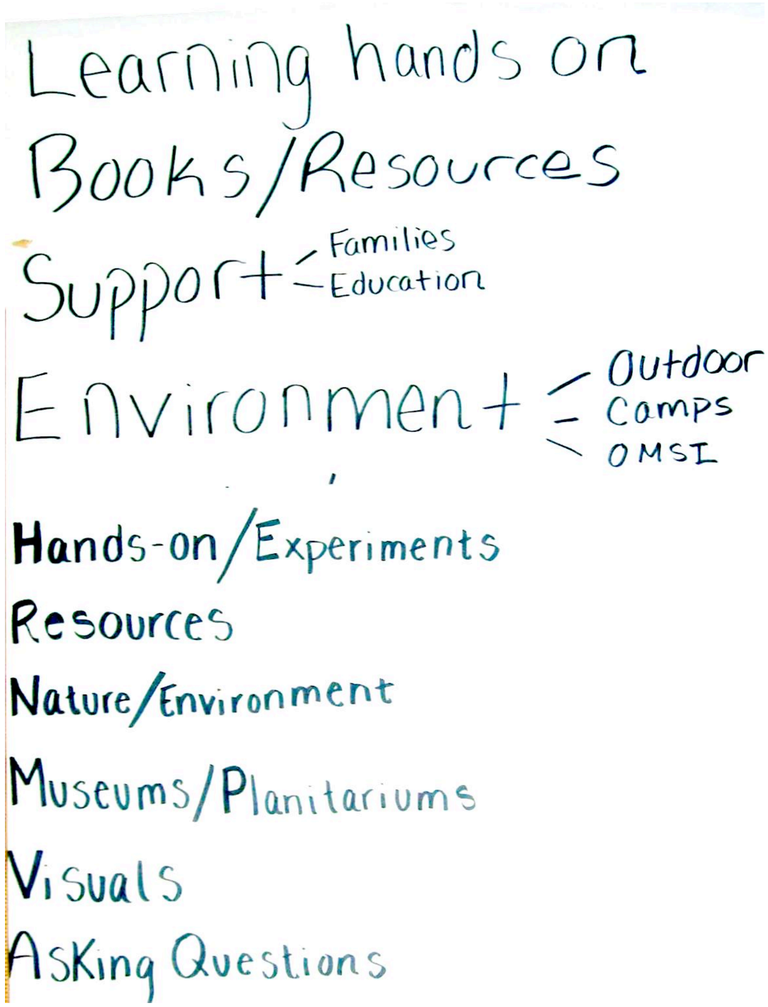


FIG. 1.2 List of ways to foster science learning identified by physics students.

This list is an example of findings from a qualitative study. The students based these findings on analyzing data that consisted of self-reported experiences by multiple individuals. The list forms an initial framework for thinking about ways to foster science learning. These ways "worked" for the individuals who generated the list and may help others learn science too.

The following is an example of a student making a claim and beginning to construct an argument to support that claim with evidence drawn from an array of personal experiences:

> *Claim: The use of the environment is an important aspect that fosters science learning.*
>
> *Evidence: During the summertime I used to lay on a sleeping bag in my backyard*

with my dad and we would watch the sky. I would spot stars, planets, the moon, and airplanes flying by. Observing my environment made me more aware and it got me to ask my dad questions about what was happening around us. Science is all around us, and using natural examples makes learning more exciting and more memorable.

Physics student, Spring 2015

This student began supporting her claim with an example drawn from a personal experience involving her home and family. Additional examples could strengthen this claim. Including group member's experiences of seeing rainbows, for example, could add support to this claim by illustrating other environmental contexts within which positive science learning occurred.

Your responses to Question 1.1. recorded some of what you already know about light and what you already know about ways to foster science learning. Next you will be documenting what you already know about the specific aspects of light that you are about to explore.

B. Documenting initial ideas about light phenomena

Question 1.2 is called a *Diagnostic Question* (DQ). Your response to a Diagnostic Question documents what you already know about a particular topic. Your response will not be graded.

Question 1.2 What do you already know about looking at something like a ball?

Equipment: Place a ball near a lamp without a shade in a dark room.

- Find a ball or another object and place it near a lamp without a shade in a dark room so that you can see it well.
- How can you see the ball?
- How could someone on the other side of the room see the ball?
- Explain with words and a sketch

Diagnostic Questions: Science & Science Learning

How would you define a “scientific explanation”?

How would you define “inquiry approaches to learning and teaching”?

To what extent are you interested in learning science?

Not interested in learning science	1	2	3	4	5	Interested in learning science

Comment:

To what extent are you interested in teaching science?

Not interested in teaching science	1	2	3	4	5	Interested in teaching science

Comment:

Later in the course, you will respond to the same questions again. Hopefully you will know more! Then you can compare your initial and current knowledge about this topic and reflect upon what has been fostering your science learning in the context of this course.

III. Developing Central Ideas Based on Evidence

In this section, you will be developing some central ideas about the nature of light by playing with light and shadows. Keeping track of what you are doing and thinking is important.

A. Documenting your explorations

One way to document what you are doing and thinking is to write an on-going record in a science notebook. The physics notebook page shown in Figures 1.3 and 1.4, for example, can help you remember your thoughts *before*, *during*, and *after* an exploration. First view the front of the physics notebook page:

Topic: What are you exploring?

Before column. Before starting your exploration, discuss with your group members what you already know about this topic, what ideas you have, what questions you are asking, how you plan to conduct the exploration, and what you think you might find out. Record these briefly in the “Before” column along with any relevant drawings.

During column. During your exploration, record what is happening and what you are thinking about what you are observing. Include sketches of equipment and observations. Indicate whether you confirm or disconfirm your predictions and what these findings suggest for next steps.

Vocabulary. Note any words that are new and their definitions.

Then view the back of the physics notebook page:

After: **Central Ideas.** After your exploration, record any central ideas that have emerged from your observations and discussions.

After: Evidence. Also note the relevant evidence on which you have based these ideas.

After: Rationale. State explicitly how the evidence is relevant and supports the claim you are making in stating the central ideas. Also note why this result is important.

After: Reflection. Then write a reflection about whatever you want to remember about this experience – perhaps what you have done and learned, how you learned this, and what implications this experience might have for teaching this topic in your own classroom…

After: Wonderings. In addition, briefly state what you are still wondering at this point.

Adam Devitt designed these notebook pages when he was assisting in this course. He was a special education elementary school teacher enrolled in a graduate program in science education. He based his design of these physics notebook pages on "before, during, and after" reading strategies that enhance literacy learning. Some of the entries have been slightly modified.

Name: Date:

Topic:

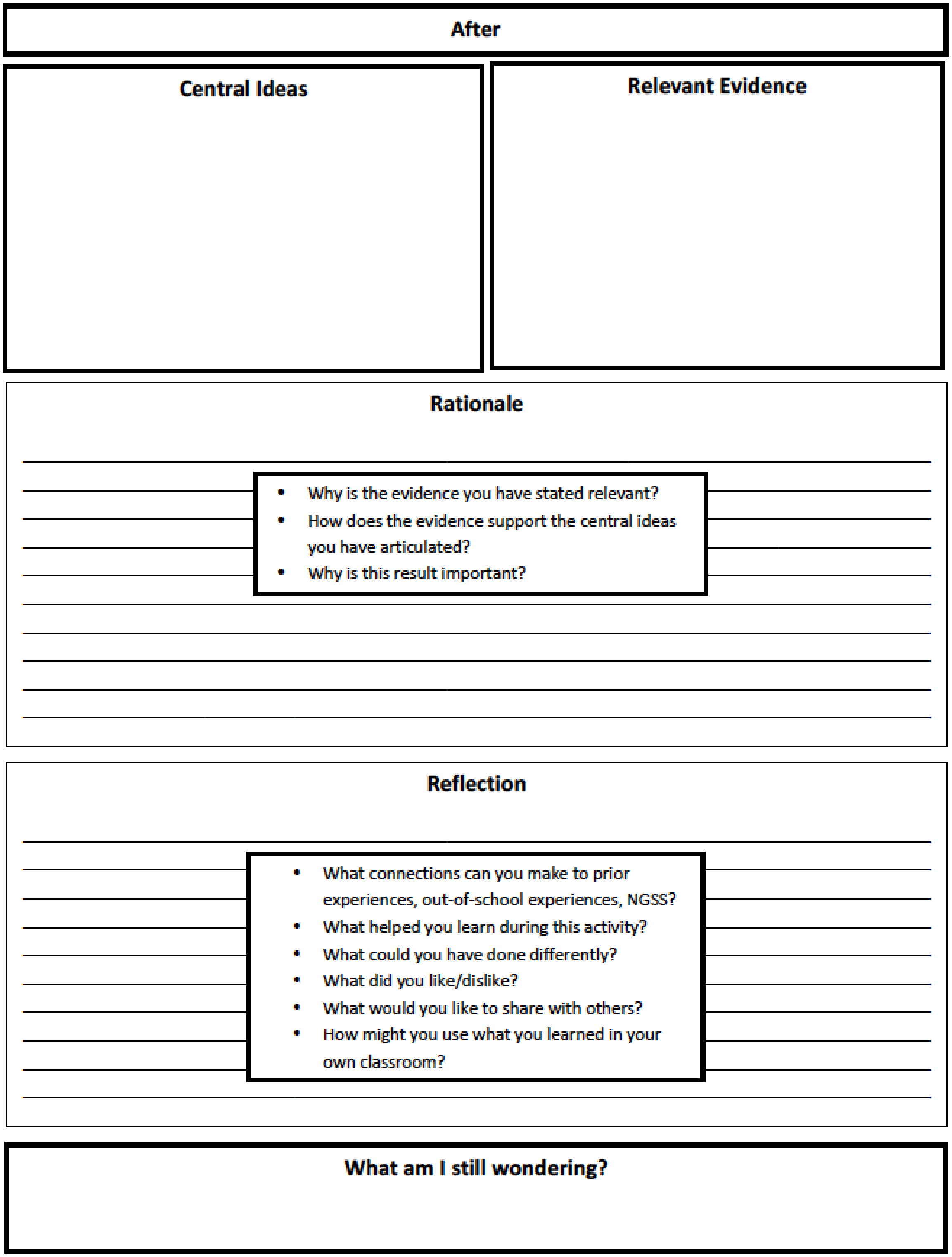
Before

- Write what you already know
- Note initial ideas
- Describe what you want to try
- Make predictions
- Draw pictures

During

- Draw pictures of what you do
- Record observations
- Note emerging ideas
- Confirm/disconfirm predictions
- Describe what to try next

Vocabulary



After

Central Ideas

Relevant Evidence

Rationale

- Why is the evidence you have stated relevant?
- How does the evidence support the central ideas you have articulated?
- Why is this result important?

Reflection

- What connections can you make to prior experiences, out-of-school experiences, NGSS?
- What helped you learn during this activity?
- What could you have done differently?
- What did you like/dislike?
- What would you like to share with others?
- How might you use what you learned in your own classroom?

What am I still wondering?

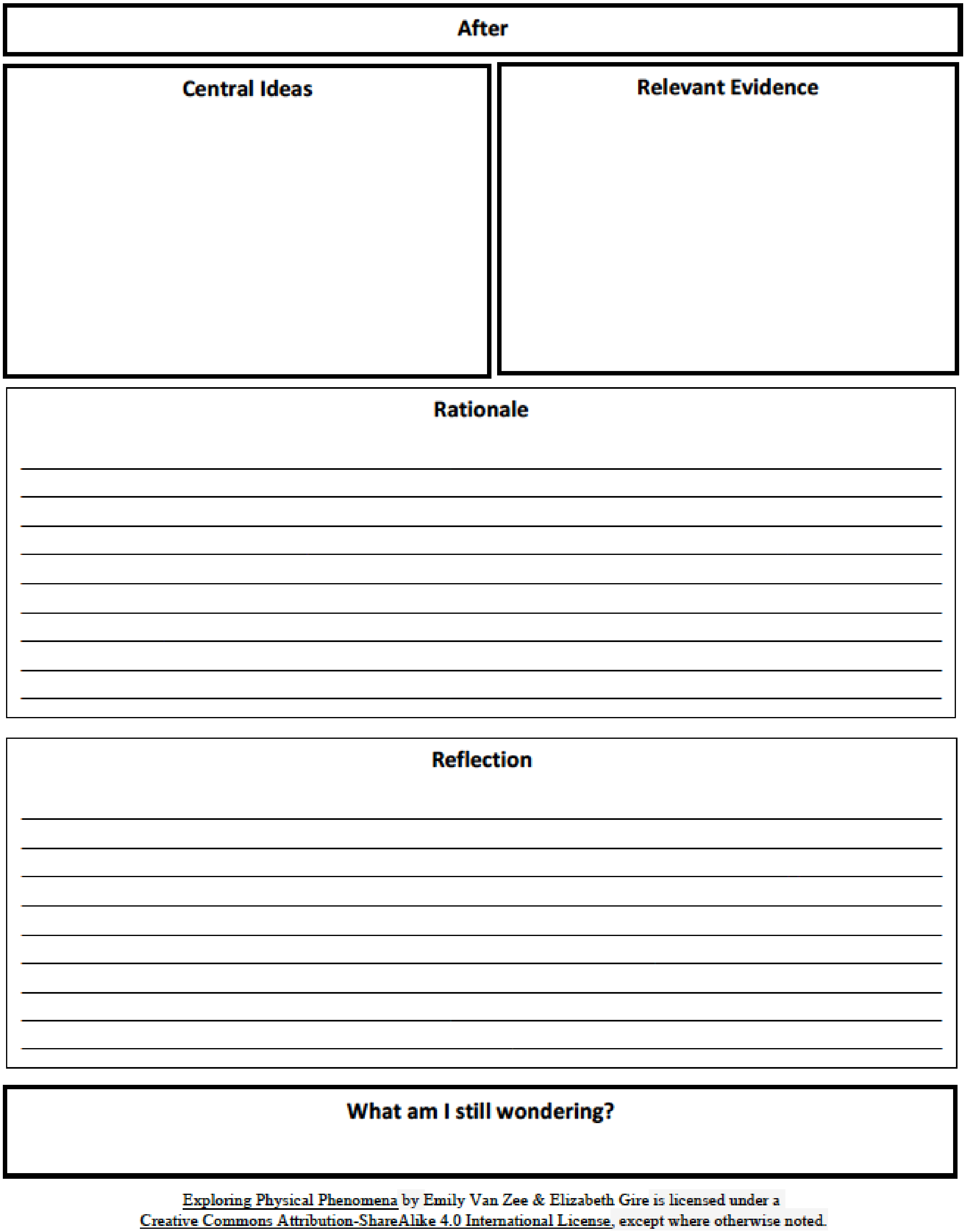
FIG. 1.3 Front and back of physics notebook page with explanations

Name: Date:

Topic:

Before:	**During:**

Vocabulary



After

Central Ideas

Relevant Evidence

Rationale

Reflection

What am I still wondering?

FIG. 1.4 Physics notebook pages template

B. Exploring the nature of light phenomena

Asking questions is an important aspect of *doing* science. Question 1.3 is a "what happens…" question:

Question 1.3 What happens when light from a source shines on a screen?

Equipment: a light source in a dark room; a screen such as a large white board covered with a piece of chart paper

- Find a dark room in which to explore the nature of light such as a room with no windows or a room with windows that have dark shades to keep out daylight.

  For a vertical *screen*, use a plain white wall or make one by taping a piece of chart paper on a whiteboard or large piece of cardboard that you can lean against a stool or box on a table.

  For a *light source*, use a lamp without a shade, that has a clear unfrosted incandescent bulb or a frosted bulb with LEDs.*

(*Look at the inside of the incandescent bulb. The narrow wire inside the bulb is called its *filament*. The filament is made out of a metal that glows when electricity flows through the lamp. LEDs (light emitting diodes) emit light by a different process that requires much less energy. LEDs have been marketed in a frosted bulb to imitate light from incandescent bulbs.)

- Place the lamp near the screen. Figure 1.5 illustrates the set-up.

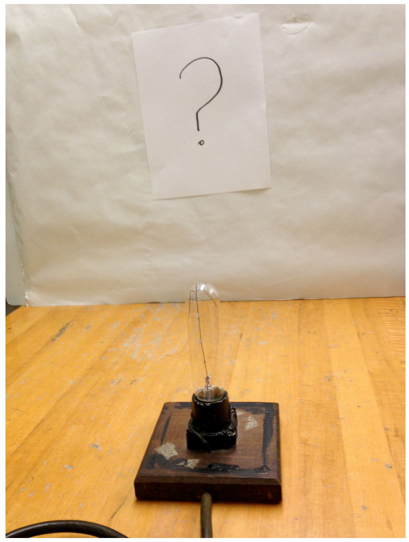


FIG. 1.5 Predict what you will see when turning on a clear light bulb near a screen.

- What will you see on the screen?

- Talk with your group members about what you think and why you think that.
- Begin to keep track of what you are doing: At the top of your physics notebook page, record the *Topic* of this exploration.
- Under *Before*, draw a picture of the set up. What do you predict will happen? Why do you predict this will happen?
- Turn on the light bulb in the dark room: what do you see on the screen?
- Under the *During* section of your physics notebook page, record what you see and interpret these results.
- Discuss your findings and formulate a relevant central idea. In the *After* section of the physics notebook page, report this idea and the evidence on which it is based.

- Use this physics notebook page and additional pages as needed to keep track of what you are doing and thinking during a series of related explorations.

In summarizing this exploration, a student noted, for example:

> *The demonstration started with a vertical light bulb being placed in front of a white piece of paper. We made predictions about what we thought would happen when the*

> *light was turned on in a dark room and I thought that the light would make a circle on the white paper, which gets dimmer as the circle gets bigger.*

Some students predict that they would see light in the shape of the filament on the screen. A student reported:

> *When a lamp is turned on in a dark room, light from the lamp shines on a screen. If the light source is a clear incandescent bulb, the light on the screen is not limited to the shape of the filament. The area of the screen directly in front of the lamp may appear brighter than areas of the screen farther away from the lamp, but all of the screen is lit. In addition, light from the lamp shines on the ceiling and the other walls of the room, as well as on the faces of those looking at the lamp and screen.*

This suggests a central idea, that ***light leaves a source in all directions.*** A student may note, however, that light leaves lasers in a particular direction. A further refinement involves pondering the use of *all*, whether one can be sure that light leaves a source in *every* direction. This suggests that ***light leaves most light sources in many directions.***

Have you ever used your fingers to make shadow shapes when playing with a flashlight in a dark room? Question 1.4 poses another "what happens?" question.

Question 1.4 What happens when you place a barrier between a lamp and screen?

Equipment: Find a *barrier* of some kind to add to your set up. This can be a card or a book that can stand up on its edge or even just fingers on your hand.

- Predict what you will see when you place the barrier between the lamp and screen as shown in Fig. 1.6.

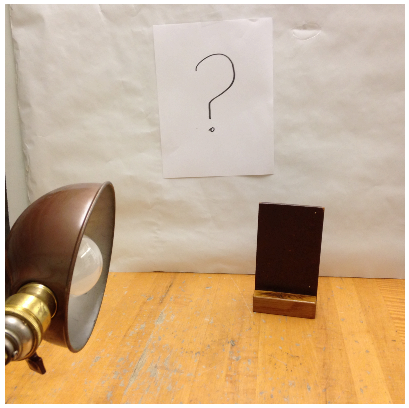


FIG. 1.6 Predict what you will see when placing a barrier in front of the screen.

- Place a barrier between a lamp and a screen: What do you see on the screen?
- Try a variety of ways of placing the barrier with respect to the lamp and screen. Making different shadows with a barrier can be a lot of fun! What do you observe?

Another kind of question asks "how" something is happening:

Question 1.5 How does light seem to travel from a source to a screen?

A meter stick or yard stick is a useful tool to explore how light travels from one place to another:

- Use a straight stick such as a meter stick or yard stick to explore how light gets from the lamp past the barrier to the edge of a shadow on the screen.

- Keep talking and refining ideas until your group and the other groups reach a consensus on several central ideas about light and shadows based on this exploration.

For example, here is what one student reported seeing:

> *We had a white piece of paper against the wall with the bottom of the paper touching the table. There was a light bulb set up to shine light toward the paper. There was a wooden block set up in front of the white paper and when the light bulb shined upon the block, the light was obstructed and as a result a shadow of the block was produced on the screen.*
>
> *We placed one end of a meter stick on the side of the light bulb; then we placed the meter stick against the edge of the wooden block and finally placed the opposite end of the meter stick against the white paper.*
>
> *We observed that the edge of the shadow, the edge of the wooden block, and the side of the light source all lined up in a straight line.*

This suggests that ***light can be envisioned as rays traveling in straight lines***.

Figure 1.7 shows an example of using a straight stick as a *physical model* for how light can be envisioned as rays traveling in a straight line from a light source past the edge of a barrier to the edge of a shadow on a screen.

FIG. 1.7 A *straight stick can provide a physical model for how light travels.*

Looking closely at a lamp and barrier setup suggests Question 1.6, a "how many?" question:

Question 1.6 *How many shadows are there when a light source shines on a barrier and screen?*

- Look at both sides of the barrier as well as at the screen.

- Keep talking and refining ideas until your group and the other groups reach a consensus about how many shadows there are when a light source shines on a barrier in front of a screen.

Here is what one student reported:

> *The first shadow that I observed was one on the white piece of paper. When an object was placed in front of a white piece of paper with a light shining on it, the object's shadow was seen on the nearby piece of paper. The second shadow that I observed was on the back side of the object. The back side of the object…was dark and had a shadow on itself.*
>
> Physics Student, Spring 2016

This suggests another central idea about light and shadow phenomena as shown in Fig 1.8: ***There are two kinds of shadows: An object blocks light a) from shining on a nearby surface (ground, table, wall, screen) and b) from shining on the back side of the object itself.***

A student supported this idea as follows:

> *An argument based on evidence to support this idea is that a shadow was seen on the piece of paper, which is the object blocking light from hitting the nearby surface, and a shadow was seen on the back side of the object which was the object blocking light from hitting the backside of itself, which shows that there are two different kinds of shadows created by an object.*
>
> Physics Student, Spring 2016

FIG. 1.8 Two kinds of shadows are formed when a barrier is placed between a light source and screen

Question 1.7 introduces an open-ended question that invites you to explore additional light and shadow phenomena by yourself, with a small group of colleagues, and/or with friends and family members:

Question 1.7 What can you find out about light and shadows with a lamp, barrier, and screen?

Equipment: Play with lamp, barrier, and screen to find out what else you can learn about light and shadows.

- Describe your explorations, evidence from your observations, central ideas about light and shadows that you infer from these explorations, the argument that supports those ideas and any relevant vocabulary.
- Reflect upon what you have learned and what you are still wondering.
- Write a summary of the central ideas based on evidence that emerged from the small group conversations and whole group discussion.

A useful way to organize outcomes from a series of explorations is to summarize them in a table as in Table I.1.

TABLE I.1 Explorations of light phenomena

TABLE I.1 Explorations of light phenomena

Description of Exploration	Evidence Observed	Central Ideas	Vocabulary
		Light leaves most sources in many directions	
		Light can be envisioned as rays traveling in straight lines	
		There are two kinds of shadows: An object blocks light a) from shining on a nearby surface (ground, table, wall, screen…) and b) from shining on the back side of object itself	
		*	
		*	

TABLE I.1 Explorations of light phenomena			
		*	

* Central idea(s) about light and shadows developed during exploration with group members and/or friend/family

During class, some groups decide to explore what happens when they move the barrier closer or farther from the light source. Others choose to move the light source. A whole group discussion of their findings suggests another central idea:

Changing the position of the barrier with respect to the lamp and/or the screen, changes the size, shape, and sharpness of the shadow on the screen.

This completes our initial exploration of the nature of light phenomena. Based on the evidence from your observations, summarize the central ideas that you have inferred about:

- How does light leave most light sources?
- How can light be envisioned as traveling from one place to another?
- What kinds of shadows form when light shines on an object?
- What influences the size, shape, and sharpness of a shadow on a screen?

These ideas form a conceptual model you can use to explain interesting phenomena you observe during additional explorations.

After summarizing your explorations in class, enjoy some students' reflections on teaching friends and children about light and shadows.

Question 1.8 What happens when exploring light and shadows with a friend or family member?

1. Examples of students' explorations of light and shadows with friends and/or family members.

A student reported:

> *During this exploration my friend and I began by discussing the previous ideas. When talking about light and shadows, we began to talk about how when we were younger we could use light to create shadow puppets with our hands. We decided to get out a lamp, turn the lights off, and use the light to create shadows onto the ceiling. During this exploration we noticed how the closer our hands were to the light source the shadow of our hand on the ceiling was bigger, and when we moved our hands further from the light source our shadows would become smaller and more defined. During this exploration I learned that as the one teaching the concepts and ideas I can also be learning and exploring with my students, the activities can be guided by both the student and the teacher experiences.*

Physics Student, Spring 2016

Another observed the following when exploring shadows with a friend:

> *When exploring shadows, my friend and I took a particular interest in the effects of having more than one light source when facing the barrier. Introducing a new light source from a new position in the room changes both the area and the position of the shadow that the barrier is making, depending on which way it is facing.*

Physics Student, Fall 2015

One student chose to explore all of the set of central ideas we had developed in class with three children whom she babysat. This was more than expected but a delightful example of a prospective elementary school teacher gaining experience teaching what she had just learned herself in class. She chose to use the initial version of the first central idea with these young children. Her verbatim quotes provide an excellent window into what preschool and elementary age children know, think, and wonder about light:

> *While working on this project I enlisted the help of three girls that I babysit. The ages of these girls are as follows: Lucie-7, Ava-4, Ruby-4. The names of these girls have*

been changed for the purpose of this assignment and for other assignments in future. I had the girls explore with light and used their own words and findings to help them understand more about how and why light works.

– ***Light leaves a source in all directions.***

For this idea the girls and I went to a room where I could close the door and there were no windows. I then placed a lamp with no lamp shade in the center of the room on a table and had each girl sit on her own bed in the room. I turned off the room light and asked the girls what they noticed about the light.

Lucie: "*The light shines up and down, up towards the ceiling and down towards the ground so we can see both.*"

Ava: "*The light in the center is brighter than the top and bottom*"

Me: "*what do you mean by that Ava?*"

Ava: "*The light in the middle of the light bulb is brighter than it is on the ceiling or the floor or the walls.*"

Me: So *where is the light shining?*

Ruby: "*Everywhere.*"

Me: *Everywhere?*

A: *Well everywhere in the room its shining.*

Me: *Where is the light shining from. Does it start at the walls and move in, is it just here, does it have a place where it starts?*"

Lucie: "The light is coming from the light on the lamp. And it shines in all of the room"

So our evidence that the light leaves a source in all directions was as follows:

–Light could be seen in all corners of the room.

–Light could be seen on the floor and ceiling of the room.

–The light came from the lamp (*source*) *and then filled the room in all areas.*

– Light can be envisioned as rays traveling in straight lines

For this idea the girls and I went outside the house to where a light post was shining light onto a wall of the barn and onto the ground. We then examined our shadows to see what we could find out about how light works. The following are observations made by the girls that allowed us to make connections to the idea that light can be envisioned as rays traveling in straight lines. They will be serving as evidence for this idea

-"When an object blocks the light it casts a shadow."

-"Even if we move or change our spots in the light, our shadows always fall the same way. So the light is traveling in only that one way."

-"If we stand outside the light and look we can see the edges of where the light shines because the light stand tunnels -focuses- the light into one spot, like a flashlight.

-When one girl stood in the light I handed a long yard stick to the other girls and asked them to make a series of lines from different positions ie. make a line with the yard stick from Lucie's hand to the same spot on Shadow Lucie's hand. The girls did so many times and ultimately decided that since the shadows blocked light in a straight line, that the light must be going in a straight line as well.

–For someone to see something, light has to travel to the person's eyes.

For the purpose of our project it is important to note that I changed the order in which these experiments took place. I first worked with the girls on the idea for someone to see something, light has to travel to the person's eyes. We then explored light bounces off of objects such as someone's nose in many different directions.

For this experiment I had the girls return to the room in which we found out that light leaves a source in all directions. In this room I changed the lights multiple times and asked the girls questions; while doing so I had the girls also switch between covering and closing their eyes and opening their eyes. The following are a list of what was changed and what the girls' answers were.

-Lucie covers and closes her eyes, but Ava and Ruby do not. I ask "who can see me? Raise your hand" Lucie is the only girl who does not raise her hand. I ask her: "why couldn't you see me?" Lucie responds that she couldn't see me because she "can't see with her eyes closed."

-Next, I had all three girls cover their eyes and asked if they could see me, the lights were on at this time. All three girls reported they could not see me.

– I then turned off the lights and had all three girls open their eyes and asked if they could see me. All three girls reported that no, they could not see me. When asked why Ava responded " it's too dark to see you."

-I then turned on the light and asked the girls if they could see me with their eyes opened. All three girls said yes. When I asked them what they thought their eyes needed to see they responded "Light!" When I asked if they only needed to open their eyes to see they said "No, because we opened our eyes with no lights on and couldn't see." So I asked them again what was needed in order for eyes to see, the girls told me you must open your eyes and also have the lights on which means that our eyes need light to see.

– Light bounces off of objects such as someone's nose in many different directions.

Since the girls had already made the connection that light is needed to see, and that it must travel to their eyes to see, this project was fairly easy. I turned off the light in the room and shined a flash light at one object at a time and asked questions as to what the girls saw. I then turned on the light and asked more questions to the girls. The following serves as our evidence for this idea.

– When the light is shined on one object such as Lucie's teddy bear the girls could all see it. When I asked why that was the girls said " because our eyes can only see what the light sends back to us, we can only see what is in the light, because our eyes need light to see."

-I then turned on the light and asked what the girls could see, they said "everything." When I asked why that was they said it was "because the lights are on." I asked if this meant the light was traveling to their eyes like earlier and they said "Yes!"

-I then pointed to my nose and asked everyone who could see it to raise their hand. All three girls raised their hand.

-I asked the girls how they could see my nose and they said because the light was on it and coming back to their eyes. I asked how each girl could see it from where they were standing. Can the light reach all of those spots or does the light only bounce off of something in one direction?

After some thought and deliberation as well as Lucie shining a flashlight at my nose, the girls came to a conclusion. In order for all of them to see my nose in different spots, my nose must be bouncing back light to all of their eyes. This means that light bounces off of objects in many different directions.

–Two kinds of shadows

For this part of the experiment I had the girls return outside to the light post. I then asked a series of questions about shadows, as well as where shadows could be seen. The following is what was discovered and decided upon as evidence.

Me: What is a shadow?

Lucie: "A shadow is where something blocks the light from traveling any farther and reflects the light only backwards."

Me: What does a shadow look like?

Ava: " Shadows are darker than the parts where the light shines through. You can't see them as much."

-I then stood with my back to the light so my back would be lit up and my front would be shadowed. In front of me a shadow was cast on the ground. I asked the girls to come touch where they saw a shadow. All three touched the shadow on the ground.

– I then asked the girls again what shadows look like and the same answer was given. So I asked the girls to look for any other areas on me or near me that looked like a shadow. After some deliberation and much circling Ava exclaimed "Your face and Belly are dark, they don't have light!" I asked if this counted as a shadow, Ava said "Yes." The other two girls were unconvinced. So I asked Ava if she could explain what she had found.

-Ava explained that "(her) back is blocking the light from reaching to her front. A shadow is when something blocks the light and doesn't let it go forwards. So (her) front is in shadow cause the light can't reach there!"

-The girls then decided that in fact there were two kinds of shadows, one on the ground and one on the back of the object casting the shadow.

Physics Student, Fall, 2015

The students generate many ideas about light and shadows through such conversations, often exploring well beyond what they might have undertaken if simply given a set of directions in class. Also teaching in a non-threatening environment with friends or family members can enhance a prospective teacher's confidence. As one student reflected, "*During this experience I learned that teaching science is not as scary as I initially thought*."

IV. Using Central Ideas to Develop an Explanation for Intriguing Phenomena

So far we have developed two central ideas based on evidence about the nature of light:

Light leaves most sources in many directions.

Light can be envisioned as rays traveling in straight lines.

These ideas form an *initial conceptual model of light*. These are ideas that most people find easy to understand; they even are evident in the art of young children, who typically draw a sun as a circle with straight rays streaming out from the circle. Figure 1.10 is an example.

FIG. 1.10 Child's drawing with with rays from the Sun.

You can use these two central ideas to explain intriguing phenomena such as what happens when light passes through a tiny pinhole.

A. Exploring pinhole phenomena

Question 1.9 What happens when light passes through a tiny pinhole and shines on a screen?

There are many ways to explore what happens when light passes through a tiny pinhole. One way involves making a *pinhole camera* with materials typically available at home. This is called a camera but no photograph is made as no film is used in this exploration.

Equipment for each student: a toilet paper or paper towel roll, square piece of wax paper, square piece of aluminum foil, two rubber bands. Equipment for each small group: a push pin. A meter stick (or yard stick) and ruler also will be helpful in developing an explanation of what one sees when looking through such a pinhole camera at a bright light bulb in a dark room. [In a remote learning situation, students might have access to a paper cup or a cardboard box with a open end such as a snack box whose bottom can be made light tight with duct tape. Possible substitutions for the wax paper include a translucent cereal box liner or plastic vegetable bag from a grocery store. A chocolate bar liner might be a source of aluminum foil.]

A student described making such a pinhole camera as follows:

> *First I laid the wax paper over one opening of the toilet paper roll and snuggly wrapped the edges down and secured the wax paper with a rubber band. I then laid the aluminum foil on the other end of the toilet paper roll and secured the edges of the aluminum foil with a rubber band. I took a push pin and made a single hole in the middle of the aluminum foil. I held the camera up so that the light from the light bulb on the table could shine through the pinhole in the aluminum foil and the wax paper faced me.*
>
> Physics student, Spring 2016

- Make a pinhole camera as described above.
- When you look through a pinhole camera at a bright light bulb in a dark room, what

do you think you will see on the wax paper screen? Record your prediction and your reasoning in the *Before* section of your physics notebook page.

- After making a pinhole camera, darken the room and turn on a light bulb without a shade. Look at the light bulb through the pinhole camera. Hold the camera away from your face and point the aluminum foil end at the bulb as shown in Fig. 1.11. Move your hand around until you clearly see something on the wax paper screen. You may need to move closer or farther from the lamp.
- Also move your head from side to side while holding the camera steady. Does this change what you see on the wax paper screen? If so, how?

FIG. 1.11 Looking at a light bulb through a pinhole camera made out of a paper towel roll.

- Record what you are doing in the *During* section of your notebook page in both words and a sketch of the set up. Include a sketch of what you are seeing on the wax paper screen.
- Complete your entry on your physics notebook page before reading an example of student work about exploring pinhole phenomena.

1. Example of student work about exploring pinhole phenomena

Figure 1.12 shows what one sees when looking at a bright light bulb through a pinhole camera in a dark room.

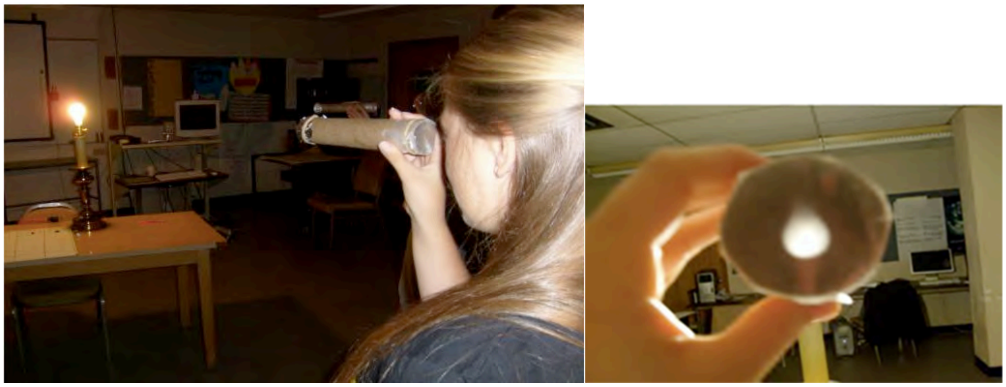


FIG 1.12 What one sees when looking at a light bulb through a pinhole camera.

A student described the surprising effect visible on the wax paper screen:, "*On the wax paper, I observed the projection of the light bulb but it looked like it was upside down*!"

The student drew the *sketch* in Figure 1.13 to represent the set up and what was visible on the wax paper screen.

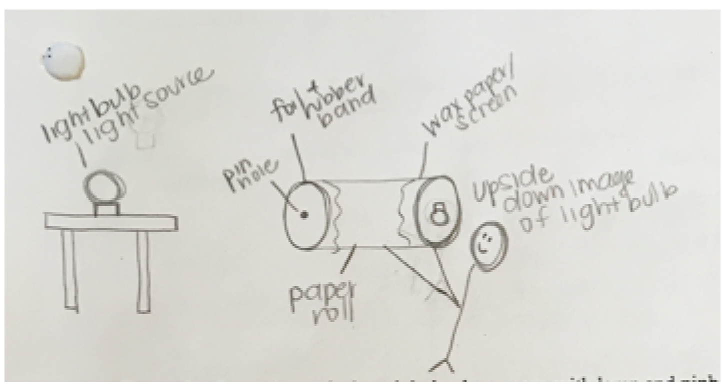


FIG. 1.13 Student's sketch of exploring pinhole phenomena.

Sketches are free form. This student wanted to show both the pinhole in the aluminum foil at one end of the roll and the upside down projection of the light bulb on the wax paper screen at the other end of the roll and so has shown both ends of the roll, although one would not see that in a 3-dimenional view. Labels include the light bulb, identified as the light source, the pinhole, foil and rubber bands holding the foil in place on one end of the paper roll, the wax paper screen on the other end of the paper roll, and the upside down image of the light bulb.

B. Explaining pinhole phenomena

After observing *what is happening…* and *how something is happening*, one likely will be asking a *why* question such as Question 1.10:

Question 1.10 Why are you seeing what you are seeing when looking at a bright light bulb through a pinhole camera in a dark room?

- Discuss with your group members some possible explanations for what you are seeing on the wax paper screen.
- Sketching what is happening can help suggest and evaluate ideas. Get a large white board or piece of chart paper and work together to sketch the ideas you have generated.
- Every so often step back and ask yourselves:*
  - What you are doing?
  - Why are you doing that?
  - How is that helping you?

(*Alan Schoenfeld (1992) suggests this questioning sequence to help people help themselves stay aware of whether what they are doing is likely to be useful in solving a complex mathematics problem.)

- Draw the light bulb and its *projection* (what you are seeing on the wax paper screen).
- Omit drawing the camera itself; just draw the light bulb and its projection roughly parallel to each other and some distance apart.
- How can you use your *conceptual model of light* (the two central ideas developed so far) to explain why you are seeing what you are seeing on the wax paper screen?

How, for example, are light rays leaving the light source? Draw some rays.

How are some of these rays traveling from the light bulb to its projection on the screen?

- How can you use your *physical model of light rays* (meter stick or yard stick) traveling from one place to another to think about how light is getting from the top of the light bulb to where the top of the projected bulb is on the wax paper screen?
- Use your physical model of light rays to draw multiple rays traveling from various parts of the light source to where you are envisioning that they land on the screen to form the projection of the light bulb you are seeing.

  In particular, draw rays leaving the top of the light bulb, the middle of the light bulb, and the bottom of the light bulb and traveling through the pinhole to form the projection of the bulb on the wax paper screen.

- Where is the pinhole located through which you are envisioning the light rays traveling from the source to the screen?

  Represent the pinhole with an open circle and add the rest of the pinhole camera to your sketch.

- Do not erase the sketch that you have been drawing. This likely is quite messy. Admire it as a document representing some of your thought processes in developing this explanation of why you are seeing what you are seeing when light from a source passes through a pinhole to a screen.

- A careful drawing with straight lines showing how one is envisioning light rays traveling from one place to another is called a *ray diagram.*

  On a new large white board or piece of chart paper, draw a careful ray diagram of this situation by using the meter stick to draw straight lines representing how you are inferring light rays leave the light bulb, travel through a tiny pinhole, and form a projection of the light bulb on the wax paper screen.

- On the back of your physics notebook page, draw a careful ray diagram by using a ruler to draw straight lines.
- Write a clear explanation about what happens when light passes through a tiny pinhole and shines on a screen.

Complete your entries on your physics notebook page and write a summary of this explanation before reading a student's example and about some nuances about exploring, representing, and explaining pinhole phenomena.

1. *Student's example explanation of pinhole phenomena*

In (Question 1.3 and 1.5), we discussed how light goes everywhere and that light rays travel in straight lines. With these ideas in mind, we inferred that all of the light rays that travel through the pinhole are traveling in straight lines. Because not all of these lines can travel straight forward, some of the lines end up traveling diagonally. As a result, the top of the light bulb gives off light rays that travel diagonally straight so that they travel through the pinhole and this diagonal line ends up projecting onto the bottom of the screen of the wax paper as shown by the blue line in (Fig. 1.14).

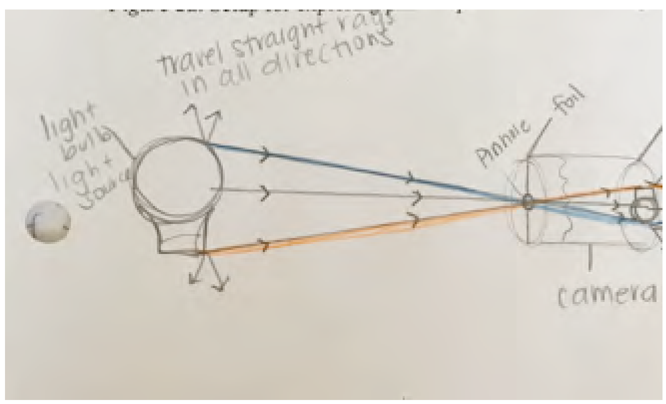


FIG. 1.14 Student's ray diagram representing explanation of pinhole phenomena.

The light rays from the center of the light bulb travel straight forward through the pinhole and project the image of the center of the light bulb on the screen of wax paper.

The orange line in Fig. (1.14) shows that the light rays given off of the bottom of the light source travel in a straight line that is diagonal and projects onto the top of the screen of wax paper.

There are many light rays given off of the light bulb between the top and the bottom *that all travel through the pinhole and project the image of the light bulb to appear upside down on the screen of wax paper.*

Physics student, Spring 2016

The separate discussion of rays from the top, middle, and bottom of the light source is helpful when explaining pinhole phenomena. Also helpful is tracing each line with one's finger while discussing each ray if one is talking about the ray diagram with someone just learning about these phenomena.

2. Some nuances in representing and explaining pinhole phenomena

Note that in the ray diagram in Fig. 1.14, the student has represented the pinhole as an *open circle*, where the lines representing the top, middle, and bottom light rays cross in the diagram. A filled-in circle would not be appropriate in a ray diagram representing pinhole phenomena because this would represent a solid barrier through which light rays could not pass. The student also used a ruler when representing light rays traveling in straight lines and put arrows on the lines to indicate the direction that the student was envisioning the light rays to be traveling.

Also note that in Fig. 1.14 the student has drawn some short rays that are leaving the top of bulb but are not heading toward the pinhole. This represents a further refinement of the first central idea about how light leaves a source.

Children's drawings of the Sun typically show rays leaving the Sun in many directions as in Fig. 1.10. Each ray, however, seems to leave a point on the source in only one direction, straight outward. Such single rays are arrayed around the circle representing the Sun. This conception of how light leaves a source prompts an issue in explaining pinhole phenomena: if rays only leave in a perpendicular direction from a source, how can any rays from near the top of the bulb be traveling at an angle, diagonally downward, toward the pinhole?

One way to address this issue is to cover the light bulb with aluminum foil or a dark cloth so that light only shines out from a hole near the top of the bulb. Does light shine from the hole only in one direction perpendicular to the surface there? Or are the ceiling, floor, walls of the room and people's faces still lit, at least dimly? If so, this suggests an additional refinement to the first central idea: ***light leaves a point on most sources in many directions.*** This is an example of an aspect of the nature of science articulated in the US *Next Generation Science Standards* that *science is open to revision in light of* *new evidence* (NGSS, Lead States, 2013, Appendix H, https://www.nextgenscience.org/resources/ngss-appendices).

The student who drew Fig. 1.14 seems to be grappling with this issue in the language used: *the top of the light bulb gives off light rays that travel diagonally straight so that they travel through the pinhole*. This student's language also illustrates a nuance that sometimes confuses students: the meaning of the word *straight*. For some people, *straight* only means *horizontal* rather than the more general meaning of *without any bends*. This student invented the phrases *straight forward* to mean *traveling horizontally without bends*, as in the center gray rays, and *diagonally straight* to mean *traveling at an angle without bends*, as in the top blue rays and the bottom orange rays. Such elaboration is not required in this course; simply discussing light as envisioned as rays traveling in straight lines is sufficient.

It is important to realize that nothing happens within the pinhole. This explanation envisions the light rays as simply passing through the pinhole in a straight line on their way to where they are going, some light rays from the top of the bulb traveling straight through the pinhole to near the bottom of the screen, some light rays from the middle of the bulb traveling straight through the pinhole to near the middle of the screen, and some light rays from the bottom of the bulb traveling straight through the pinhole to near the top of the screen. The light rays are envisioned as simply passing through the pinhole on their way to separate places on the screen.

Sometimes students use the word *flipped* to refer to the upside down projection that they see on the screen. This word is not appropriate here, however, because it suggests that something happened to the rays to cause a flip but nothing happens to flip the rays that form the projection. The rays forming the upside down projection are envisioned as simply continuing to travel in straight lines from the source through the pinhole toward the screen. One can see the upside down bulb because the aluminum foil blocks other rays from traveling to the screen.

A confusion also can occur over the use of the word *projection*. Does the phrase *top of the projection* refer to what one sees near the top of the screen (which is the projection of the bottom of the bulb) OR does the phrase *top of the projection* refer to the projection of the top of the bulb (which occurs near the bottom of the screen)? To avoid confusion, it is important to use the cumbersome but clear phrase "where these light rays form the projection of the top of the bulb near the bottom of the screen." The word *projection* is preferred over the word *image* here as the word *image* in physics typically refers to different light phenomena involving mirrors and lenses.

Like adults, children typically are surprised and intrigued by seeing an upside down light bulb when they look through a pinhole camera. As indicated by their drawings of the sun, children already know the key idea for understanding pinhole phenomena, that light can be envisioned as rays traveling in straight lines.

When discussing pinhole phenomena, with both children and adults, it is helpful to use a finger to trace the line on a ray diagram while discussing how rays from a particular part of the source are traveling:

Some light rays from the top of the light bulb are traveling straight through the pinhole to form the projection of the top of the light bulb near the bottom of the screen,

Some light rays from the middle of the light bulb are traveling straight through the pinhole to form the projection of the middle of the light bulb near the middle of the screen,

Some light rays from the bottom of the light bulb are traveling straight through the pinhole to form the projection of the bottom of the light bulb near the top of the screen and

Some light rays from all up and down the light bulb are traveling straight through the pinhole to form the rest of that upside down projection of the light bulb on the screen.

C. Exploring a critical issue

Missing from the discussion so far is a critical issue, how is information about what is happening getting to an observer?

Question 1.11 How does someone see this projection on the screen?

- Look again at what you see when looking at a bright light bulb through a pinhole camera.
- Hold the camera steady while moving your head from side to side. Does your view of the projection change? If so, how? What does this imply about how light travels through translucent materials such as the wax paper screen?
- Also consider what has to happen for someone to see something: How did the light rays get from the projection on the wax paper screen to your eye?
- Where on your ray diagram would you represent your eye looking at the projection on the screen?
- How would you represent on the ray diagram what is happening when you see the

projection on the screen?

Complete your entry on your physics notebook page and Table 1 (continued). Then write a summary of what you have learned before reading example student work explaining how one sees pinhole phenomena.

TABLE I.1 Explorations of light phenomena (continued)

TABLE I.1 Explorations of light phenomena (continued)			
Description of Exploration	Evidence Observed	Central Ideas	Vocabulary
		Light rays emerge from translucent material (such as wax paper) in many different directions	translucent
		For someone to see something, light has to get to the person's eyes.	

1. *Example of student work about how one sees the projection on the screen*

A student reported, "*I was still able to see the projection on the wax paper when I would move my head from side to side*" and offered an explanation "*We are able to see the image even when we move our head because the light rays travel in many directions as they emerge from the translucent wax paper so some of them still travel to our eyes*."

This student was invoking two additional central ideas developed in class:

Light rays emerge from translucent material (such as wax paper) in many different directions. Some of those directions are toward the eye.

For someone to see something, light has to get to the person's eye.

The student added an eye to the ray diagram, with straight lines from the projection to the eye to represent light leaving the projection and traveling to her eye as shown in Fig. 1.15.

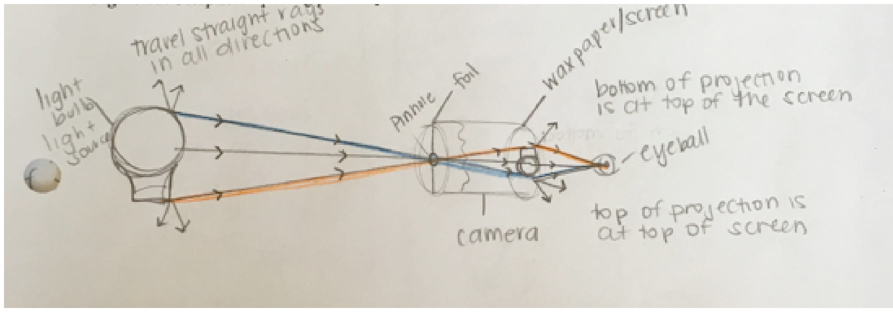


FIG. 1.15. Ray diagram for pinhole camera that includes light getting to viewer's eye.

The student explained the complete ray diagram as follows:

> *The orange line represents light rays traveling from the bottom of the light bulb through the pinhole to the top of the screen and then some of the rays travel in a straight line to the eyeball.*
>
> *The middle grey line represents the light rays that travel from the center of the light bulb through the pinhole, creating the image of the middle of the bulb on the screen, then some travel to the eyeball.*
>
> *The blue line represents the light rays that travel straight from the top of the light bulb diagonally down through the pinhole and then project the image of the top of the light bulb onto the bottom of the screen of wax paper. Some of the blue rays then travel …to the eyeball.*

The notes added near the top and bottom on the right side of this diagram illustrate the confusion of the meaning of the word *projection* – does this refer to what one is seeing? (bottom of the bulb near the top of the screen) or to the entity itself (the top of the projection refers to what is at the top of the screen)? In this course, avoid the phrases "bottom of projection" and "top of projection" and use instead the clear phrase "where these light rays form the upside down projection of the top of the bulb near the bottom of the screen."

D. Exploring variables affecting pinhole phenomena

Another type of question focuses upon identifying what is important to notice in a situation:

Question 1.12 What variables affect what one is seeing on the screen?

- Discuss with your group members ways you can change the pinhole camera you made and ways that you are using it.
- Explore and report on some of these possibilities in Table I.2

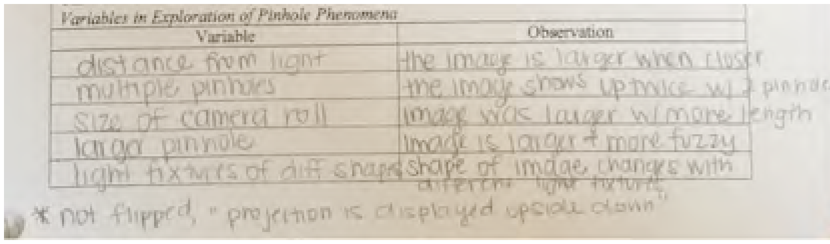
TABLE I.2 Variables in exploration of pinhole phenomena	
Variable	Observation

- In the "After" section of your physics notebook page, record two new central ideas, the evidence that supports these claims, and a rationale that explains how the evidence supports the ideas and why these are important.
- Also write a reflection about what you have learned.
- What are you still wondering?

Complete your entry on your physics notebook page and write a summary of what you have learned before reading examples of student work of exploring variables that affect pinhole phenomena

1. Example of student work about variables that affect pinhole phenomena.

How big is the projection? How bright is it? How sharp is it? How many projections does one see? Do distance from the light source, length of the roll, size of the pinhole, shape of the light fixture, or number of pinholes matter? As shown in Fig. 1.16, a student included the following variables in reporting findings: distance from light, multiple pinholes, size of camera roll, larger pinhole, and light fixtures of different shapes:



Variables in Exploration of Pinhole Phenomena

Variable	Observation
distance from light	the image is larger when closer
multiple pinholes	the image shows up twice w/ 2 pinholes
size of camera roll	image was larger w/ more length
larger pinhole	image is larger + more fuzzy
light fixtures of diff shapes	shape of image changes with different light fixtures

* not flipped, "projection is displayed upside down"

FIG. 1.16 *Student's table of variables in exploring pinhole phenomena.*

This student then described these findings using "projected image" rather than the more technically preferred "projection." The multiple examples illustrate well, however, the many ways even young students can enjoy exploring pinhole phenomena:

When the distance between the camera and the light bulb increases, the projected image of the light bulb on the wax paper screen becomes smaller. When there are multiple pinholes in the aluminum foil, there will be multiple projected images of light bulbs on the screen of wax paper. When the length of the paper roll of the camera increases, the projected image of the light bulb gets larger. When the pinhole is made into a larger hole, the image becomes larger and fuzzier, it is more difficult to tell if the image is still upside down or not.

When the camera is used to view light bulbs of different shapes, the projected image of the light bulb on the wax paper screen will change with the light fixture. For example, in class we looked at a light bulb that was similar to a tear drop shape and our projected image looked similar to an upside down teardrop. When I used the camera on a spherical light fixture, the projected image looked like an upside down circle. Some other questions that I have is: is this how our pupils work? How did people discover the pinhole phenomena?

Physics Student, Spring 2016

In this course, we are not exploring what happens within the eye, just getting light to the eye. If you are wondering what happens next, after the light enters the eye, consult a book or internet website about how eyes work such as https://nei.nih.gov/kids/about_the_eye .

The eye's pupil acts like a pinhole with a variable diameter that controls how much light enters the eye. The projections on the retina are upside down and are turned 'right side up' by your brain. Some additional information about how the eye works is at: http://www.mind.ilstu.edu/curriculum/vision_science_intro/vision_science_intro.php

Some historical information about pinhole cameras is at https://jongrepstad.com/pinhole-photography/pinhole-photography-history-images-cameras-formulas/

E. Exploring pinhole phenomena with friends and/or family members

Question 1.13 What happens when exploring pinhole phenomena with a friend or family member

- Continue exploring pinhole phenomena outside of class with a friend or family member.
- Complete your entry on your physics notebook page and write a summary of what you have learned before reading examples of student work exploring pinhole phenomena with friends and/or family members .

1. Examples of student explorations of pinhole phenomena with friends and/or family

A student explored pinhole phenomena with a cousin:

I showed the pinhole phenomena with my 15 year old cousin. Before seeing the projection he guessed that the projection on the wax paper would be the shape of the pinhole. When he saw the projection his exact words were "what the fudge?"

It took Z. a moment to realize what he saw was an upside down light bulb. When *asked why he thought the projection was upside down he said "I have no idea.... I don't even know how it is projecting the stupid light bulb!"*

I then asked Z. what he knew about light; after some discussion he and I came to the conclusion that light travels in all directions and that light travels in straight lines called rays.

I asked Z. to draw on a whiteboard a representation of what he saw, much like what I myself did in class with my group. Z. did so, and I then asked him to use a ruler and his pen to draw rays leaving the light bulb. At first Z. drew only light rays leaving in vertical and horizontal lines. I then asked Z. to tell me again how light travels. Z. said that it travels in all directions in straight lines. I asked him to show me lines that traveled in all directions, so Z. drew more lines leaving the bulb in all directions much like the lines above.

I then posed the question to Z. of how light was getting through the tube and onto the screen. Something seemed to click with Z. then because he erased his original drawing and drew a new bulb with about 10 rays some of which went through the pinhole and onto the screen. He then told me that since the rays that he drew at the top of the bulb "would continue traveling on their downward path and would be projected onto the bottom of the screen. The lights from the bottom of my bulb will travel towards the top and be projected there. Is that right?"

I was honestly amazed at how quickly he picked up on the information. I told him he was right and showed him my own ray diagram and he said that it made sense. He then helped me find ways to alter the experiment, which are shown in table 2.

From my experience working with and teaching Z. I realized how frustrating it can be to work with older students. I do not mean for this to sound bad, because in some ways it was refreshing to work with an older student. Yet, as I worked with Z. I found that I am so accustomed to working with younger children, these children need a certain amount of guidance, more so than he did. Z. did need my help to understand but much of what he was able to figure out on his own was frustrating and interesting to me. His mind works so quickly and he needed only a slight push in the right direction to understand. Knowing this it was hard to hold my tongue and not explain everything to him before allowing his mind to make the connections first.

Physics student, Fall 2015

Another student chose to explore pinhole phenomena with a roommate:

I explored pinhole cameras with one of my roommates. I began by asking her what she knew about light (such as the direction it travels, whether or not it travels in a *straight line). To my surprise she already knew that light traveled in all directions and in a straight line. I told her to keep that in mind.*

I then showed her the pinhole camera I had made in class and explained what she would be doing with the light bulb and the camera. Before turning on the light bulb I asked her what she thought would happen. She said that she thought the light bulb would appear on the wax paper.

I then turned on the light bulb and asked her to look and tell me what she saw. She was puzzled to find that the light bulb that appeared on the wax paper was actually upside down. She could not tell me why this happened.

I gave her a piece of paper and pencil and asked her to draw the entire set up including what she had seen. I then asked her again to tell me what she knew about light. When she said that light traveled in a straight line I told her to stop and think about that.

She thought for a few seconds and then told me that light was entering the pinhole camera in a straight line. I encouraged this by giving her a ruler to add some straight light rays to her picture. After drawing straight lines for a few seconds she connected the top of the light bulb to the bottom of the light bulb on the camera with a straight line. She did the same for the bottom of the light bulb. I asked her to tell me what this meant. She explained that the ray coming from the top of the light bulb travels in a straight line through the pin hole to the bottom of the screen and the ray coming from the bottom of the light bulb does the same, except it appears at the top of the screen.

I learned that being patient and providing my roommate with adequate thinking time (private reasoning time), she was able to tell me exactly what had happened. I prompted her throughout the experiment with questions instead of telling her the answers. I also encouraged her to build off of what she already knew (for example: that light travels in a straight line).

Physics student, Spring 2014

This concludes this example of using central ideas based on evidence to explain intriguing phenomena.

V. Developing Mathematical Representations of Pinhole Phenomena

Pinhole phenomena can provide useful tools in estimating quantities that are otherwise hard to measure. To do so, we need to develop ways to represent pinhole phenomena mathematically, both geometrically and algebraically.

A. Representing pinhole phenomena geometrically

The visual display provided by a ray diagram suggests describing pinhole phenomena geometrically. First we simplify the diagram, next name and label angles, and then interpret geometric aspects of two triangles evident in the refined ray diagram.

Question 1.14 How can you describe pinhole phenomena geometrically?

The ray diagram in Fig. 1.14 includes realistic sketches of the light bulb, the upside-down projection, and the pinhole camera as well as lines representing light rays inferred to be leaving the source and traveling straight through the pinhole to the screen.

This realistic portrayal of what we can actually see (the light bulb, camera, and projection on the screen) was helpful in using our conceptual model for light in explaining the upside-down projection of the light bulb observed on the screen: We could infer that light was leaving points on this source in many directions and envision that some light rays were traveling in straight lines:

- from the top of the light bulb straight through the pinhole to form the projection of the top of the light bulb near the bottom of the screen,
- from the middle of the bulb traveling straight through the pinhole to form the projection of the middle of the light bulb near the middle of the screen, and
- from the bottom of the bulb traveling straight through the pinhole to form the projection of the bottom of the light bulb near the top of the screen.

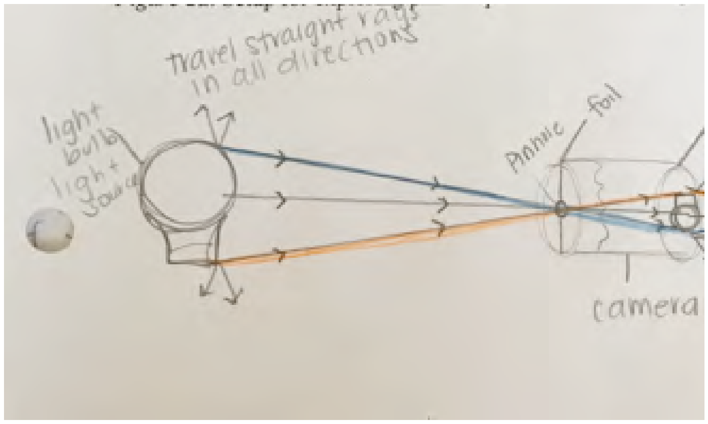


FIG. 1.14 (repeated) Student's ray diagram representing explanation of pinhole phenomena.

A more abstract stylized ray diagram, however, can focus attention on the envisioned light rays without the details of source, camera, and screen as shown in Fig. 1.17:

- Instead of a drawing of a light bulb, a vertical line represents the light source.
- Instead of a drawing of an upside-down projection of the light bulb on the screen, a parallel shorter vertical line represents this projection.
- Instead of an open circle, the pinhole is represented by an opening between short vertical lines above and below the point where the lines representing envisioned light rays cross. These short vertical lines represent the opaque end of the camera through which a pin was pushed to make the pinhole

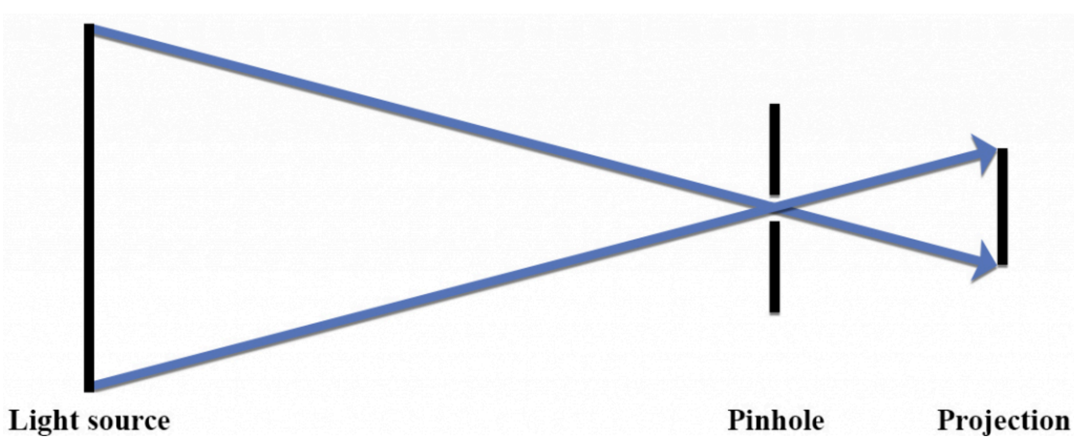


FIG 1.17 *Stylized ray diagram representing pinhole phenomena.*

In Fig. 1.17, vertical black parallel lines represent the source and projection rather than sketches of the bulb and upside down projection. An opening between two small black vertical lines represents the open pinhole. The blue straight lines represent rays of light inferred to be traveling from the top and bottom of the bulb to the bottom and top of the screen where they form the upside down projection of the light bulb. The rest of the details of the source and the camera are not shown. The description of what is happening is the same:

- We are envisioning rays of light from the *top* of the vertical line representing the light bulb traveling straight through the opening representing the pinhole to form the projection of the top of the light bulb near the *bottom* of the screen.
- We are envisioning rays of light from the *bottom* of the light bulb traveling straight through the opening representing the pinhole to form a projection of the bottom of the light bulb near the *top* of the screen.

By using straight parallel vertical lines to represent the source and the projection, Fig. 1.17 simplifies the ray diagram so that two triangles become evident.

- What do these two triangles represent?
- How are these two triangles related?

One way to describe a ray diagram geometrically is to begin by naming the vertices of the triangles. In Fig. 1.18 for example, the vertices of the triangle on the left are labeled A, B, C, whereas the vertices of the triangle on the right are labeled F, E, C. (Later the letter D will represent the distance between line AB and vertex C, so D is omitted in naming vertices here.)

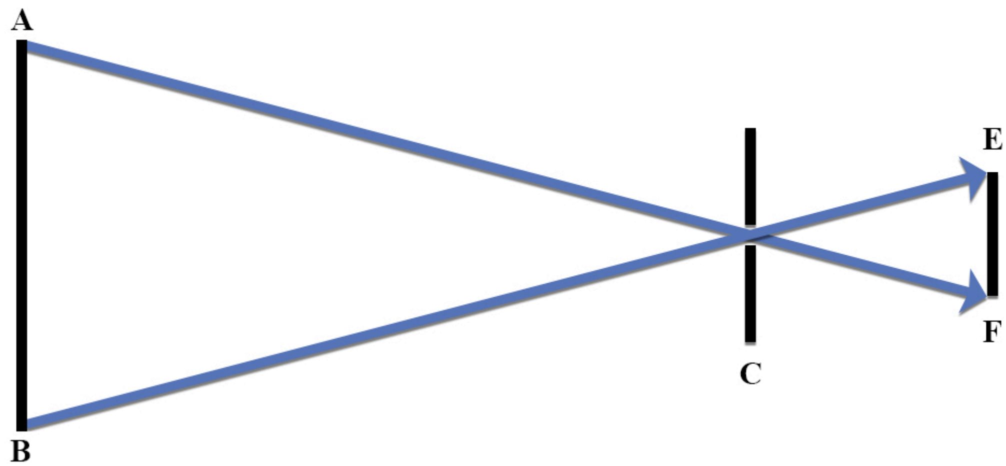


FIG. 1.18 *Triangles ACB and FCE.*

- How are the angles in these triangles related?
    - What does it mean, for example, for two angles to be *corresponding*? Which angle in triangle FCE corresponds to Angle A in triangle ACB? Which angle in triangle FCE corresponds to Angle B in triangle ACB? Which angle in triangle FCE corresponds to Angle C in triangle ACB?
    - What does it mean for two angles to be *congruent*?
    - When are two angles congruent if formed by intersecting lines?

Triangles with three congruent corresponding angles are called *similar triangles*.

- Are triangles ACB and FCE similar triangles? If so, which are the three congruent corresponding angles?
- If triangles ACB and FCE are similar triangles, how are corresponding lengths related?

If you need to learn about similar triangles, see www.mathopenref.com/**similartriangles**.html and http://www.mathopenref.com/similartrianglesparts.html

For information about vertical angles, see http://www.mathopenref.com/anglesvertical.html

For information about congruent angles created by parallel lines and a transversal (sometimes called *alternate interior angles*), see http://www.mathopenref.com/anglesalternateinterior.html

Complete writing your own response to Question 1.14 before reading an example of student work and some nuances in representing pinhole phenomena geometrically.

1. *Example of student work representing pinhole phenomena geometrically*

A student drew the ray diagram in Figure 1.19 at the close of a class session in which the students developed and then used mathematical representations of pinhole phenomena to estimate a quantity. This student drew single, double, and triple lines to indicate clearly the congruent corresponding angles of the two triangles formed in the ray diagram:

Single lines indicate that angle c of the large triangle on the left corresponds to and is congruent with angle c of the small triangle on the right

Double lines indicate that angle a corresponds to and is congruent with angle f.

Triple lines indicate that angle b corresponds to and is congruent with angle e.

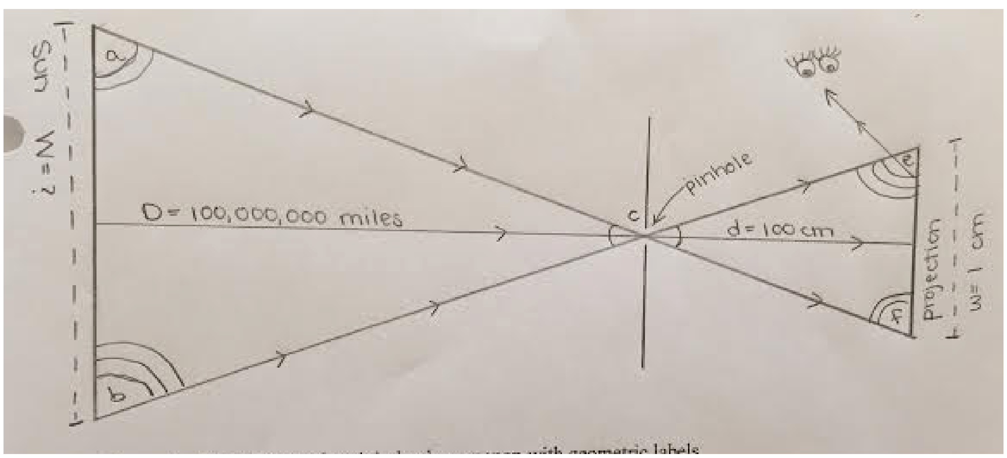


FIG. 1.19 Student's *ray diagram showing corresponding congruent angles.*

The student described this ray diagram geometrically:

> *(The figure above) is a ray diagram consisting of two triangles that share a point. I have labeled the vertices of each of the triangles a b c, c e f, noticing that their shared vertex is c…We can conclude that the two triangles are similar because of two*

different properties. The first property, vertical angles property, states that angles acb and ecf are congruent. Next, the alternate interior angles property allows us to confirm that two different sets of angles are congruent: angles abc and fec as well as angles bac and efc. The two triangles above, written acb and ecf, are similar because each of their corresponding angles is congruent. We know this because of the AAA, or Angle Angle Angle, theorem. Because these triangles are similar, we can set up a proportion…

Physics student, Spring 2016

(This student also included some numerical information on this ray diagram that refers to the activity involving pinhole cameras discussed below under section VI.)

2. Some nuances in representing pinhole phenomena geometrically

In writing about the ray diagram shown in Fig. 1.19, the student invoked several geometric ideas:

- Angles formed by two intersecting lines are called *vertical angles* (as occurs at the pinhole C in Fig. 1.19) and are congruent, that is, they have the same measure; if one is 30 degrees, the other also is 30 degrees.
- Some angles formed by a line (a *transversal*) intersecting two other lines are called *alternate interior angles* (such as angles a and f; also angles b and e in Fig. 1.19).

  Alternate interior angles are congruent *only if* the two other lines are *parallel*. If the two other lines are not parallel, the angles will still be alternate interior angles but they will not have the same measure, that is, they will not be congruent.

- Two triangles are similar if all three corresponding angles are congruent:

  Angle a is congruent with Angle f because they are alternate interior angles formed by a transveral crossing two parallel lines.

  Angle b is congruent with Angle e because they are alternate interior angles formed by a transveral crossing two parallel lines.

  Angle c of the big triangle is congruent with Angle c of the little triangle because they are vertical angles

- Corresponding lengths of similar triangles are proportional.

In naming the triangles “triangle acb” and “triangle ecf” this student did not follow the convention to name similar triangles so that the names of the corresponding angles are in the same position: the position of Angle a in the name “triangle acb” would correspond to the position of Angle f in name “triangle fce”; the position of Angle c in the name “triangle acb” would correspond to the position of Angle c in the name “triangle fce”; and the position of Angle b in the name “triangle acb” would correspond to the position of Angle e in the name “triangle fce”.

In referring to “angles abc and fec as well as angles bac and efc”, however, this student has followed the convention in that congruent angles a and f are in the same position, congruent angles b and e are in the same position, as are the angle c’s.

Note that this student used lower case letters, rather than capital letters, to identify angles on the ray diagram and then named each angle by listing three lower case letters with the angle letter in the middle. In this course, capital letters placed outside the vertex as in Fig. 1.18 are preferred in labeling angles of triangles such as Angle A and in naming triangles, as in the statement “Triangle ABC is similar to Triangle FEC”.

The ray diagram in Fig. 1.19 clearly represents the congruent corresponding angles in these two triangles. Note that the student has used the space between two short vertical lines to represent the pinhole as well as a ruler to make straight lines. The line with arrows drawn from the projection to the viewer’s eyes is ok in that light all the way along the projections bounces off the screen to the viewer’s eyes. However, starting this line higher, at the vertex of Angle e, would better represent rays *continuously* traveling from the bottom of the source straight through the pinhole to form the projection of the bottom of the light bulb near the top of the screen and then travel to the eye.

Note that the eye is shown to the left of the screen. This represents a scenario in which the student was looking at a projection on a screen where the light forming the projection reflected off an opaque screen back to the eye as in Fig. 1.21 below rather than passing through a translucent wax paper screen as in Fig. 1.15 above.

B. Representing pinhole phenomena algebraically

The visual display provided by a ray diagram also suggests describing pinhole phenomena algebraically. First, we name and label lengths as well as angles, identify ratios of corresponding lengths that are equal, and consider nuances in representing pinhole phenomena algebraically.

Question 1.15 How can you represent pinhole phenomena algebraically?

Representing pinhole phenomena algebraically requires naming aspects of pinhole phenomena that you can measure and use in a calculation. Identifying such quantities involves thinking about the *variables* in a situation: what, for example, affects the size of the projection that you see?

- What can you do to make the projection bigger? Smaller?
  - What happens to the projection if you move the camera closer to the source? Farther from the source?
  - What happens to the projection if you make the camera longer? Shorter?
  - What happens to the projection if you choose a higher light source? Lower?
- Give names to those variables and draw a ray diagram that includes identifying those variables with symbols, in addition to labeling angles A, B, C, E and F.

  Include, for example, a horizontal line from the middle of the vertical line representing the light source, AB, to the middle of the vertical line representing the projection to EF.

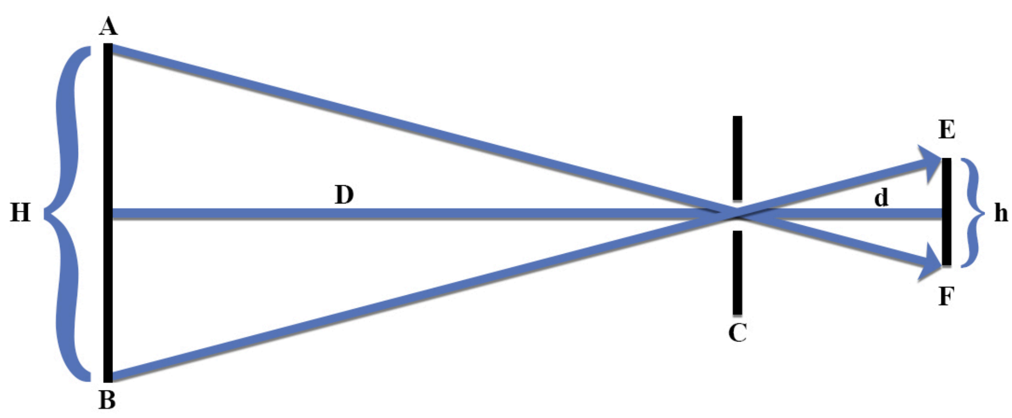


FIG. 1.20 *Ray diagram representing pinhole phenomena.*

Figure 1.20, for example, includes a line representing light rays leaving the middle of the source, traveling straight through the pinhole, to form the projection of the middle of the source on the middle of the screen. This line also can represent two variables, the length, *Distance D*, between the light source and the pinhole, and the length, *distance d*, between the pinhole and the projection on the screen. The ray diagram in Fig. 1.20 also identifies H as *the Height* of the source AB and *h* as *the height* of the projection EF.

Note that the symbols H, D, h and d represent *lengths* in the two triangles whereas the symbols A, B, C, E, and F represent angles.

- How are lengths related in similar triangles?

If two triangles are similar, their corresponding lengths are proportional.

- How would you express the relationship of corresponding lengths in similar triangles algebraically with symbols?
- How would you express the algebraic relationship of corresponding lengths in similar triangles with words?

Complete writing your own response to Question 1.15 before reading an example of student work and some nuances in representing pinhole phenomena algebraically.

1. *Example of student work representing pinhole phenomena algebraically*

A student summarized the mathematical relationship among the lengths of similar triangles as follows:

> *The property of similar triangles states that triangles can be different sizes as long as they have the same shape. The same shape depends on corresponding angles and proportionate sides. In the figure we can see the relevant vertices of the triangles and proportionate sides where "H" is the height of the bulb and "d" is the distance from foil to wax paper. The Height of the bulb over the Distance from the bulb to the foil is equal to the height of the projection over the distance from the pinhole foil to the wax paper.*

$$\frac{H}{D} = \frac{h}{d}$$

$$\frac{\text{Height of the bulb}}{\text{Distance from the bulb to pinhole}} = \frac{\text{height of the projection}}{\text{distance from the pinhole to the projection}}$$

Physics student, Spring 2014

This student understood the basic property of similar triangles, that they have the same shape but may be different sizes and that this means that the ratios of corresponding lengths are equal.

2. *Nuances in representing pinhole phenomena algebraically*

There are several aspects of representing pinhole phenomena algebraically that need attention. These include choices made in using language, naming variables, forming ratios, justifying the equal sign, deciding on an appropriate algebraic representation to use, and using one's sense-making skills to envision and monitor what one is doing.

(a) Using language. Part of learning physics is learning to use language precisely. What words, for example, describe "H/D"? Colloquially this often is referred to as "H over D" or "height over distance". The use of the word "over" refers to how one expresses this relationship in writing: one writes the H "over" the D. Such language can be confusing for someone who does not infer the process represented by the word 'over' and the line drawn between the H and D. A more precise version would be to refer to "H divided by D" or "height divided by distance". This articulates the mathematical process involved, division. However, a more informative version would be to refer to "the ratio formed by comparing H to D" or "the ratio formed by comparing the height of something to some relevant distance, such as "the ratio formed by comparing the height of the light source to its distance from the pinhole."

(b) Naming variables. In developing an algebraic description of a phenomenon, one has to give names and symbols to the variables that matter, in this case how high the light bulb and its projection are, and how far they each are from the pinhole. *Height* and *Distance* seem the natural names for these variables with H and D used for the height of the light source and its distance from the pinhole in the large triangle and h and d used for the height of the projection and its distance from the pinhole in the smaller triangle.

The horizontal line representing two distances here, however, would typically be described as the heights of triangle ABC and triangle FEC. Should one give a name to this variable that refers to what it is representing, distance from the pinhole, or a name to this variable that refers to its geometric role in the diagram, height of a triangle?

To avoid this confusion, sometimes we have used *length* to refer to the vertical lines, but the lower-case l looks like a one and L/D = l/d is also confusing. Note in Fig. 1.19, that this student had used the letters W and w to represent the *width* of a circular light source and its projection where use of a D and d might have been expected for representing their *diameters*, but D and d were already in use for representing *distances* from the pinhole.

The advantage of using the name *height* for the variables represented by the vertical lines AB and EF is that this connects the mathematical description to the objects the lines are representing, the light bulb and its projection.

An essential aspect of developing a mathematical representation of a phenomena is that after deciding on the names and symbols one wants to use, be sure to state clearly what each variable and its symbol represent.

(c) Forming ratios. When considering two similar triangles, it can be helpful to form a ratio with variables in one triangle and set this equal to a ratio formed with the corresponding variables in the other triangle. The equation with ratios that this student stated, for example, H/D = h/d, compares two lengths of the large triangle, representing the height of the light source and its distance from the pinhole, and sets this equal to a comparison of the two corresponding lengths of the small triangle, representing the height of the projection and its distance from the pinhole.

It is important to be able to express the equality of such ratios with words as well as symbols: With H/D = h/d, one is equating "how the height of the light source compares to the light source's distance from the pinhole" with "how the height of the projection compares to the projection's distance from the pinhole."

One also has the choice of in what order to make such a comparison. With D/H = d/h, for example, one is equating "how the light source's distance from the pinhole compares to the light source's height" with "how the projection's distance from the pinhole compares to the projection's height."

In both cases, this approach has the advantage that the units used within the same triangle will match. In this case of comparing one length to another length, with both lengths measured in the same units, the ratios will be dimensionless. This means that, if convenient, one can use units for the lengths in the large triangle that differ from the units for the lengths in the small triangle.

Sometimes, however, one might want to compare the same variable in the two triangles, setting the ratio of the heights, for example, equal to the ratio of the distances: H/h = D/d In this case, one is setting equal "how the light source's height compares to the projection's height" with "how the light source's distance from the pinhole compares to the projection's distance from the pinhole." One also could set this equation up as: h/H = d/D. Here one is setting equal "how the projection's height compares to the light source's height" with "how the distance of the projection from the pinhole compares to the distance of the light source from the pinhole."

Although cumbersome, keeping in mind the word description of what these ratios represent can prevent randomly setting up an equation that may look appropriate: h/D = H/d but is not justified in this context.

(d) Justifying the equal sign. When setting one algebraic expression equal to another in this course, it is important to justify the equal sign explicitly. For example, one student wrote:

> *In the figure, there are two triangles seen, triangle* ABC *and triangle* FCE. *The two triangles are similar because they have three sets of congruent angles. The first set of congruent angles are vertical angles, in which Angle* ACB ≈ *Angle* FCE. *The second set of congruent angles are alternate interior angles, in which Angle* CAB ≈ *Angle* CFE.
>
> *The third set of congruent angles are alternate interior angles, in which Angle* CBA ≈ *Angle* CEF.
>
> *Since the two triangles have congruent angles, they are therefore similar triangles because of the* AAA *theorem. The corresponding sides of similar triangles are proportional, which is why we are able to set up a proportion comparing the two triangles.*
>
> Physics student, Spring 2016

Note that this student has not used the convention in naming the triangles. Triangle ABC puts angle C in the third position but Triangle FCE puts angle C in the second position. An alternative would be Triangle ABC is similar to Triangle FEC or Triangle ACB is similar to Triangle FCE. The student has used the conventions in naming angles so that the angle of interest is the middle letter: Angle ACB and Angle FCE are both referring to the angle where the two lines cross at C. Angle CAB refers to the angle at A and Angle CFE refers to the angle at F, a set of alternate interior angles at A and F. Angle CBA refers to the angle at B and Angle CEF refers to the angle at E, the other set of alternate interior angles.

(e) Choosing an appropriate algebraic representation. If H/D = h/d, D/H = d/h, H/h = D/d and h/H = d/D, which set of equal ratios should one use?

If you can measure three of the variables and need to calculate the forth, any of these will work. However, some are easier to use than others.

Solving for an unknown that is in the numerator for many students is easier than solving for an unknown in the denominator. If asked to find the height of a projection, h, for example, choose a version with h in the numerator: H/D = h/d or h/H = d/D . Then isolate h by multiplying both sides by the variable in the denominator:

$$h = d\,(\frac{H}{D}) \text{ or } h = H\,(\frac{d}{D})$$

Note: Avoid using x to represent multiplication in an algebraic equation as this can be misinterpreted as representing an unknown. Use parentheses or a dot:

$$h = H \bullet \frac{d}{D} \text{ to represent multiplication.}$$

f) Using sense-making skills to envision what an equation is doing. People in this course typically differ in their experiences and comfort in setting up and solving algebraic equations. If you are feeling some anxiety after reading this section, it is important to give yourself time to connect each symbol with what it means, not only by writing out its definition and labeling it on your ray diagram but also by visualizing what the symbol represents within an equation.

When solving a pinhole problem, for example, write h = height of the projection and place an h next to the vertical line representing the projection on your ray diagram; then step back and visualize the size of the upside down projection you saw on the wax paper screen of the pinhole camera. Do the same for the d, H, and D.

The goal is to become familiar enough with the symbols that when you see H/D = h/d, your mind visualizes what those ratios mean:

- you can "see a comparison in your head of the big Height of the light bulb with the big Distance from the light bulb to the pinhole of your pinhole camera;
- you can "see" a comparison in your head of the little height of the projection with the little distance from the pinhole to the wax paper screen of the pinhole camera;
- and you can "see" that those comparisons seem about equal;
- that, for example, the big Height of the light bulb is about a tenth of the size of the big Distance from the light bulb to the pinhole in the pinhole camera in your hand
- and that the little height of the upside down light bulb projection seems about a

tenth of the size of the little distance from the pinhole in the aluminum foil end of the tube to the wax paper screen.

Also use words to tell yourself a story about what the equation is doing, that the equation is comparing heights to distances in two similar triangles and if the triangles are similar, the comparisons of heights to distances are equal even when the sizes of the triangles are very different. Visualizing what the equation is doing is key to clarifying in your mind whether you have set up the equation in a way that makes sense.

(g) Using sense-making skills to monitor what one is doing. In addition to visualizing what an equation is doing, it is important to use sense-making skills to monitor what you and your group members are doing. In solving a complex problem, it is easy to get focused on some detail that in the end is not needed. To make productive progress, it is important to step back for a moment to ponder:

- What are we doing?
- Why are we doing that?
- How will that help us?*

This is particularly important to do periodically when engaged in a multi-step endeavor, such as designing an experiment, collecting data, and using the data and one's knowledge of physical phenomena to estimate a quantity that can not be directly measured such as the diameter of the Sun.

*These questions are suggested by Alan Schoenfeld (1992) as meta-cognitive checks when engaged in problem-solving.

Schoenfeld, A. (1992). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. In D. Grouws (Ed.), *Handbook for Research on Mathematics Teaching and Learning* (pp. 334-370). New York: MacMillan

VI. Using Mathematical Representations to Estimate an Interesting Quantity

Pinhole phenomena can provide a way to estimate a quantity that one can not directly measure.

A. Using pinhole phenomena to estimate the diameter of the Sun

Question 1.16 How can you use pinhole phenomena to estimate the diameter of the Sun?

How big do you think the Sun is? It would not be possible to travel to the Sun and measure its diameter directly. Using pinhole phenomena, however, provides a way to estimate this quantity from Earth.

- In the *Before* section of a notebook page, record your initial estimate of the size of the Sun.

  It looks about the same size as the Moon in the sky. Both seem small compared to the size of the Earth from which we are viewing them. However both are far away and things far away look smaller than they are. How big do you think the Sun's diameter might be?

- How could you use pinhole phenomena here on Earth to estimate the Sun's diameter?
- A good way to start designing an exploration is to draw something that will help you think about what to do. For example, draw a ray diagram representing pinhole phenomena.
  - Which line on your ray diagram could represent the diameter of the Sun?
  - Which line could represent a projection of the Sun here on Earth?

- What equipment would you need to make such a projection of the Sun?
- How would you use this equipment?

Figure 1.21 shows one approach.

FIG. 1.21 *Student drawing to illustrate using pinhole phenomena to estimate the diameter of the Sun.*

Equipment: One way to estimate the diameter of the sun involves using a meter stick, some aluminum foil, a piece of cardboard to support the aluminum foil, scissors to cut a hole in the center of the cardboard, tape to tape the aluminum foil in place, a pin to make a pinhole in the foil, a white paper screen, a piece of cardboard to which to tape the white paper screen to keep it firm, a pencil to trace the Sun's projection on the white paper screen, and a sunny day.

[In a remote learning situation, students may not have access to a meter stick or yard stick but they likely have a ruler and shoestrings. After tying the shoestrings together to make a long string, use the ruler to measure where to tie a knot on the long string to measure 100 centimeters (or 3 feet if the ruler only has inches marked). Keep the string taunt when establishing the distance between the pinhole and the screen.]

- In the *During* section of your physics notebook page, record what you do to measure the projection of the Sun by using such equipment.

Also draw a ray diagram to represent this setup and identify on the diagram each relevant quantity with a word or phrase and symbol.

In addition, state and justify an algebraic equation that represents the mathematical relationship among these quantities. Solve that equation for the diameter of the Sun.

Also create a table, Table I.3, that organizes the relevant information such as the name of each quantity identified, its symbol, its numerical value, and status as measured, provided, chosen, or calculated.

- In the *After* section of your physics notebook page, record the claim you are making about the diameter of the Sun, the evidence that you have used to support that claim, and the rationale that explains how you have interpreted the measurement you made to calculate an estimate of the Sun's diameter.

- In the *Reflection* section of your physics notebook page, comment upon your experiences in using mathematical representations of pinhole phenomena to estimate an interesting quantity in this way.

  What have you learned not only about the Sun but also about the scientific process of designing explorations, using geometrical reasoning, writing and justifying algebraic equations, estimating quantities, and considering whether the estimate is reasonable?

- Also record on your physics notebook page, what you are still wondering.

Complete your entry on your physics notebook page and write a summary of what you have learned before reading an example of student work in estimating the diameter of the Sun. Also read about nuances in using mathematical representations of pinhole phenomena. In addition, you may find interesting reflections about using pinhole phenomena to estimate the Sun's diameter with friends and/or family members and some thoughts about the nature of science in this context.

1. Example of student work in estimating the diameter of the Sun

A student described the exploration process as follows:

> *First create a camera using foil, a piece of paper, cardboard, a push pin, a meter stick, and a sunny day. First cut a square out of the middle of the cardboard and*

cover that opening with the foil. Poke a hole in the middle of the foil with a push pin.

To carry out the experiment, hold the screen up so that it faces the sun. Another person will hold the foil and cardboard between the sun and the screen and direct the sun rays that are traveling through the pinhole to project the upside-down image of the sun onto the screen. A third person will hold a meter stick with one end touching the screen and one end touching the cardboard with foil. A fourth person will trace the projected upside-down image of the sun that is on the paper.

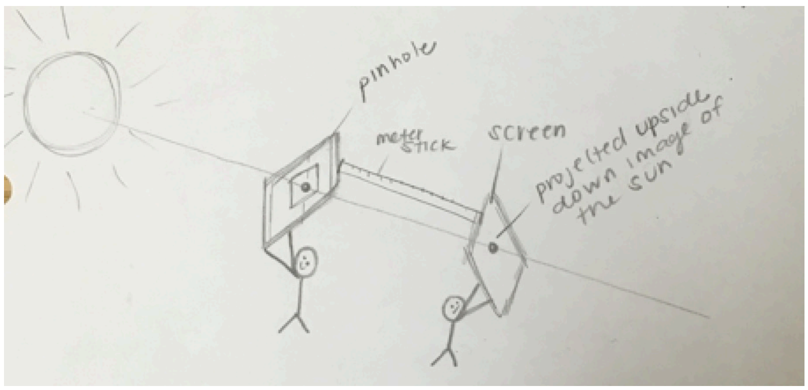


FIG. 1.22. Sketch of estimating the sun's diameter with pinhole phenomena.

Physics student, Spring 2016

The student sketched this exploration process as shown in Fig. 1.22. In this class, we referred to the diameter of the sun as its *Width*, represented by the symbol capital W, in order to avoid confusion with the symbol D representing the distance from the sun to the pinhole. We referred to the diameter of the Sun's projection as its *width*, represented by the lower-case symbol w in order to avoid confusion with the symbol d representing the distance of the screen from the pinhole. Note that in this activity the Sun's rays should be shown as bouncing off the opaque screen rather than shining through as in the previous pinhole activity shown in Fig. 1.15.

This student described her group's interpretative process as follows:

The group will measure the diameter of the traced projection onto the screen. This was estimated to be about one centimeter (1 cm). This will be variable w which represents the width of the projection.

We know that the distance from the pinhole to the projection is one-meter-long (1 *m) since we used a meter stick to separate the two. We will convert the one meter (1 m) to one hundred centimeters (100cm) so that the units are overall easier to work with. We will label this distance as variable d.*

We are given the distance from the sun to the earth and our camera, which is about one-hundred million miles (100,000,000 mi) and will label this as variable D.

We want to find out the width of the sun so we will label this as variable W.

Since we know that this experiment creates triangles that are similar, we can set up a proportion using our known and unknown variables to determine the width of the sun.

Physics Student, Spring 2016

This student drew a ray diagram and wrote the relevant mathematics as shown in Fig. 1.23.

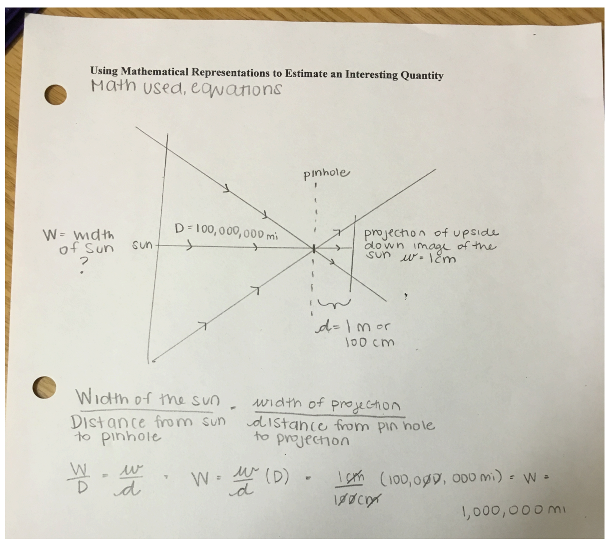


Figure 1.23. Student ray diagram and relevant mathematics for estimating the diameter of the Sun.

The student labeled the diagram well:

- the long vertical line on the left as representing the Sun, with the symbol W defined as the width of the Sun, and ? to indicate that this was the unknown
- the horizontal line from the "Sun" to the pinhole as the distance D, equal to about 100,000,000 miles
- the dotted line representing the foil with a pinhole in the middle as the pinhole
- the short horizontal line from the pinhole to the projection as d, equal to 1 meter or

100 centimeters

- the short vertical line on the right as representing the projection of upside down image of the Sun, with the symbol lower case w, equal to 1 centimeter.

Fig. 1.23 clearly shows the representation of pinhole phenomena by this student in estimating the diameter of the Sun. There are, however, several minor issues to consider in this otherwise excellent ray diagram. An open circle, rather than a solid line, would better represent the pinhole through which light rays are envisioned moving. A solid rather than dotted line would better represent a solid surface that blocks other rays from traveling through the pinhole. The rays from the Sun bounced off the opaque screen back to the eyes as shown in Fig. 1.19 rather than continuing through a translucent wax paper screen as in Fig. 1.14.

This student wrote out the relevant ratios in words first before representing them with symbols:

$$\frac{\text{Width of the sun}}{\text{Distance from Sun to pinhole}} = \frac{\text{width of projection}}{\text{distance from pinhole to projection}}$$

$$\frac{W}{D} = \frac{w}{d}$$

$$W = (\frac{w}{d})D$$

Writing out an equation in words as well as in symbols is important to do when teaching in order to be sure that students are following the reasoning.

The justification for the equal sign was that the triangle formed by the rays from the Sun and the pinhole is similar to the triangle formed by the pinhole and rays from the Sun inside the camera, and that the ratios of corresponding lengths of similar triangles are equal.

The student solved for the unknown, W = (w/d) (D),

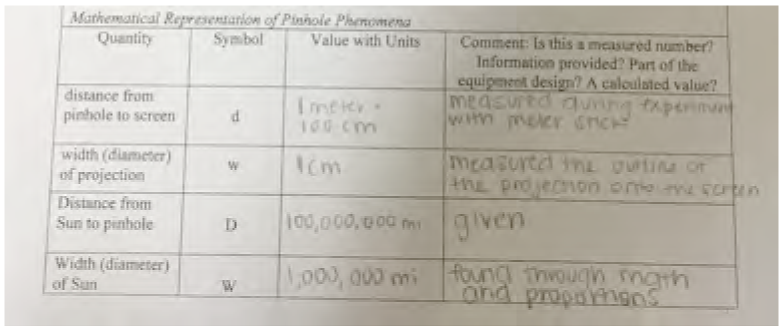
substituted numerical values, $W = \frac{1\,cm}{100\,cm}(100,000,000\,miles)$

and calculated the estimate for the sun's diameter, 1,000,000 miles.

In this case, the students did not need to convert miles to centimeters because the ratio w/d was dimensionless, 1 cm/100 cm = 1/100.

The distance of the sun to the pinhole was given as 100,000,000 miles (rather than about 93,000,000 miles) so that calculating the estimate would be easy and the attention would be on the magnitude of this estimate rather than on details involving a more accurate value for the distance to the sun. What is one hundredth of a hundred million miles? One million miles! If you can envision what the equation is representing, one can calculate this estimate in one's head!

The student also reported the status of the variables, as shown in Fig. 1.24 below.



Mathematical Representation of Pinhole Phenomena

Quantity	Symbol	Value with Units	Comment: Is this a measured number? Information provided? Part of the equipment design? A calculated value?
distance from pinhole to screen	d	1 meter = 100 cm	measured during experiment with meter stick
width (diameter) of projection	w	1cm	measured the outline of the projection onto the screen
Distance from Sun to pinhole	D	100,000,000 mi	given
Width (diameter) of Sun	W	1,000,000 mi	found through math and proportions

FIG. 1.24 Student's report of the status of variables in estimate of the diameter of the Sun.

In designing and carrying out a mathematical estimation, it is useful to consider what each symbol represents. The value represented by the symbol d, for example, the distance of the projection from the pinhole, was *chosen* as part of the design of the exploration by the availability of a convenient tool, a meter stick of length 100 centimeters.

The diameter of the projection, w, 1 centimeter, was *measured* during the exploration. Some students' tracing of the projection had a diameter of 0.9 cm; others 1.1 cm; many 1.0 cm. Using 1.0 cm seems a reasonable value given the variation in ways small groups held the pinhole and screen a meter stick length apart.

The distance D of the Sun from the Earth was *an approximate value provided by the instructor* based on an accepted value of about 93 million miles. This approximation made calculating the estimate easy so the students' focus would be on the phenomena and not on detailed calculations.

The diameter of the Sun, W, was the *unknown*, estimated by calculating its value in the equation based upon the mathematics describing pinhole phenomena.

Is a diameter of one million miles a sensible result for an estimate of the diameter of the Sun?

What sense-making strategies can you use to consider the reasonableness of this result?

2. Some nuances in using mathematical representations of pinhole phenomena

Students often use an equal sign to represent "the next step is" to solve for the unknown variable. That is best represented by an empty space between two equations as the ratio w/d does not equal W.

After writing the equal ratios in words and the equivalent mathematical statement in symbols, this student appropriately solved for the unknown, W, with W = (w/d) (D) before substituting numerical values. This is a process that is very important to do. Substituting numerical values before solving for the unknown often leads to calculation errors.

By solving an equation for the unknown before substituting numerical values, one can readily check whether the dimensions of both sides match:

If (W in length units) = (w in length units/d in length units) (D in length units), the w/d will be dimensionless and the result will be length units on the left and length units on the right.

By solving an equation for the unknown before substituting numerical values, one also can consider whether the mathematics processes indicated are conceptually appropriate:

W = (w/d) D indicates that first one is finding a ratio of two quantities (w/d) and using that to find out how much of the distance D in the other triangle, the other width W would be. If the little width w is half the length of the little distance d for one triangle, for example, then the big width W would be one half of the big distance D. Such visualizing of what the equation is doing is a useful way to check whether the equation one has derived makes sense.

This form of the equation, W = (w/d) (D), also makes clear that the ratio w/d is dimensionless (w/d = 1 centimeter/100 centimeters = 1/100) so there is no need to convert between centimeters and miles when substituting values. This is an example of a detail that can consume a lot of time, if one just does what one thinks one is supposed to do, converting centimeters to miles, without monitoring whether it makes sense to do so. It was necessary to convert 1 meter to 100 centimeters to use centimeters for both quantities in the ratio of w/d in order to obtain the dimensionless ratio of 1/100 but it was not necessary to convert centimeters to miles.

We used the approximate value of 100,000,000 miles for the distance between the Earth and the Sun (the distance D of the source from the pinhole). This made the calculation easy, as 1/100 of 100 million miles is 1 million miles. Although the Sun looks small in the sky, its diameter is very large!

A "not to scale" note would be helpful, given that rays of light from the Sun are coming from so far away that they are nearly parallel as they reach the earth rather than coming in at such a large angle. Such a "not drawn to scale" also would be appropriate given that the 1 cm projection is shown as larger than the 100 centimeter distance to the pinhole. A more realistic ray diagram for this situation would be similar to Fig. 1.25:

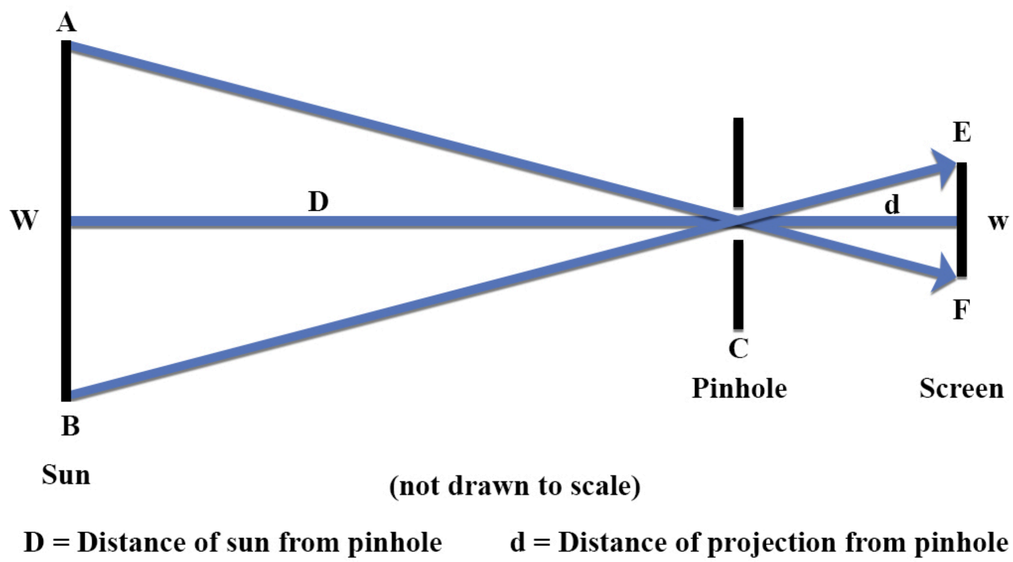


FIG. 1.25 Ray diagram representing pinhole phenomena with an object very far away

You can use your knowledge of pinhole phenomena to generate and solve pinhole math problems. To make up such a problem, decide on a scenario and specify three of the four variables involved: height of the object, H; its distance to the pinhole, D; height of its projection on the screen, h; and its distance to the pinhole, d.

In this course, the goal in solving a pinhole math problem is not the "answer." The goal is to build your ability to help someone else understand what to do and why. Start by helping the learner to understand what is happening by describing the scenario verbally with words and visually with a sketch. Next review the physics involved by stating what the relevant central ideas are. Also draw a careful ray diagram and use it and the central ideas to explain why the projection is upside down. Then describe the ray diagram mathematically, being clear about what each symbol represents, why the two triangles are similar, and how the lengths of similar triangles are related. Finally write the equation in both words and symbols, solve for the unknown in symbols, substitute values and calculate the answer. Be sure to also discuss why that answer seems reasonable. In facilitating a conversation with someone about pinhole phenomena, ask questions rather than tell answers throughout this process. In responding to homework problems in this course, however, follow the format provided here:

Solving a Pinhole Math Problem

a. **Describe** the scenario in words
b. **Make a sketch**
c. **Review what you know** about this phenomenon (the relevant central ideas)
d. **Draw a careful ray diagram.** Include:
    - light source
    - object and projection
    - eye
    - 3 example rays from light source (from top, middle, bottom of object) that pass through the pinhole to form the projection
    - light rays traveling to eye
    - gap representing pinhole (or small circle)
    - arrows to show direction light rays are traveling
e. **Tell the 'story' of the ray diagram** with the relevant central ideas to **explain** why the projection is upside down. Describe what happens to each example ray separately.
f. **Label angles and sides of triangles.** Define symbols with words and record any numbers you know or can estimate.
g. **Justify that the triangles are similar.**
h. **Write an equation** that relates the sides of the triangles using words to describe the quantities.
i. **Rewrite your equation using your symbols.**
j. **Algebraically isolate the unknown quantity.**
k. **Plug-in numbers and calculate answer.**
l. **Check answer.** Does the number you get from the calculation seem reasonable?

Explain.

3. Using pinhole phenomena to estimate the Sun's diameter with friends and/or family members

Question 1.17 What happens when estimating the diameter of the Sun with friends or family members?

A student reflected upon engaging her sister and mother in estimating the diameter of the Sun as follows:

> *To explore pinhole phenomena, I involved my younger sister to perform the same experiment we did in class. I first explained what we did and she stated that she has never heard of it before. Because she said she has never heard of pinhole phenomena, I was excited to show her. I used the same materials and made my own pinhole on a sheet of tinfoil. My mom also helped by holding the meter stick. My mom also said she has never heard of it. My mom is a third-grade teacher so she was excited to try it out.*
>
> *During the experiment, I asked them how big they thought the projection on the white sheet was. Like I did, they thought it looked like about one centimeter wide in diameter. My sister asked, "How can someone use such a small reflection of the sun to help find the diameter of the actual sun since the sun is so large and this is so small?" Because my mom and sister don't have as much of a math background as I do, I was very careful about what questions I asked.*
>
> *I started out by giving them a hint and asked, "Have you heard of similar triangles and corresponding angles?" I could tell my mom was a little lost because math isn't her strong suit. Much like my sister, she is a lot better at literature. My sister said yes! I told them the distance from the sun is 100,000,000 miles, so by using the three dimensions, I asked, "How can we use equal fractions to find the missing dimension (diameter of sun)?"*
>
> *My sister yelled, "Ratios!" My mom seemed a little lost so I then drew similar triangles a lot like we did in class and labeled each dimension we knew. I explained how the sides and angles were proportionate, which is how we could create equal ratios. I asked them if our units needed to be the same and my sister said yes. As a group, we found the same results as we did in class.*

My sister took calculus in high school and my mom doesn't know much about math. Having those two different types of "students" that were at either end of the spectrum, gave me the opportunity to practice for when I am trying to explain to two students where one is at a higher level than the other. I wanted my sister to explain the concept to my mom because I know that some students learn better when they explain things to other students.

Through this experience, I learned that when you have two students where one understands the concept faster than the other, it's important to let both students talk but also let the one student who understands, explain what they know to the other student. This helps them learn from each other.

I also learned to make sure I give time for the student that doesn't understand to ask any questions they have and not let the other student do all the work. I know it's important to make sure you leave a lesson knowing that both students understand the process.

The last thing I learned was how to ask questions to give a hint when the student is completely lost without giving them the answer. I understand how frustrating it is when the teacher asked questions you have no idea what the answer is. It's sometimes better to give them a nudge when they are completely lost in the beginning and let them do the rest of the work once they understand how they are going to find the outcome.

Physics student, Fall 2016

4. Some thoughts about the nature of science in this context:

This completes an example of the process outlined for each unit:

Students first identify resources by reflecting upon what they already know about a topic, such as the nature of light.

Next, they develop some central ideas based on evidence, such as light leaves a point on most sources in many directions and light can be envisioned as rays traveling in straight lines.

They can use those ideas to explain an interesting phenomenon, such as why the projection of a light bulb seen through a pinhole camera is upside down.

Then they develop mathematical representations of the phenomenon, such as an equation stating that the ratio of the height of the light source to the distance of the source from the pinhole is equal to the ratio of the height of the projection to the distance of the projection from the pinhole.

Finally, they use those mathematical representations to estimate an interesting quantity, such as the diameter of the Sun. It is not possible for anyone to travel to the Sun and use a measuring device to directly measure its diameter. An estimate is feasible, however, using simple equipment, some additional information from a reliable source, and the scientific process developed here.

This process illustrates the strength of scientific ways of knowing. One may be able to estimate a quantity of interest through a similar process of identifying resources, developing central ideas based on evidence, using these ideas to explain a puzzling phenomenon, figuring out ways to represent the phenomenon mathematically, and using those mathematical tools to estimate the quantity one wants to know.

Several students recognized that this estimation process might be useful in other contexts such as answering the question: 'how big is the Moon"? Note that making the decision to go there, or not, or to fund creating a settlement on the Moon, or not, is a question of a different kind, one that involves cultural issues and societal values as well as the technical and scientific knowledge needed.

Many students also experienced some of the human aspects of science in their surprise that the projection was upside down, frustration in making sense of the mathematics, and perhaps pleasure in persisting through to understanding what seemed for many to be an initially confusing experience.

The process involved in estimating the diameter of the Sun assumes that the ratio of small distances here on Earth can be compared to the ratio of very large distances in the solar system. This is an example of an aspect of the nature of science articulated in the US *Next Generation Science Standards* that *scientific knowledge assumes an order and consistency in natural systems.* Third to fifth grade students, for example, should understand that *basic laws of nature are the same everywhere in the universe* (NGSS, Lead States, 2013, Appendix H) https://www.nextgenscience.org/resources/ngss-appendices).

VII. Developing Additional Central Ideas Based on Evidence

When you look in a mirror, swim in a pool, or enjoy playing with a prism, you are experiencing a variety of light phenomena. In this section, you will develop additional central ideas about reflection, refraction, and dispersion. Then you will use these central ideas to explain an intriguing phenomenon: seeing rainbows in the sky.

A. Exploring reflection phenomena

The word *reflection* has many meanings in many different contexts. In physics, the word *reflection* has a specific meaning. *Reflection* refers to one aspect of what happens when light shines on smooth or rough surfaces.

Question 1.18 What happens when light shines upon a smooth surface?

Equipment: To explore reflection phenomena, obtain a flashlight, flat mirror, table, two straight sticks such as meter sticks, yard sticks, rulers or pencils, a dark room and at least three people with whom to collaborate. Clean the surface of the mirror so that the light reflects from the mirror rather than from dust on the surface.[In a remote learning situation, a student working alone with a clear mirror and two rulers, can place the mirror on a table next to a wall, lean one end of a ruler against the wall, place the other end of that ruler on or next to the mirror, place one end of the other ruler next to the first ruler on or next to the mirror, and hold the flashlight so that it is shining on the mirror at the same angle as the ruler. Move that ruler (and flashlight) at different angles to see how the reflection of the light moves up and down on the wall. Note the angle of the ruler when the reflection on the wall is on the top of the first ruler.]

- Record the ***Topic*** of this exploration on your physics notebook page.
- What happens when a flashlight shines on a flat mirror in a dark room?

Note your initial ideas in the ***Before*** section of the physics notebook page documenting your exploration of reflection phenomena.

- What can you find out about reflection phenomena by playing with the flashlight and mirror? Keep track of your explorations in the ***During*** section of your notebook page.
- Next explore reflection in a particular way: place the flat mirror on the table. Ask group members to each stand on one side of the table as shown in Fig. 1.26

Person 1 is the person holding the flashlight.
Person 2 is the person standing at the other end of the table.
Person 3 is standing at one side of the table. (If there is a fourth person, Person 4 is standing at the other side of the table.)

- Persons 1 and 2 start the activity while Persons 3 and 4 report what happens. After a while switch positions so that everyone experiences what happens in each location.
- How can Person 1 aim the flashlight at the mirror so that light shines on Person 2's face at the other end of the table?

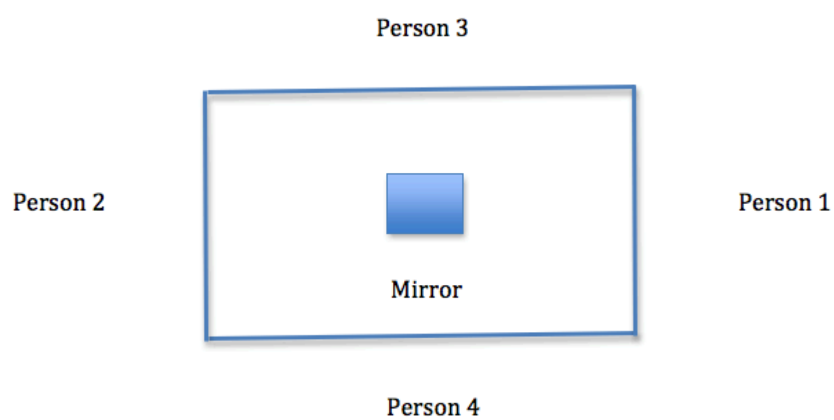


FIG. 1.26 Who can see the light from the flashlight in the mirror?

- When Person 2's face is lit, who can see light from the flashlight shining on the mirror?

Person 1 with the flashlight?

Person 2 at the other end of the table?
Person 3 at one side of the table
Person 4 at the other side of the table?

- If Person 2 goes up on tiptoes or crouches down low, what does Person 1 need to do to keep the light reflecting off the mirror onto Person 2's face?

- Can you see light rays traveling from the flashlight to the mirror?
Can you see light rays traveling from the mirror to Person 2's face?

- To envision light rays traveling from the flashlight to the mirror and from the mirror to Person 2's face, use a physical model for light rays:
  - Hold one meter stick so that it models light rays traveling from the flashlight down to the mirror.
  - Hold the other meter stick so that it models light rays traveling from the mirror up to Person 2's face.
  - Make sure the two meter sticks are meeting on the mirror at the spot where Person 2 sees the beam of light reflected in the mirror.
- The meter sticks make angles with the flat mirror. How do these angles compare?
- Make a sketch showing one meter stick modeling light rays traveling from flashlight to mirror and the other meter stick modeling light rays traveling from the mirror to Person 2's face.
- Focus first on the meter stick modeling light rays traveling from the flashlight to the mirror. The meter stick and the mirror on the table are modeling the angle that one can envision *incident light rays* making with the mirror. This angle is called the *angle of incidence*.

About how big is this angle of incidence? (about 15°? 30°? 45°? 60°? 75°?)

- Now look at the meter stick modeling light rays traveling from the mirror to Person 2's face. This meter stick and mirror on the table are modeling the angle that one can envision *reflected light rays* making with the mirror. This angle is called the *angle of reflection.*

About how big is this angle of reflection? (about 15°? 30°? 45°? 60°? 75°?)

- Draw a ray diagram that represents what you infer is happening when light from the flashlight reflects off the mirror into Person 2's face.
- Label the angle of incidence and the angle of reflection. How are these angles related?

Question 1.19 What happens when light shines upon a rough surface?

- Now shine the flashlight on the table rather than on the mirror.

Who can see the light from the flashlight shining on the table?

Person 1 with the flashlight?
Person 2 at the other end of the table?
Person 3 at one side of the table
Person 4 at the other side of the table?

- How does what you see here or do not see here compare with what you saw or did not see when the flash light was aimed at the mirror rather than the table?
- Although the table may seem smooth, it is a rough surface compared to the mirror. What are the similarities and differences in what you observe when a flashlight is aimed at the mirror or at the table?
- Under the ***During*** section of your physics notebook page, record your observations and interpret these results.
- Use sketches of light rays reflecting from smooth and rough surfaces to explain these differences.
- Discuss your findings and formulate central ideas about how light is reflected from smooth and rough surfaces. In the ***After*** section of the physics notebook page, report these ideas, the evidence on which they are based, and the rationale that connects the evidence to these claims and notes their importance.

To complete this exploration of reflection phenomena:

- Using the everyday meaning of the word, reflect upon your experiences in exploring the nature of reflection phenomena.
- What are you still wondering?
- Add the central ideas about reflection from smooth and rough surfaces to Table I.1:

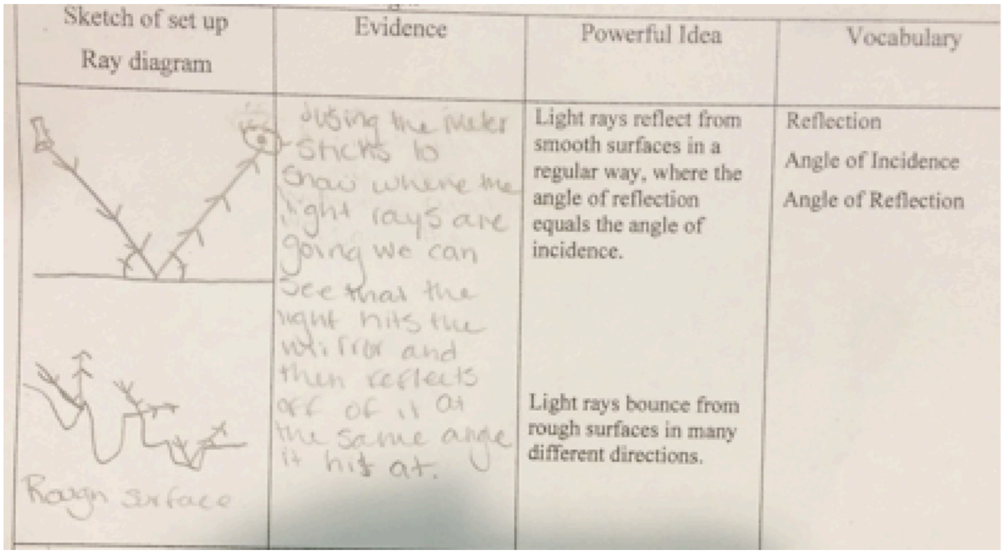
TABLE I.1 (continued) Explorations of light phenomena: Reflection

TABLE I.1 (continued) Explorations of light phenomena: Reflection			
Sketch of set up Ray diagram	Evidence	Central Idea	Vocabulary
		Light rays reflect from smooth surfaces in a regular way, where the angle of reflection equals the angle of incidence. Light rays bounce from rough surfaces in many different directions.:	

Complete entries on your physics notebook page and Table I.1. Then write a summary of what you have learned about reflection phenomena before reading an example of student work in response to questions 1.18 and 1.19.

1. *Example of student work about reflection phenomena*

As shown in Fig. 1.27, a student added to Table 1.1 about reflection phenomena ray diagrams for reflection from smooth and rough surfaces. For evidence to support the two new central ideas stated, the student wrote: "*Using the meter sticks to show where the light rays are going we can see that the light hits the mirror and then reflects off of it at the same angle it hits at.*"



Sketch of set up Ray diagram	Evidence	Powerful Idea	Vocabulary
Rough surface	Using the meter sticks to show where the light rays are going we can see that the light hits the mirror and then reflects off of it at the same angle it hit at.	Light rays reflect from smooth surfaces in a regular way, where the angle of reflection equals the angle of incidence. Light rays bounce from rough surfaces in many different directions.	Reflection Angle of Incidence Angle of Reflection

FIG. 1.27 Student's addition about reflection in Table 1.1

> ***Light rays reflect from smooth surfaces in a regular way, where the angle of reflection equals the angle of incidence.*** *In this experiment we used two surfaces; the smooth surface of a mirror; and the rough wood surface of the table. We found that when the light rays traveling in straight lines from the flashlight to the mirror hit the mirror's surface, the light is reflected. We can see this when looking at the face of the person on the opposite side of the table; light is hitting her face. The angles of the line of incidence and the line of reflection appear to be the same. For any one particular light ray the angle of incidence equals the angle of reflection.*
>
> ***Light rays bounce from rough surfaces in many directions.*** *As demonstrated in the ray diagram, any one single ray of light that hits the rough surface will still have an equal angle of incidence and angle of reflection but individual rays of light hit the surface at a different angle.*
>
> Physics student, Fall 2015

When shining on a rough surface, the light from a flashlight can be envisioned as rays traveling in the same direction but that direction will form different angles of incidence with different parts of a bumpy surface, so that the rays bounce off at many different angles of reflection.

2. Some nuances in explaining reflection phenomena

Defining the angles of incidence and reflection with respect to the mirror is a choice made here because the angle between the meter stick representing the light rays and the mirror is visually easy for children to perceive and compare.

Physics texts typically define a different set of angles, however, for the angle of incidence and angle of reflection. Draw a line perpendicular to the mirror at the point that the light beam shines on the mirror. This perpendicular line is called the *normal* line. As shown in Fig. 1.28, physicists define the angle of incidence as the angle between the incident beam and the normal to the surface. Physicists define the angle of reflection as the angle between the reflected beam and the normal to the surface.

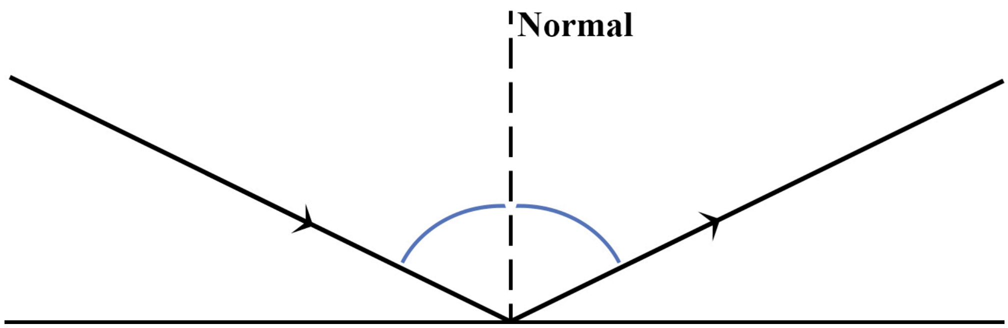


FIG. 1.28 Angles defined with respect to a normal line rather than to the mirror.

If the surface of the flat mirror were clean, only Person 2 should have been able to see the light from the flashlight in the mirror. Persons 1, 3, and 4 would not have been able to see light in the mirror if all of the light rays incident on the mirror were being reflected at the same angle toward Person 2's face.

If the surface of the mirror were dusty, however, some of the light rays may have bounced off the dust in directions toward the other members of the group and they may have reported seeing the light in the mirror. If the classroom still uses chalk on a blackboard, one can clap an eraser near the mirror and "see" a beam of light from the flashlight to the mirror and from the mirror to Person 2's face as some light bounces off the chalk dust in many directions and makes such beams visible.

When the flashlight was aimed at the table surface, all members of the group should have been able to see light on the table as some light rays were being reflected in many directions by the rough surface of the table as shown in Fig. 1.29.

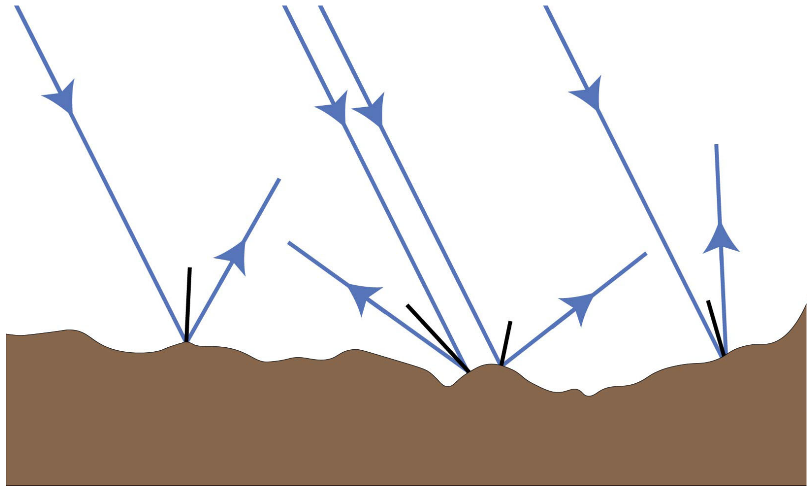


FIG. 1.29 Light rays reflecting in different directions from bumps in a rough surface.

There are several ways to think about what happens when light shines on rough surfaces. One way is to notice what happens when a group of people look at someone speaking in a room. Who can see that person's nose? Can someone by the window see the speaker's nose? What about someone over in a corner? Someone on the other side of the room? One can infer that light is bouncing off that person's nose in many different directions if all of these people can see that person's nose,

This visual representation of a model of light in which light rays bounce off a surface with the angle of incidence equal to the angle of reflection suggests a visual experience you may have had:

- What happens when a basketball player dribbles a ball down a court? How does the ball bounce off the floor? Or when a tennis player practices by hitting a ball hard against a wall with a forehand shot and the ball rebounds to be hit again backhand?
- Try this by rolling a basketball at an angle toward a wall. How does the basketball rebound from the wall?

Make a sketch of how balls rebound when bouncing at an angle off a floor or wall.

- If such a sketch is analogous to a diagram showing how light rays reflect from a mirror, what does this suggest about the nature of light?

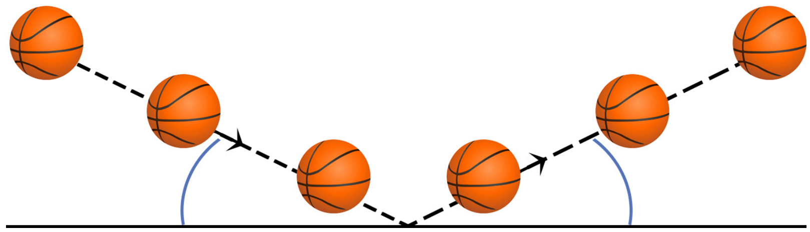


FIG. 1.30 A ball rebounding from a surface.

As shown in Fig. 1.30, a ball thrown against a wall rebounds in a way that suggests **another physical model for light:** envision light rays as streams of particles traveling in straight lines and reflecting from a surface with angle of incidence equal to angle of reflection. When this physical model for light is used, the particles are called *photons*. Such streams of photons can be envisioned as rays of light reflecting from a surface with the angle of reflection equal to the angle of incidence. Thus our initial physical model for light rays traveling in straight lines, a meter or yard stick, can now be elaborated as a stream of photons traveling in straight lines from a source.

Question 1.20 How well do different materials reflect light?

Sunlight shines on many different materials such as water, sand, soil, asphalt pavement, grass, trees, people… How each material responds depends upon the material's *properties*. Such properties include how well the material reflects light, its *reflectivity*.

Equipment: Use a digital light probe connected to a computer or calculator to show a graph of light intensity versus time as you move the probe over various materials. Or use a free app on a cell phone, search for LUX light meter.

Try whatever is nearby as well as white paper and various colors including black, wax paper, aluminum foil, paper towel, cardboard, and dark cloth.

- What can you find out about materials' reflectivity with the light probe or light meter? In the ***Before*** section of a physics notebook page, record your questions and your predictions.
- Begin by playing with the light probe or light meter to see what you can find out with

this device.

If using a light probe: you may need to reduce the highest value on the vertical axis of the graph on the computer screen if you do not have very bright lights in the room. Click on the top number on the vertical axis and reduce it until the signals from the probe are high enough on the graph to be seen easily.

How can you use it and the various materials to make a graph that looks like the letter W? a sharp W? a rounded one? a letter M ? sharp or rounded M's ? What other letters can you make on the graph on the screen?

Trace one of the graphs with your finger and tell the story of making a line that rises steeply or not so steeply. How do you make a line that descends steeply? Not so steeply?

- Compare how light reflects from a variety of materials, such as paper of different colors, aluminum foil, wax paper, cardboard, dark and light cloth…
- How does the distance from the material affect the intensity reading?
- If using a light probe: one way to keep it the same distance away from each material is to use a rubber band to hold a ruler next to the light probe. Attach the ruler so that it is extending a certain distance (say 5 cm) beyond the end of the light probe as shown in Fig. 1.31.

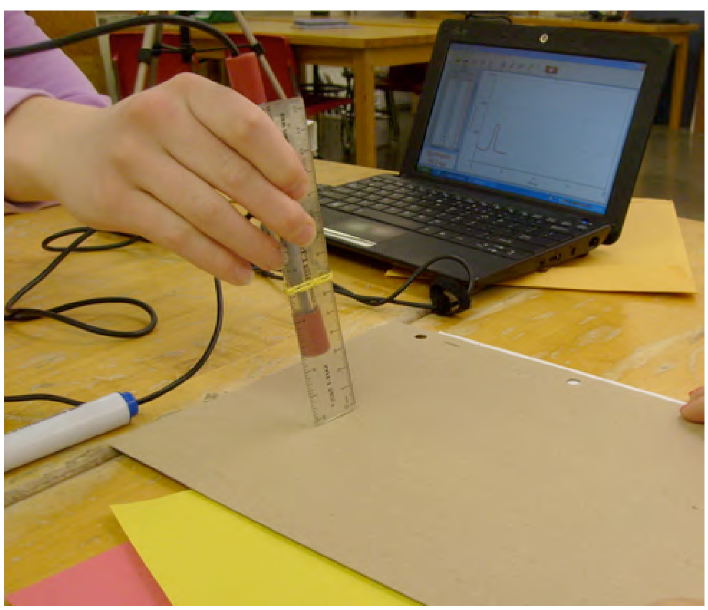


FIG. 1.31 Using a light probe connected to a computer to compare the reflectivity of various materials.

- In the ***During*** section of your physics notebook page, record your findings. If using a light probe: draw a picture of the graph and indicate the parts of the graph that represent the different materials that you tested. Note any vocabulary that is new to you.
- Discuss your findings and formulate relevant central ideas. In the ***After*** section of the physics notebook page, report these ideas and the evidence on which they are based.
- Write a rationale that explains how the evidence supports the ideas and why these are important.
- Also reflect upon this exploration such as what connections can you make to other experiences? How might you use what you learned in your own classroom?
- What have you learned and what are you still wondering?
- Complete documenting your exploration and writing a summary before looking at an example of student work and nuances about exploring the property of reflectivity.

3. Example of student work about the property of reflectivity

Materials differ in the property of reflectivity, how well they reflect light. Corollary: Materials differ in how well they absorb light. *To measure the light reflectivity of different materials we took a light sensor to the surface of different materials and recorded them on a computer. We used the program* LoggerLite *which records and graphs the amount of light being reflected off any particular surface. We used different materials like foil, dark cloth, white paper, and even our clothing and nothing at all; we tried just pointing the sensor directly at the light.*

In Figure (1.32) below you can see the different levels of reflectivity of light. The furthest point to the left that I circled represents when we were covering the end of the sensor with our hand; it was reflecting no light at all.

The next point is circled in close to the top of the graph; this spot in the graph represents us pointing the sensor straight at the lights above us. There was quite a bit of reaction because we were pointing the sensor at the direct light.

The next circle that I circled to focus on is close to the bottom of the graph. This spot isn't as low as when we were covering the end of the sensor, but we were shining the sensor at our hand, which wasn't very reflective.

The next circled spot in the graph represents when we shined the sensor at a piece of tin foil. The graph went very high telling us that this material was very reflective.

The last circled section of the graph represents when we shined the sensor on a piece of navy blue fabric. We held it here for a few seconds and the line leveled out, telling us that the material wasn't reflective and that this was a consistent reading.

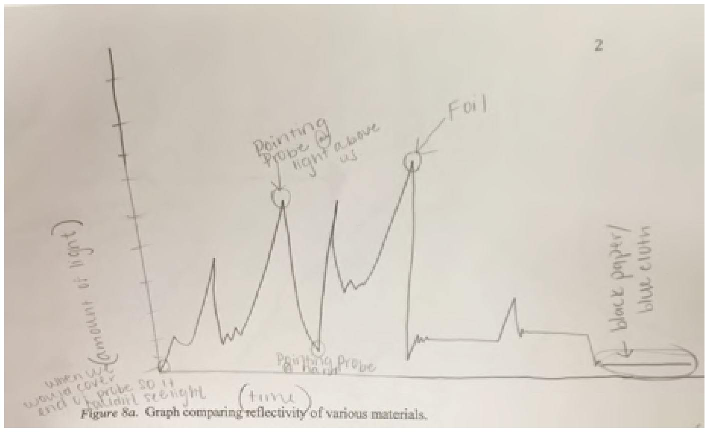


FIG. 1.32 *Student graph from exploring reflectivity of various materials.*

This student labeled both axes: "amount of light" on the vertical axis and "time" on the horizontal axis. The student used small circles to direct attention to different parts of the sketched graph, based on the graph produced by the computer as the students moved the light probe from one material to another. The student described the circle at the origin as "when we would cover end of probe so it couldn't see light." The first labeled peak was "pointing probe at light above us;" the second labeled peak as "foil;" and the low horizontal line as "black paper/blue cloth."

4. Some nuances about exploring the property of reflectivity

Taking a photograph of the graph on the computer screen is helpful for retaining accurate information. Sketching the graph is helpful for noting important aspects, as this student did, such as the meaning of peaks and flat lines.

The peaks in Fig. 1.32 represent pointing the probe briefly at a reflective material; the flat lines represent pointing the probe at a material for more than a moment. A more careful graph would have perpendicular axes, with the same labels as those used by the computer program and with the values represented by the vertical marks noted. One is puzzled by how the intensity of light reflected by the foil could have been more than the intensity of the incoming light, perhaps identification of these peaks was switched later during preparation of this report. Or perhaps this group was near a window and additional light from the Sun was shining on the foil. However, this graph clearly conveys the information that the intensity of reflected light varies with materials.

• How can you use your knowledge of reflectivity to design a solar oven? Which two of the above materials would you choose to use?

See http://static.lawrencehallofscience.org/diy_sun_science/downloads/diy_ss_cook_solar_oven.pdf and https://climatekids.nasa.gov/smores/ for examples.

This is a context within which students can participate in *engineering design* as advocated in the *Next Generation Science Standards* (NGSS Lead States, 2013). See Appendix I at https://www.nextgenscience.org/resources/ngss-appendices . Engineering design involves defining a problem, developing solutions, and optimizing the solution (see pages 3-6).

B. Exploring refraction phenomena

When light shines on a surface, light *reflects* from the surface as just discussed but sometimes some of the light does not. Some of the light *refracts* instead as it keeps on traveling through the surface into a new *medium*. The word medium refers to the substance through which the light is traveling, such as air or water.

Question 1.21 What happens when light travels from one medium into another medium, such as from air into water or from water into air?

Equipment: To explore refraction phenomena, use a pencil or stirring rod, a tray, two paper cups, a pen, and access to some water.

- What happens if you drop something into a pail of water? How does it look different if at all? What if you are swimming under water and look up through the water at something overhead?

  Note some of your experiences with looking at objects in water in the ***Before*** section of the physics notebook page documenting your exploration of refraction phenomena.

- Make a large dot in a paper cup about a third of the way down from the top. Place the cup with the dot on a tray. Fill the other cup with water and put it on the tray.
- Bend down until you can just see the dot in the cup. Then bend a little more so that

you can no longer see the dot as shown in Figure 1.33. What do you think will happen when water is poured into the cup and covers the dot?

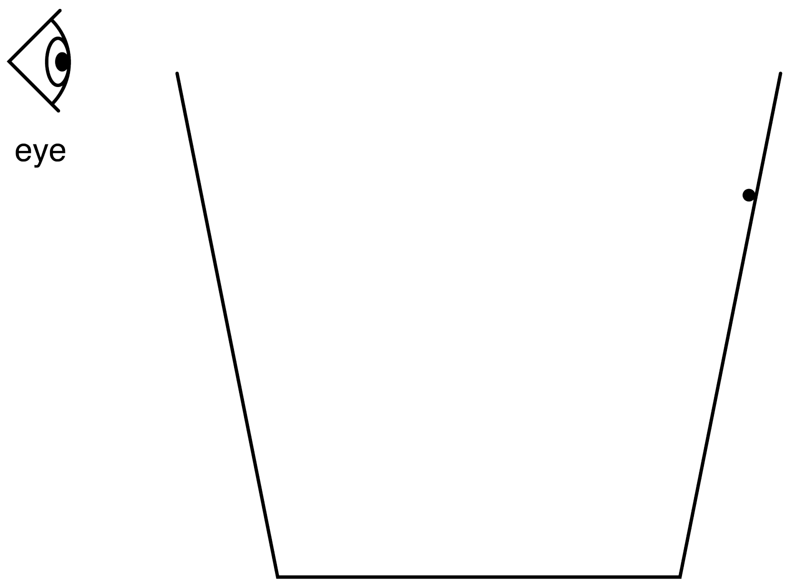


FIG. 1.33 An observer's eye is just below the point where the person can see the dot in the cup.

Light rays bouncing off the dot in the direction toward the eye are blocked from reaching the eye by the side of the cup near its rim.

- Have someone pour water into the cup until the water flows above the dot.
  What happens?
  Record what you observe in the ***During*** section of your physics notebook page.

- Why do you see what you see? Discuss with your group members some ideas about why someone would see the dot appear to move in the way it does when water is poured into the cup and covers the dot.
- Sometimes when one is puzzled by a phenomenon, it helps to think about a similar phenomenon. Put a pencil or stirrer in a glass or tub of water as in Fig. 1.34. What do you see?

Does the pencil appear higher or lower in the water? Does the dot appear to be higher or lower in the water in the cup?

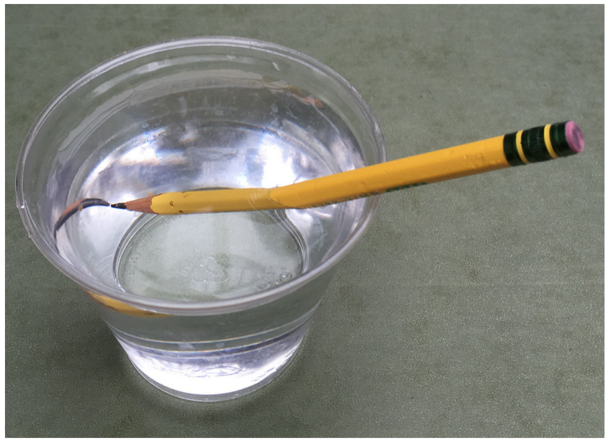


FIG. 1.34 Pencil appearing bent in a glass of water.

- How could you draw rays representing light traveling from the dot to the eye so that the eye would perceive the light coming from the "apparent dot" rather than from the real dot?
- Discuss various possibilities with your group members. How can you use the technique of drawing rays to represent a straight line path of light in this scenario?
- As you work together generating ways to think about explaining why the dot appears to be moving up as you pour water into the cup, step back occasionally and ask yourselves,
    - What are we doing?
    - Why are we doing this?
    - How is this helping us?
- One way to think about something puzzling is to make a sketch of what is happening. On a large white board, draw an outline of the cup without water, dot, and observer's eye just below where the observer could see the dot as in Fig. 1.33

  Also draw an outline of the cup with water, dot, and observer's eye in the same position. Use a *dashed line* to outline where the dot *appears to be* in the cup with water.

- How is light apparently traveling from the apparent dot to the observer's eye?
    - Place a physical model of light rays, a ruler, on your drawing in a way that represents the path of light rays appearing to travel from the apparent dot

toward the eye.

  - Which part of that path would represent light rays apparently traveling from the apparent dot toward the observer's eye?
  - Draw a dashed line to represent the apparent path of light rays from the apparent dot.
  - Which part of that path would represent light rays actually traveling to the observer's eye?
  - Draw a solid line to represent the actual path of light rays to the eye from the end of the apparent path from the apparent dot.
  - Interpret the point where the dashed line and solid line meet. What is happening at that point? How do the actual light rays get to that point?
  - Draw a solid line from the actual dot to the point where the dashed line representing the apparent path of light from the apparent dot meets the solid line representing the actual path of light to the eye.
  - Where is this point?
- Describe in words this envisioned path of light rays when they travel from the actual dot to the surface of the water and then to the observer's eye.
- Note any vocabulary that is new to you.
- Discuss your findings and formulate a relevant central idea. In the ***After*** section of the physics notebook page, report this idea and the evidence on which it is based.
- Write a rationale that explains how the evidence supports this central idea and why this is important
- Also reflect upon this exploration such as what helped you learn during this exploration and how might you use this in your own classroom?
- What are you still wondering?
- Write a summary of what you have learned about refraction phenomena that states a central idea about refraction and explains why the dot seems to move up in the cup when covered with water.
- Add this idea about refraction to Table I.1:

TABLE I.1 (continued) Explorations of Light Phenomena: Refraction

TABLE I.1 (continued) Explorations of light phenomena: Refraction			
Sketch of set up Ray diagram	Evidence	Central Idea	Vocabulary
		Light rays refract (bend, change direction) at the surface when light moves from one medium into another such as from air to water or from water to air	Refraction

- Complete your entries on your physics notebook page and the continuation of Table I.1. Write a summary of what you have learned about refraction phenomena before reading an example of student work. Then:
- Share what you have learned about refraction by engaging a friend or family member in the dot-in-the-cup activity. Describe what your learner asked, said, did and found in exploring this example of refraction phenomena. Also reflect upon what you learned from this experience in learning and teaching science.
- In addition, read a student's description of engaging a friend in exploring refraction phenomena as well as some thoughts about the nature of science exemplified by these explorations.

1. *Example of student work about exploring refraction phenomena*

A student added to Table 1.1 about explorations of refraction phenomena as shown in Fig. 1.35. The sketch is labeled "can't see dot" before the water covers it and "can see dot" after the water is up to the top of the cup. The ray diagram shows the "original" dot with a solid line showing the path the light traveled and the "perceived dot" with a dotted line to show the light's apparent path.

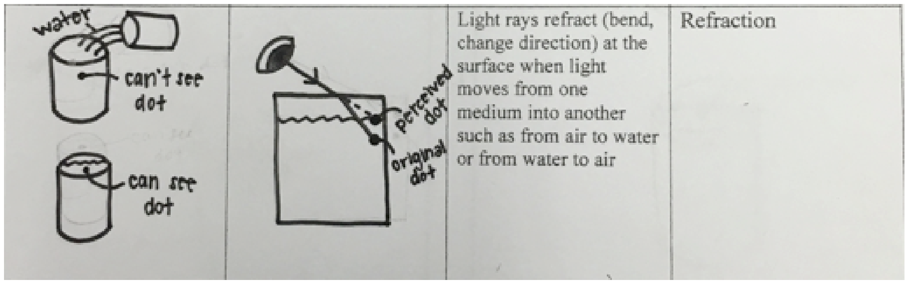


FIG. 1.35. Student's addition to Table 1.1. about refraction phenomena.

Note that in Fig. 1.35, the bend is shown occurring at the top of the cup rather than at the top of the water line. Figure 1.36 presents a diagram of a dot in a cup without and with water where the bend is drawn at the water line.

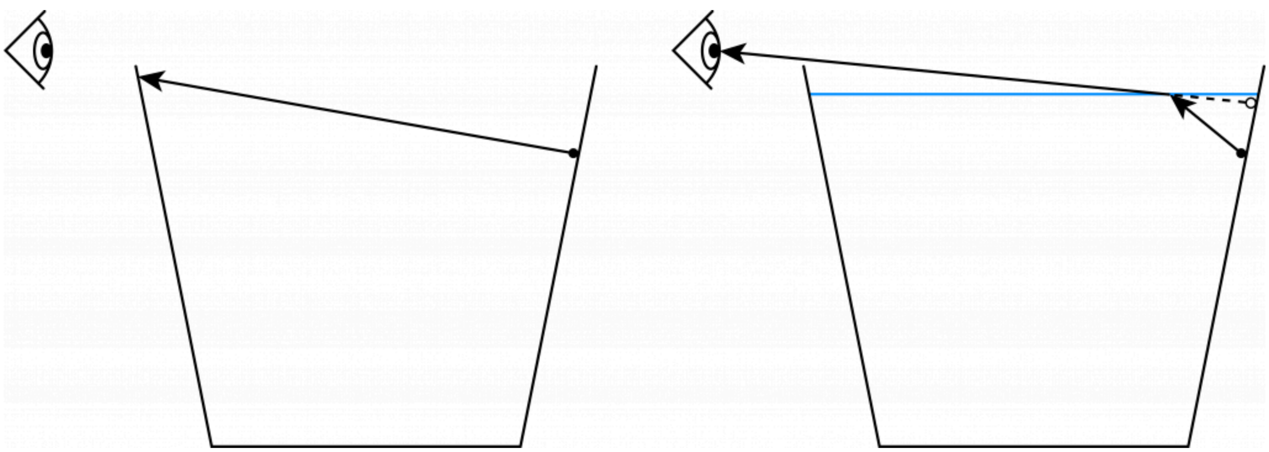


FIG. 1.36. Diagram of the dot in a cup without and with water as seen by an observer.

A student stated a central idea about refraction phenomena and used it to explain this phenomenon as follows:

> ***Light rays refract (bend, change direction) at the surface when light moves from one medium into another such as from air to water or from water to air.*** *In this experiment students had two cups. One cup was filled with water, the second cup was empty and had a dot drawn on one inside wall. Students were asked to crouch in front of the cup to where they could just see the dot; then they were told to go just lower than that. A second student poured the water from cup 1 into cup 2 and asked the students what they saw. As the student watched the cup being filled, water rose to the top. When the water rose*

above the dot on the wall of the cup, the crouching student could see the dot once more, even though the student had not moved.

The dot gave the appearance of moving up the wall of the cup. Light was traveling to the dot the entire time it was in the cup. That is why the students could see the dot when they were standing up and looking in the cup and when they first crouched down…However when the student crouched down farther the light leaving the dot was not able to reach the student's eyes. As water rose over the dot, the light that was leaving the dot was refracted, meaning that the light ray traveled in a straight line under the water, but when it reached the surface of the water and moved into another medium (from water to air) the light rays bent traveling in many directions, one of which happened to be to the student's eyes.

Physics student, Fall 2015

What the student seemed to mean in the last sentence is that light rays traveling from the dot to the surface of the water bend as they move from the water into the air; each ray bends in a particular direction, depending upon the direction and angle at which the ray had been traveling in the water when it moved through the surface of the water to the air; some of these rays happen to bend in just the right way that they travel from the dot to the surface of the water and then, as they enter the air, bend in the direction toward the student's eyes.

2. Nuances about exploring refraction phenomena

A good place to start in thinking about why the dot seems to be moving up when covered with water in the cup is with the conceptual model of light developed so far: the central ideas that light can be envisioned as rays moving in straight lines and that for someone to see something, light has to get to the person's eyes. Also relevant is the central idea that light rays bounce off a rough surface in many directions.

It is important to remember that thinking about light rays is simply a way to *envision* how light could be moving through the water and the air to get to the observer's eye when the dot appears to be moving up as water is covering the dot in the cup.

Because the dot can be seen from many different positions when looking down at the dot in the water, the dot can be considered a rough surface. Note that the source of the light somewhere up in the air above the cup of water has not been included here. Thinking about what happens has been limited to envisioning what happens after incoming light rays bounce off the dot in many directions as shown in Fig. 1.37.

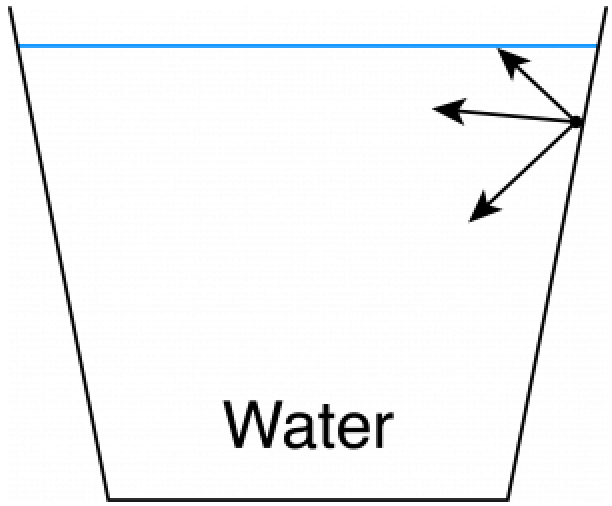


FIG. 1.37 *Light rays bouncing in many directions off the real dot in the water.*

Envision many light rays, after bouncing off the dot, traveling at many different angles to the surface of the water. Choose to focus only on those light rays that happen to be traveling at an angle in the water such that when they bend at the surface of the water they are headed in the direction of the observer's eye.

The phrase *bend at the surface of the water* does not refer to a curving path for the rays of light from the dot to the eye; this phrase refers instead to a path represented by one straight line, from the dot to a point on the surface, that changes direction at that point, and continues as another straight line, representing light rays traveling from that point on the surface of the water to the eye.

A ruler can provide a physical model of how light rays appear to be moving in a straight line from the apparent dot to the eye as shown in Fig. 1.38.

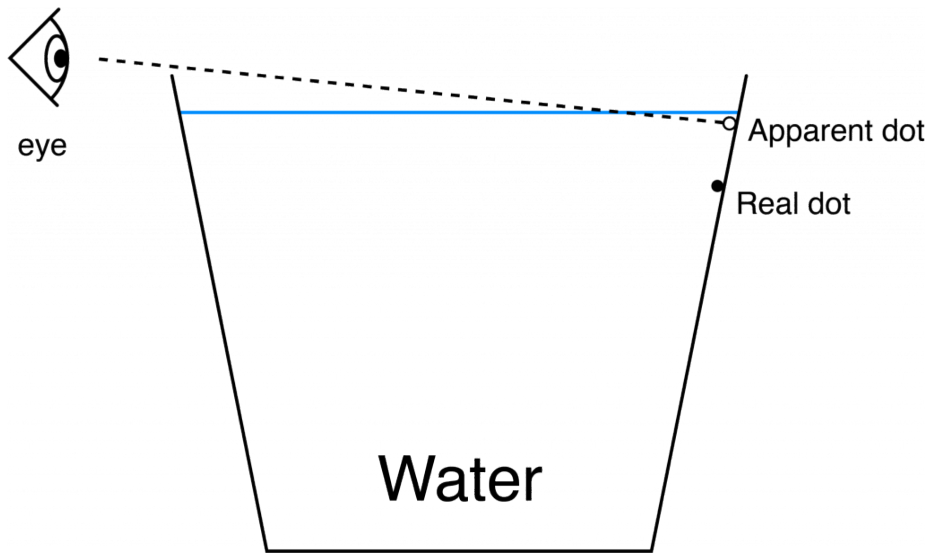


FIG. 1.38. Dashed line representing a ruler modeling the apparent straight path that light rays are traveling from the apparent dot to the eye.

This ruler represents, however, both the actual path of light rays that get to the eye and an apparent path from the apparent dot.

Where does the apparent path of light rays from the apparent dot turn into the actual path of light rays to the eye?

Consider the point that represents envisioning where light from the apparent dot crosses the surface of the water. A solid line from the real dot to this point represents some light rays bouncing off the real dot and traveling straight to this point in the water as shown in Fig. 1.39 where the point is labeled as the location that “Refraction” occurs.

Making the dashed line into a solid line from this point on the surface of the water to the eye represents envisioning light rays bending at this point and traveling to the eye. The dotted dot at the end of the dotted line represents the illusion of where the dot is.

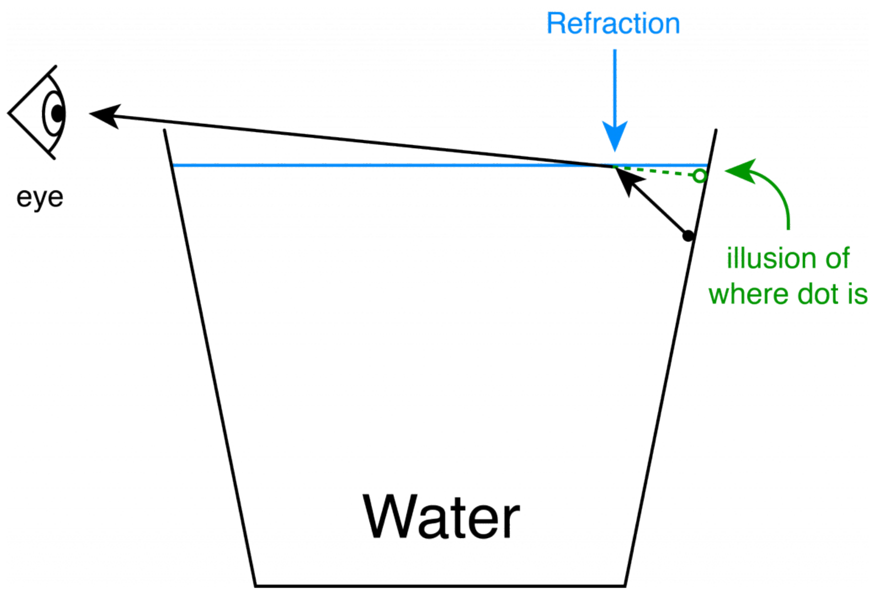


FIG. 1.39 Dashed and solid lines represent envisioning apparent and actual paths for light rays traveling from the apparent and real dots to the eye.

The dotted line on this ray diagram represents envisioning the apparent path of light rays from the apparent dot to the point where the actual light rays bend at the surface.

The solid line with arrows on this ray diagram represents envisioning the actual path of light rays from the dot to the surface of the water, the sharp bend at the surface, and the solid line from that point at the surface to the eye.

It is helpful to think about examples of refraction in a variety of contexts. In some positions, for example, a pencil or a stick looks like it is bending at the surface of the water as in Fig. 1.40. Why does it look bent?

As shown in Fig 1.40, light is envisioned as shining on a pencil in the water and bouncing off in many directions. Some of the rays are envisioned as bouncing off the pencil and traveling in straight lines toward the surface of the water. At the surface, these rays are envisioned as bending as they move into air. Some of the rays are envisioned to be bending in such a way that they travel straight to the observer's eye. The observer perceives the rays as if they had traveled in a straight line from a location different from where the actual pencil is located so the person perceives the pencil to be bent.

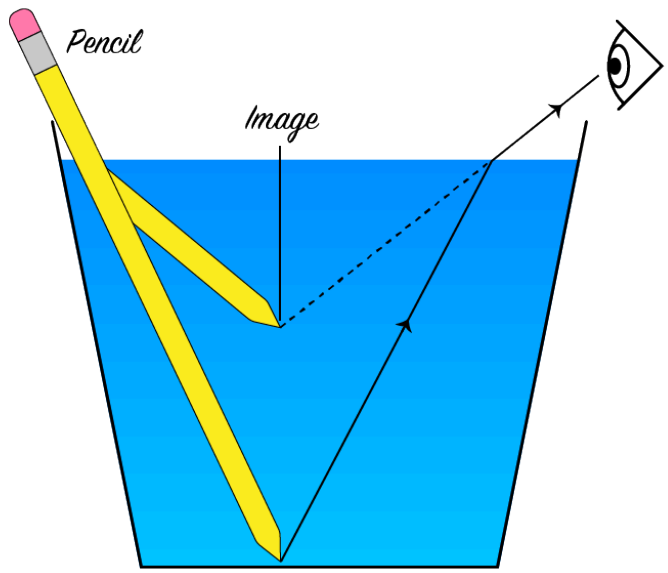


FIG. 1.40 Ray of light envisioned as bouncing off the tip of a pencil and bending at the surface of the water on way to the eye.

Another example of refraction occurs in a different context, spear fishing, as shown in Fig. 1.41. Where should you aim when spear fishing? (See: http://www.schoolphysics.co.uk/age14-16/Light/text/Refraction_and_fishermen/index.html)

FIG. 1.41 Spear fishing depicted in a wall painting from the tomb of Usheret in Thebes, 18 Dynasty around 1430 BC
https://commons.wikimedia.org/wiki/File:Tomb_of_Usheret_01.jpg

Question 1.22 What happens when exploring refraction with friends and/or family members?

3. Exploring refraction phenomena with a friend or family member

After class, our students have explored refraction phenomena with friends and/or family members and reflected upon this experience by describing details about what their learners ask, say, do, and find. They also have commented upon what they learn about learning and teaching science through this experience. A student, for example, wrote:

> *When I originally showed the phenomena to my roommate L, she said "whoa, when did you start doing magic tricks!" I laughed and told her that I was not doing magic but merely working with the phenomena of refractions.*
>
> *She asked "what is refraction?" I told her it was what allowed her to see the dot. I then showed her the experiment again. Afterwards I had her stand and asked if she could see the dot, she said "yes." I asked why, and she said because she was standing high enough. So, I turned off the lights and asked if she could see it. She said "No!" I turned back on the*

lights and asked what she must have to see the dot and she said "I need light to see the dot." So I kept the lights on and covered the dot so only I could look into the cup and see it. I asked if she could see the dot, the light was there so she should be able to. L then told me that the "light needs to hit the dot and then come to my eyes, I can't see it if you block the light from getting to my eyes."

So I asked L what must have happened for the light to travel from the dot, which was below her line of sight and go to her eyes. "Well," said L "the dot didn't move, cause that is impossible. So the light must have moved in the water to get to my eyes. Cause I only saw the dot look like it moved up after the water covered it."

At this point L was so close that it was very hard for me to not just tell her the answer. I refrained, but only barely. I asked L how she thought the light was moving; she said she didn't know.

So I drew out the flat ray diagram with the image of the dot on the side of the cup and her eye where it could not see the dot, but I did not draw the rays of light. I asked L to draw what she thought was happening. L drew a curved line from the dot to her eye.

Once again L was so close that it was hard not to give the answer away. So I asked L how light travels, she said "in rays, like the rays of the sun". I was surprised that she knew this but I was glad. So I asked her to show me a ray, a straight line leaving the dot and going to the surface of the water. She did so.

I asked if she thought this was how the light might have moved; she said, "well maybe, because the water going over the dot was what bent the light, so maybe the light only bends when it leaves the surface of the water." I was thrilled! She had figured it out! I then showed L the ray diagram of how light refracts and bends towards our eyes when leaving the surface of the water and going into the air.

The experience was hard for me. It was difficult for me to try and explain a concept to someone that was a new concept for me as well. However, it was rewarding to see that if I was patient, and continued to ask questions and only give small supplementary bits of information that L was able to understand the phenomena.

It was hard to try and think in a way that would foster L's own thinking about how the light rays traveled and to try and form questions that would help L to think in a certain way about light. I believe this will be much of what I feel as a teacher later. I will need to think of many different approaches for my students. Not all of them will understand instantly why a phenomena works; they will need more guidance or more questions, they may even need to experiment on their own to see if they can understand. I as a teacher must learn not to rush this process and to allow them to learn about the *subjects themselves. This is in the hopes that the students will remember more about the information as well as be more interested in the learning process.*

Physics student, Fall 2015

4. *Thoughts about the nature of science exemplified by these explorations*

The explorations of light phenomena so far exemplify the nature of science in that students developed central ideas based on evidence and modified those ideas as necessary after observing new phenomena. Initially, for example, explorations of light and shadow phenomena provided the basis for development of a conceptual model of light that included the central ideas that (a) *light leaves a source in all directions*, which, after discussion and additional exploration, was modified to *light leaves a point on most sources in many directions.* Additional explorations provided evidence for the central ideas that (b) l*ight can be envisioned as rays traveling in straight lines*, and (c) f*or someone to see something, light has to get to the person's eye*. A ray diagram representing how rays seemed to travel in straight lines was useful in developing an explanation of an intriguing observation, that the projection of an object in a pinhole camera was upside down. A straight meter or yard stick provided a physical model for thinking about light as behaving like rays traveling in straight lines.

Additional explorations of reflection and refraction phenomena, however, provided evidence that this conceptual model needed further revision. Observations of these phenomena provided evidence for development of three additional central ideas that refer to what happens when light shines on surfaces: c) that *light rays can be envisioned as being reflected from smooth surfaces with the angle of reflection equaling the angle of incidence*, d) that *light rays can be envisioned as bouncing off of rough surfaces in many directions*, and e) that *light rays can be envisioned as refracting (bending, changing direction) at the surface when traveling through a surface from one medium to another*. These are examples of the on-going nature of scientific knowledge, which is *open to revision in light of new evidence* and *can change when new information is found* (NGSS, Lead States, 2013, Appendix H).https://www.nextgenscience.org/resources/ngss-appendices

A bouncing ball also provided an elaborated physical model for light as rays composed of particles (photons) traveling in straight lines until interacting with a surface. More complex ray diagrams were useful in explaining another intriguing phenomenon, the apparent upward movement of a dot on the inside of a cup as water is poured into the cup. Additional modifications of this conceptual model for light may become necessary after exploring more phenomena. Meanwhile we turn next to elaborating experience with refraction phenomena in a new context.

C. Exploring dispersion phenomena

In this section, we explore light phenomena known as dispersion.

Question 1.23 What happens when light from the Sun passes from air into a prism or water droplet?

> Equipment: To explore dispersion phenomena on a sunny day, use a piece of white paper and a prism, a glass or quartz crystal, or a hose and sprinkles of water; inside use a prism or crystal with a bright lamp.

- What have you seen when light from the Sun passes through a glass or quartz crystal? Old-fashioned window panes? A prism? Water droplets when sprinkling with a hose?

  Note some of these experiences in the ***Before*** section of the physics notebook page documenting your exploration of dispersion phenomena.

- On a sunny day, take a prism or crystal outside and enjoy displaying what you see against a white wall or a piece of white paper on the ground. (Do not look directly at the Sun!)
- Or spray water with a hose and stand in such a way that you can admire making your own rainbow.
- Or play with a prism or crystal near a very bright light inside. What do you see? (Do not look directly at the bright light.)
- In the ***During*** section of your physics notebook page, record your findings. Draw a picture of what you did and saw. Note any vocabulary that is new to you.
- Discuss your findings and formulate a relevant central idea. In the ***After*** section of

the physics notebook page, report this idea and the evidence on which is based.

- Write a rationale that explains how the evidence supports the central idea and why this is important.
- Also reflect upon what you have learned during this exploration
- What are you still wondering?
- Add this central idea about dispersion to Table I.1:

TABLE I.1 (continued) Explorations of Light Phenomena: Dispersion

TABLE I.1 (continued) Explorations of light phenomena: Dispersion			
Sketch of set up Ray diagram	Evidence	Central Idea	Vocabulary
		White light disperses into its component colors when moving from one medium to another such as from air into a glass prism or water	Dispersion

Complete your entries on your physics notebook page and Table I.1. Summarize what you have learned about dispersion phenomena before reading an example of student work and nuances about exploring dispersion phenomena.

1. *Example of student work about exploring dispersion phenomena*

As shown in Fig. 1.42, a student added to Table 1.1 about explorations of light phenomena and stated as evidence, "White light from the Sun hit the prism and was broken up into its different colors."

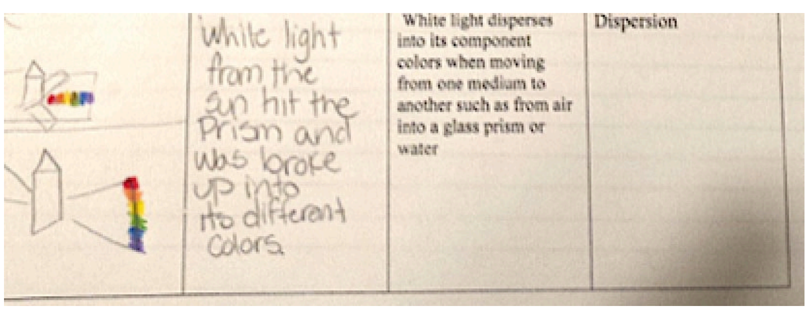


FIG. 1.42 Student's addition to Table 1.1 about exploring dispersion phenomena:

The student summarized this new central idea about dispersion phenomena as follows:

> ***White light disperses into its component colors when moving from one medium into another such as from air into a prism or water.*** *For this experiment, students were given triangular prisms made of a clear material that may have been glass. We were then taken outside into the sunshine and told to move our prisms around and see what happened.*
>
> *It took a moment before someone exclaimed, "Hey I see a rainbow!" Soon many students began to really watch what happened when they tilted the prisms one way or another. Some students placed a piece of white paper on the ground and tried to project the "rainbows" onto the paper. When students set the prisms onto the paper facing the sun we were able to see two figures that looked like shadows but much lighter. It was light being dispersed through the prism onto the paper.*
>
> *When we moved the prism slightly we were able to see the light on the paper change from a slight white color to the rainbow of colors Red Orange Yellow Green Blue and Violet (ROYGBIV).*
>
> *The students then talked about what must be happening and our TA's told us that the sun sends out a kind of light called white light that holds all of the colors of the rainbow in it. The students decided that what must happen is that as the light passes through the prism it is broken up into the different colors when it is sent back out of the prism. This experiment is represented in a picture on (Fig. 1.41) as well as a ray diagram. In the ray diagram light goes into one side of the prism, where it is broken up into the many colors, and then dispersed on the other side into the different colors that were seen by the students.*
>
> Physics student, Fall 2015

2. Nuances about exploring dispersion phenomena

Figure 1.43 shows red and violet rays bending as they move from air into a prism and bending again as they move from the prism back into air. The violet rays bend more than the red rays and this difference separates the white light into its component colors. The colors between red and violet bend intermediate amounts.

Note that the orientation of the two surfaces of the prism differ, one side slants toward the left, the other side slants toward the right. If one draws a line perpendicular to the surface of the prism (a normal line) at the point where the white light enters the prism, the rays bend *toward* this normal as they move from air into the prism.

If one draws a line perpendicular to the surface of the prism at the point where each ray leaves the prism, the rays are bending *away* from the normal as they move from the prism back out to the air. The result of the different orientations of these surfaces is that the rays keep bending "down" as they enter and then leave the prism.

The drawing shows rays of light as they are inferred to be traveling. One can not actually "see" these colored rays as represented in the drawing. What one sees is the spectrum of colors when the rays land on some kind of screen such as a wall or piece of paper, or in the case of a rainbow, on the retina of an eye. This is a *model* of what seems to be happening. The next section uses this model to develop an explanation for an amazing natural event, the formation of a rainbow.

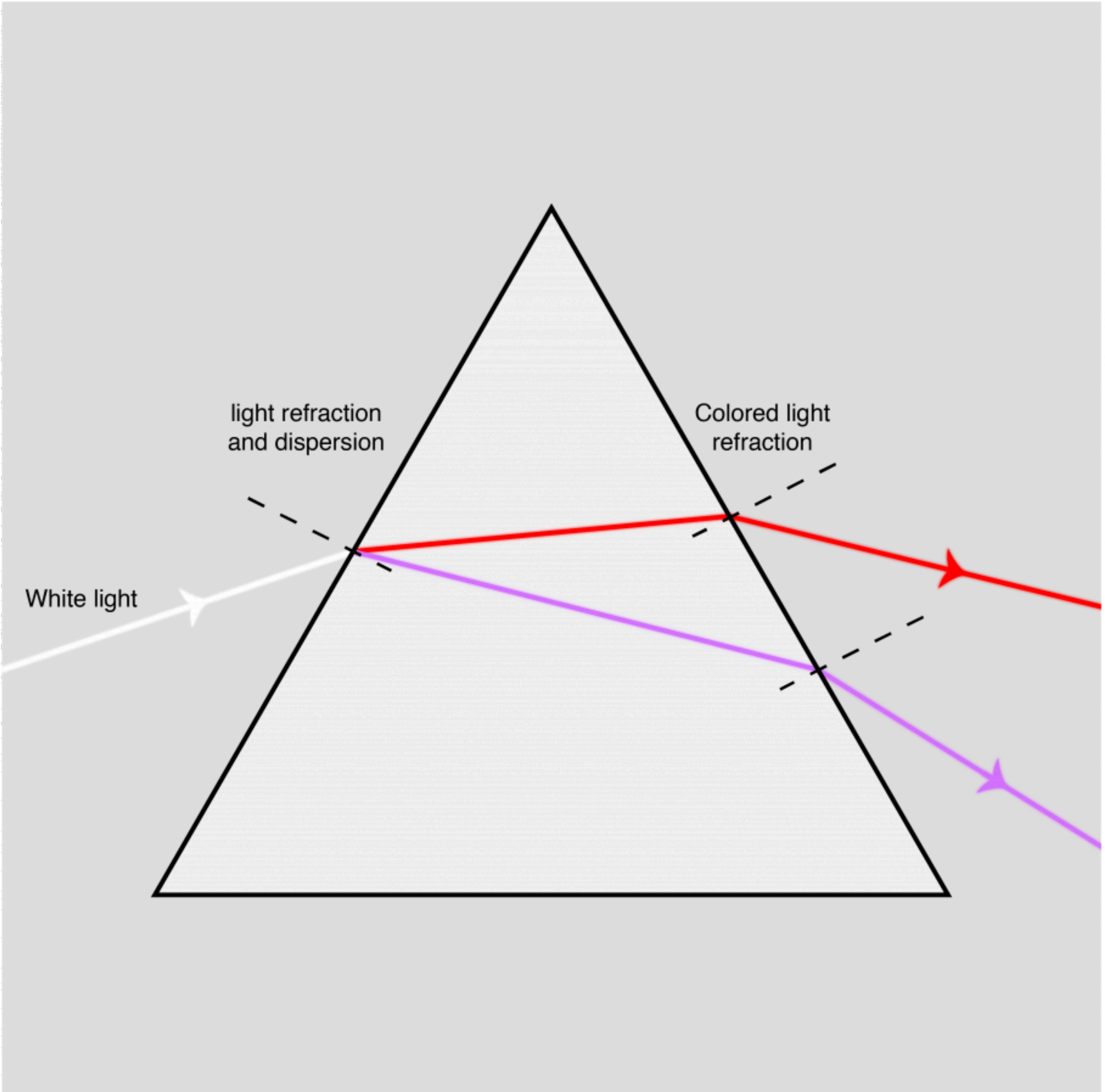


FIG. 1.43 Dispersion of white light into its spectrum of colors. The spectrum ranges from red to violet as shown here. Modified from https://wikivisually.com/wiki/File:Prism_rainbow_schema.png CC 3.0

VIII. Using Additional Central Ideas about Light to Explain an Intriguing Phenomenon

We can use these additional central ideas about reflection, refraction, and dispersion to explain a beautiful phenomenon: a rainbow.

Question 1.24 How are rainbows formed?

- When you see a rainbow, where are you standing with respect to where the sun and rain are?
  - Is the sun behind you, high above you, or in front of you?
  - Is the rain behind you, raining straight down on you, or some distance away in front of you?
  - Make a sketch that shows where you are with respect to the sun and rain.
- What happens when light from the sun enters a water drop?
  - What happens when light rays move from one medium into another such as from air into water?
  - Make a ray diagram showing white rays from the sun entering a water drop. Show only one color as rays of that color move from air into the drop.

- What happens when light rays reflect off a smooth surface?
  - Continue your ray diagram showing rays of one color reflecting off of the inner surface of the drop, back into the drop.
- What happens when light rays move from one medium into another, such as from water into air?
  - Continue your ray diagram showing rays of one color leaving the water drop and traveling through the air.
- Will colors from the same drop reach the observer's eye?
  - Continue your ray diagram showing rays of one color traveling to the observer's

eye.
  - Consider whether rays of another color would exit this drop in a direction toward the observer's eye.
  - Add another drop at a different height from which a different color reaches the observer's eye.
- Summarize how light from the sun sometimes forms a rainbow in the sky.

Complete your ray diagram and summary before looking at an example of student work and nuances about explaining rainbows.

1. Example of student work explaining rainbows

A student began explaining rainbows with a sketch of where someone is who is seeing a rainbow, with respect to the sun and the rain, and a ray diagram showing how one can envision what happens when light rays enter water drops in just the right way to form a rainbow as shown in Fig. 1.44.

(Figure 1.44) is a sketch of someone seeing a rainbow. The Sun is behind the person and the cloud with raindrops is in front of the person.

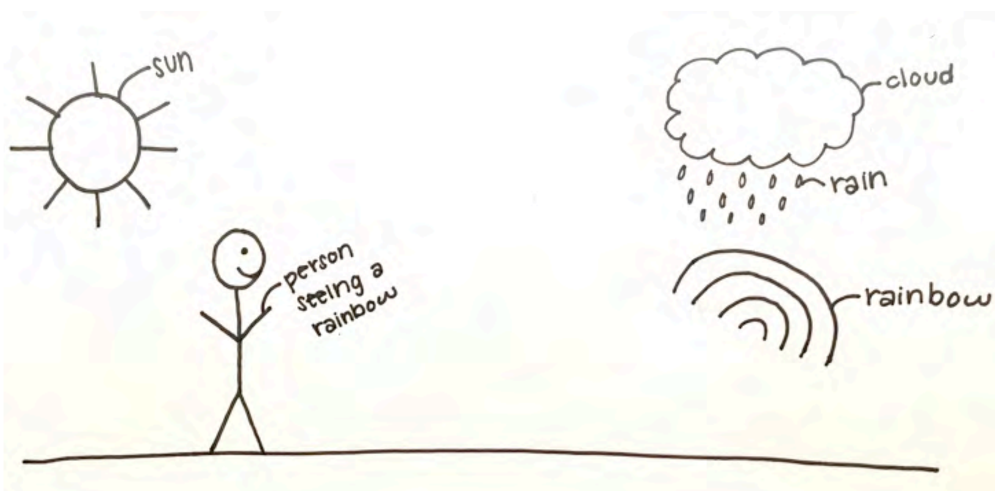


FIG. 1.44 *Sun, person, cloud, and rain when a person is seeing a rainbow.*

(Figure 1.45) is a ray diagram with the Sun, two rain drops, and a person's eye.

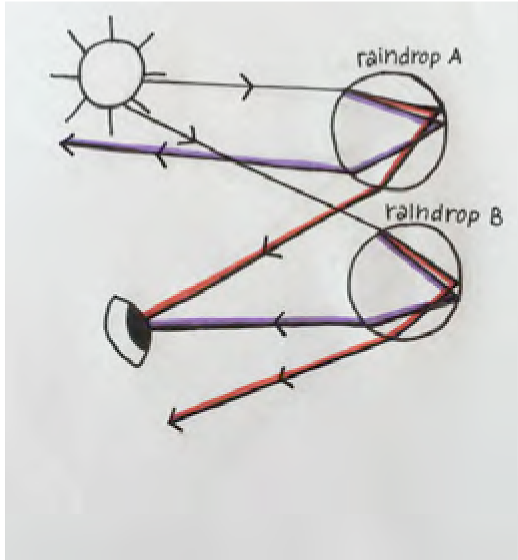


FIG. 1.45 Student ray diagram for two raindrops and person seeing a rainbow.

The ideas above can be used in tracing the two continuous rays in (Fig. 1.45), in order to explain how someone can see a rainbow.

First of all, white light disperses into its component colors when moving from one medium into another such as from air into a prism or water.

In Figure (1.45), the two light rays that are shown leaving the sun in the direction of the raindrops are white light. Once those white light rays hit the raindrops, which is a change in medium from air to water, it can be seen that the white light disperses into its component colors, which is represented by the red and violet rays seen inside of the raindrops. Next, light rays refract (bend, change direction) at the surface when light moves from one medium into another such as from air to water or from water to air. This refraction is first seen in Figure (1.45) in each of the raindrops directly when the light rays first hit the raindrops, since the rays are moving from the medium of air to the medium of water.

Next, light rays reflect from smooth surfaces in a regular way, where the angle of reflection equals the angle of incidence. This is seen in Figure (1.45) when both the red and the violet rays hit the back of the raindrops, which are smooth surfaces, and they reflect off in the same angles as which they came in, which are the angles of incidence.

Finally, refraction is seen again in Figure (1.45). The second time that refraction is seen is when the light rays are leaving the raindrops, since the rays are moving from *the medium of water to the medium of air. When the light rays leave the raindrops, the red rays bend less than the violet rays. So, in the raindrop on the top, only the red light rays exit at the correct angle to travel to the observer's eye. In the raindrop on the bottom, only the violet light rays exit at the correct angle to travel to the observer's eye. Since we only see one color from each raindrop, that is how a rainbow is seen.*

Physics student, Spring, 2016

2. Nuances in using central ideas about reflection, refraction, and dispersion to explain rainbows

A step by step view of the processes involved in forming rainbows can be helpful:

First the white light rays from the Sun are envisioned as being **refracted** on entering a water drop with different colors bending at different angles. Violet bends the most, red the least. The other colors bend in between. Figure 1.46 shows this first step of white light entering a raindrop and one of its component colors bending toward the normal at a particular angle at the surface of the drop.

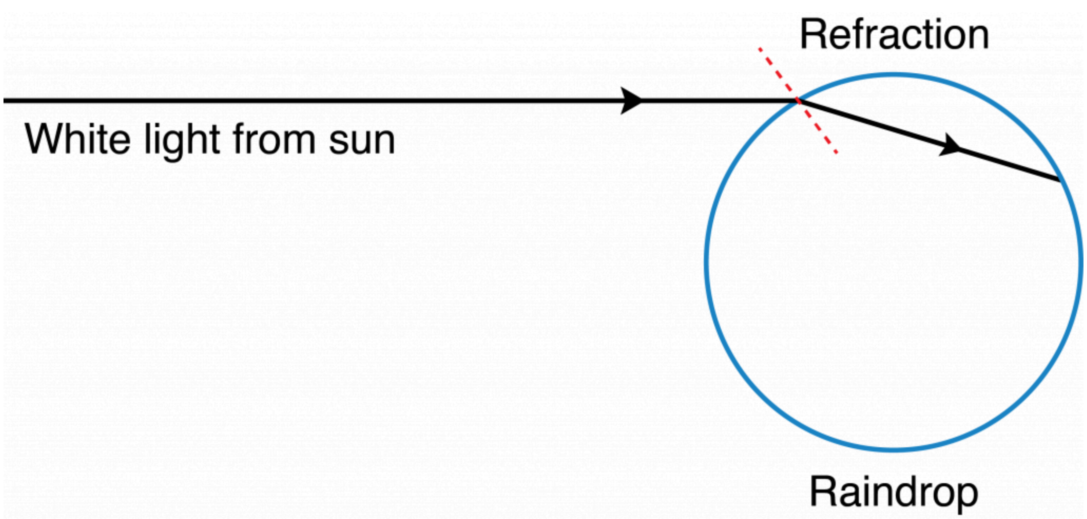


FIG. 1.46 White light ray from the Sun ***refracts*** *as it enters a raindrop.*

Next the colored light ray is envisioned as moving through the rain drop and encountering the inner surface of the other side of the raindrop. What happens there?

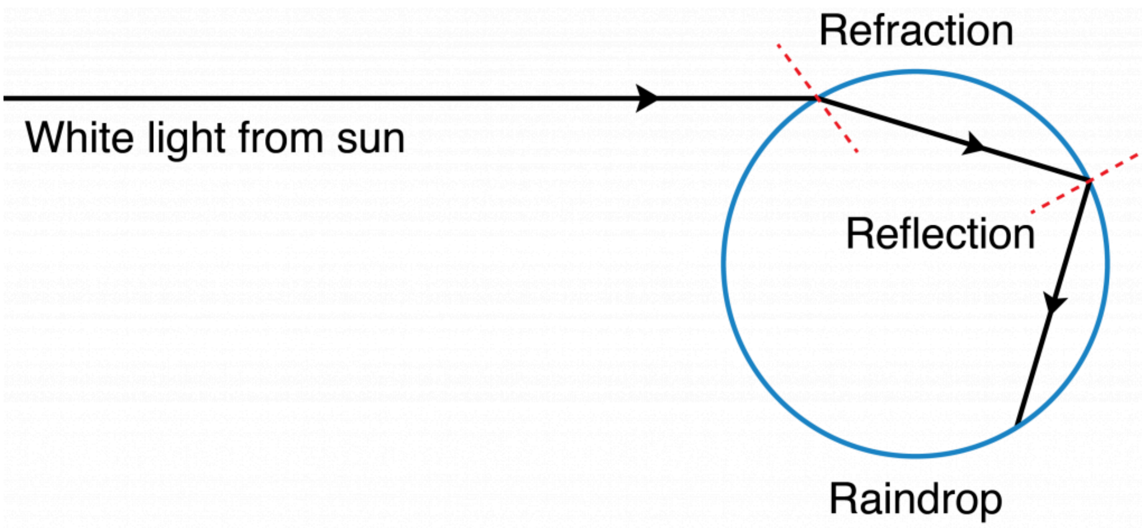


FIG. 1.47 Light ray of a particular color is ***reflected*** *at the smooth inner surface of the rain drop.*

As shown in Fig. 1.47, when rays of a particular color enter a drop, they are envisioned as bending and continuing to move in a straight line in a direction away from the observer until they reach the smooth inner surface of the raindrop. As shown in Fig. 1.47, some are envisioned as being **reflected** internally at the inside surface, where angle of reflection equals the angle of incidence for each color. These rays are envisioned as now heading back in a direction toward the observer.

Then the rays of all colors are envisioned as moving back through the raindrop to the original side they entered, but now traveling in the opposite direction. What happens there?

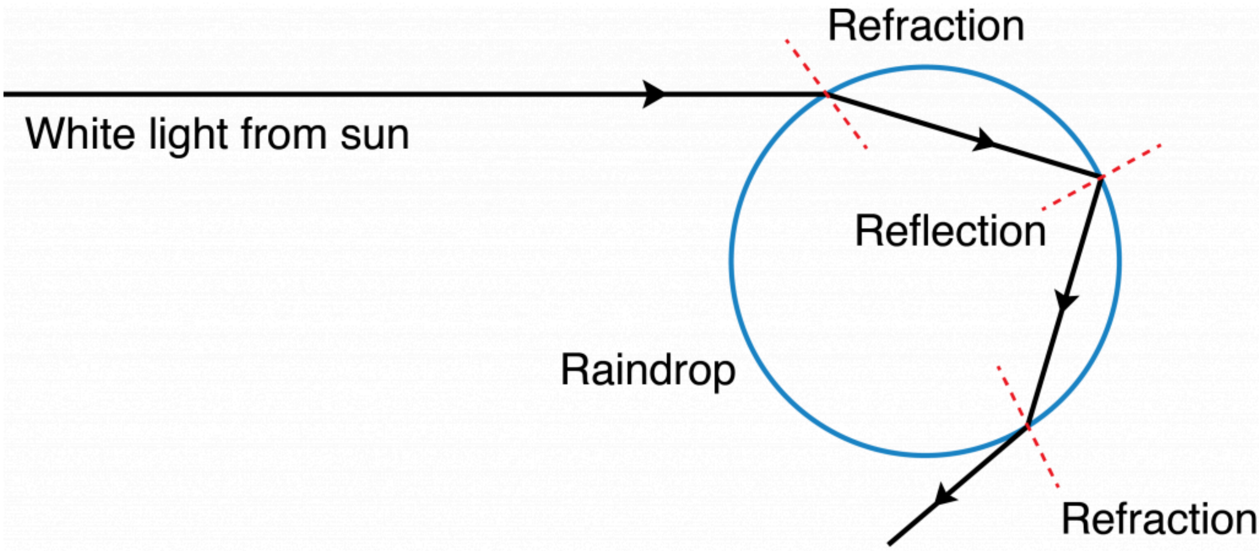


*FIG. 1.48 Light ray of a particular color is **refracted** again as it moves from water into air.*

As shown in Figure 1.48, rays of this color are envisioned as being **refracted** again as they leave the raindrop in the direction of the observer, bending again, but away from the normal at a particular angle for that color. The red rays leave the surface below the green rays, which are below the blue rays. This is the inverse order to colors seen in a rainbow.

As shown in Fig. 1.48, the entire trip through a rain drop is envisioned as involving a) **refraction** as white light enters the raindrop and separates into its component colors as each color bends at its own angle, b) **reflection** of each color at the opposite inner surface with color's angle of reflection equal to its angle of incidence, and then c) **refraction** again but in a direction toward the observer as the rays of each color leave the raindrop.

Note that if you see a rainbow you are seeing light from DIFFERENT raindrops. The red light is coming from drops high in the sky, the violet light from drops lower in the sky (See: http://science.howstuffworks.com/nature/climate-weather/atmospheric/question41.htm).

Figure 1.49 shows a ray diagram drawn by Rebecca McDowell when she was a second year Bachelor of Teaching student at the University of Melbourne, Victoria, Australia. She included many colors of the spectrum and represented someone seeing different colors from raindrops at different heights.

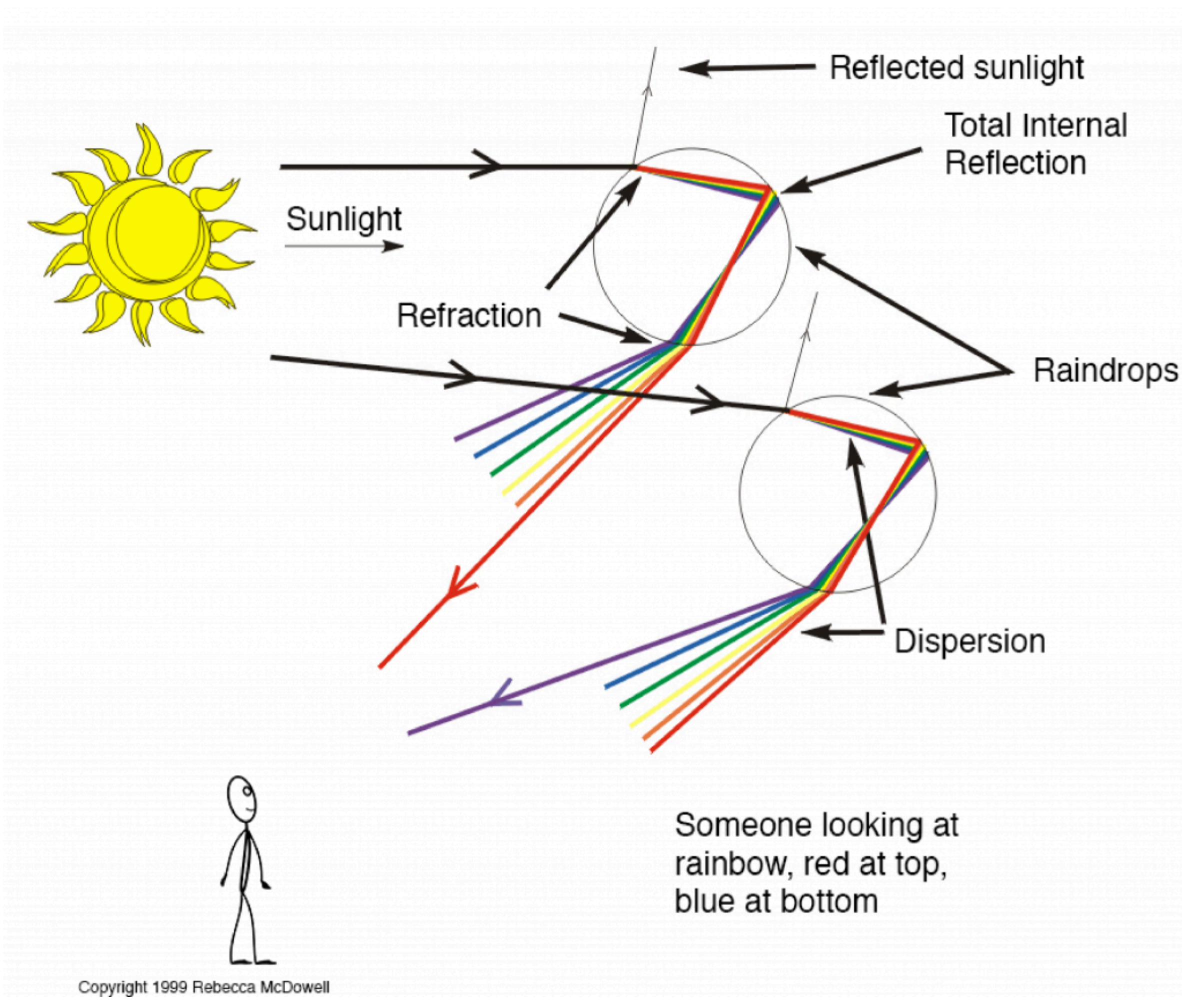


FIG. 1.49. Seeing different colors from different raindrops at different heights. Rebecca McDowell, How Rainbows Form, University of Melbourne (1999) [*http://www.rebeccapaton.net/rainbows/formatn.htm*](http://www.rebeccapaton.net/rainbows/formatn.htm) *accessed* May 28, 2019.

Next time you see a rainbow, enjoy!

Fig. 1.50 Rainbows!
Images by Katrina van Zee from a sailboat in Loch Nevis, Scotland.

As shown on the right in Fig. 1.50, the order of the colors in the faint secondary bow of a double rainbow is reversed with red light forming the inner arc. The explanation involves a similar model of envisioning light rays from the Sun refracting, reflecting, and refracting as they enter and leave raindrops. In a secondary bow of a double rainbow, however, the incoming refracted light rays are envisioned as reflecting twice within a raindrop rather than once, with violet light coming from higher drops and red light from lower ones. (See https://www.metoffice.gov.uk/weather/learn-about/weather/optical-effects/rainbows/double-rainbows and http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/rbowpri.html#c2.)

The process of using models to develop explanations of complex phenomena is an example of an aspect of the nature of science articulated in the US *Next Generation Science Standards* that *science models, laws, mechanisms, and theories explain natural phenomena* (NGSS, Lead States, 2013, Appendix H) (See: https://www.nextgenscience.org/resources/ngss-appendices.)

IX. Historical and Current Perspectives on the Nature of Light

Historical interpretations of the spectrum of colors dispersed by a prism

Archeologists have found glass prisms in ancient Roman ruins as well as natural prisms such as rock crystals in Pompeii (Rossi & Russo, 2017, p. 335). These findings suggest that people have been seeing a spectrum of colors displayed when white light shines through a prism since ancient times. Greek and Roman writers also discussed optical phenomena. Euclid (325 BC-265 BC), for example, envisioned light as rays moving in straight lines, formulated a law of reflection, and knew about refraction effects (Mach, 1926/2003, p. 3-4).

People also have pondered the nature of light and colors for a long time. The Greek philosopher Aristotle (384 BC-322 BC), for example, wrote that colors were mixtures of light (white) and darkness (black). This became widely accepted and led to the view that light from the Sun was a single form of light, white, and that a prism modified pure white light into the different colors as the white light moved through the prism.

This view of white light persisted until the publication of a letter to the Royal Society of London in 1671/72 by Isaac Newton. He stated and supported a different view, that white light was already a mixture of colors, with each color bending as it entered a prism at its own angle of refraction.

Newton (1671/72) referred to refraction as "refrangibility" and stated that:

> *As the Rays of light differ in degrees of Refrangibility, so they also differ in their disposition to exhibit this or that particular colour…The least Refrangible Rays are all disposed to exhibit red colour, and contrarily those Rays, which are disposed to exhibit a Red colour, are all the least refrangible: So, the most refrangible Rays are all disposed to exhibit a deep* Violet Colour, *and contrarily those which are apt to exhibit such a violet colour, are all the most Refrangible. And so to all the intermediate colours in a continued series belong intermediate degrees of refrangibility. (p. 3081, #1 and #2)* https://royalsocietypublishing.org/doi/abs/10.1098/rstl.1671.0072

In addition, Newton noted that when we perceive an object to have a particular color, that effect is due to the object primarily reflecting light of that color to our eyes:

> *…the Colours of all natural Bodies have no other origin than this, that they are variously qualified to reflect one sort of light in greater plenty than another. And this I have experimented in a dark Room by illuminating those bodies with uncompounded light of divers colours…and consequently when illuminated with day-light, that is, with all sorts of Rays of any colour promiseuously blended, those qualified with red shall abound most in the reflect light, and by their prevalence cause it to appear of that colour* (*ibid*, *p.* 3084-3085, #13)

Newton claimed that the colored rays already existed within the white light and that these rays separate as they bend at different angles within the prism (p. 3083, #7). To support this claim, Newton showed that not only did a prism disperse white light into separate colors but also that a lens could converge these colored rays back into white light like that that comes from the Sun. He presented evidence for this claim by describing his experimental setup and findings:

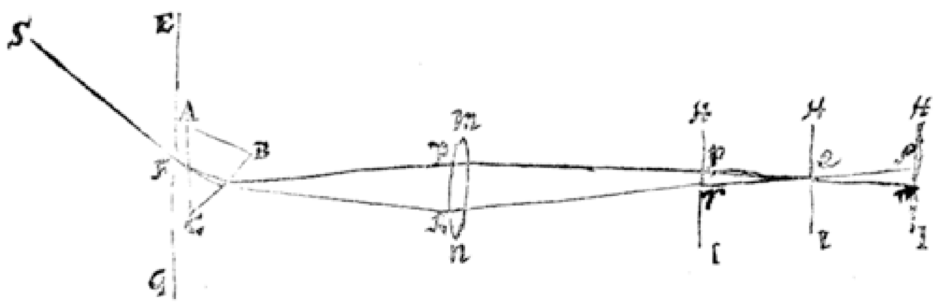
> *In a darkened room make a hole in the shut of a window, whose diameter may conveniently be about third part of an inch, to admit a convenient quantity of the Suns light: And there place a clear and colourless Prisme, to refract the entering light towards the further part of the Room, which, as I said, will thereby be diffused into an oblong coloured Image. Then place a Lens of about three-foot radius (suppose a broad Object-glass of a three foot Telescope,) at the distance of about four or five foot from thence, through which all those colours may at once be transmitted, and made by its Refraction to convene at a further distance of about ten or twelve feet. If at that distance you intercept this light with a sheet of white paper, you will see the colours converted into whiteness again by being mingled.*

He provided some details of how to do this and suggestions of what to observe:

> *But it is requisite, that the Prisme and Lens be placed steddy, and that the paper, on which the colours are cast, be moved to and fro; for, by such motion, you will not only find, at what distance the whiteness is most perfect, but also see, how the colours gradually convene, and vanish into whiteness, and afterwards having crossed one another in that place where they compound Whiteness, are again dissipated, and severed, and in an inverted order retain the same colours, which they had before they entered the composition…*(*ibid.*, *p.* 3086)

Newton also provided the ray diagram reproduced in Figure 1.51 to illustrate this experiment. In Figure 1.51, rays of white light from the sun (SF) enter a hole in a window (EG), pass through an equilateral prism (ABC), and are dispersed, with example rays FP bent more than FR. Lens (mn) converges these rays so that they meet at point Q on paper HI as white light, although they are seen as colored spots before and after Q if the paper HI is moved back and forth. (This excerpt from the letter also includes some of the text, in which the font for s looks like an f.)

In the annexed defign of this Experiment, A B C expreffeth the Prifm fet endwife to fight, clofe by the hole F of the window



E G. Its vertical Angle A C B may conveniently be about 60 degrees: *M N* defigneth the *Lens*. Its breadth 2½ or 3 inches. S F one of the ftreight lines, in which difform Rays may be conceived to flow fucceffively from the Sun. F P, and F R two of thofe Rays unequally refracted, which the *Lens* makes to converge towards Q, and after decuffation to diverge again. And H I the paper, at divers diftances, on which the colours are projected: which in Q conftitute *Whitenefs*, but are *Red* and *Yellow* in R, r, and ϱ, and *Blew* and *Purple* in P, p, and π.

1F

FIG. 1.51. *Excerpt from Newton* (1671/72) *showing white light* (SF) *dispersed by prism* (ABC) *into rays that are converged by lens* (mn) *back into white light on a piece of paper* (HI) *at* Q. (*p.* 3086)
https://royalsocietypublishing.org/doi/abs/10.1098/rstl.1671.0072

Newton also applied this understanding to explain the colors in the rainbow (#10 on pages 3083-3084). We too can use what we now know about reflection, refraction, and dispersion to make sense of why we sometimes can see beautiful rainbows in the sky.

References in this section:

Newton, I. (1671/72). A letter of Mr. Isaac Newton, Professor of the Mathematics in the University of Cambrdige; Containing his new theory about light and colors: Sent by the author to the publisher from Cambridge, Febr. 1671/72; in order to be communicated to the R. Society. *Philosophical*

transactions of the Royal Society of London, 6, (60-80) 3075-3087. https://royalsocietypublishing.org/doi/abs/10.1098/rstl.1671.0072

For information about this letter and its problematic reception at the time, see Patricia Fara's article celebrating the 350th anniversary of the journal *Philosophical Transactions of the Royal Society*:

Fara, P. (2015). Newton shows the light: a commentary on Newton (1672) 'A letter…containing his new theory about light and colors…' *Philosophical Transactions of the Royal Society*, *http://rsta.royalsocietypublishing.org/content/373/2039/20140213*.

Other references mentioned in this section:

Ernst Mach, *The principles of physical optics: an historical and philosophical treatment*. Trans. J. S. Anderson and A.F.A. Young. (Methuen & Co, London; Dover, Mineola, NY, 1926/2003).

Cesare Rossi and Flavio Russo, *Ancient Engineers' Inventions: Precursors of the Present*. (2nd ed.) Cham, Switzerland: Springer International, p. 335. (2017). ISBN 978-3-319-44476-5

Library of Universal Knowledge, A Reprint of the Last (1880) Edinburgh and London Edition of Chambers's Encyclopaedia, p. 731

https://play.google.com/store/books/details?id=ichZAAAAYAAJ&rdid=book-ichZAAAAYAAJ&rdot=1

https://play.google.com/books/reader?id=ichZAAAAYAAJ&printsec=frontcover&output=reader&hl=en&pg=GBS.PA731 p. 731

In addition to referring to light as rays, Newton envisioned rays as composed of "small particles". In a later major document summarizing his exploration of light phenomena, the book *Opticks*, he wrote:

> *Are not the Rays of Light very small Bodies emitted from shining Substances? (p. 371, Question 29)*

Newton, I. (1730). *Opticks: Treatise of the Reflections, Refractions, Inflections and Colours of Light*. (4th ed.) London: William Innys at the Westend of St. Paul's . http://www.gutenberg.org/ebooks/33504

Christiaan Huygens (1690), a Dutch contemporary of Newton, however, proposed an alternative way of envisioning light, as analogous to sound, traveling outward in all directions from a source like a wave formed when a pebble drops into a puddle of water:

> *It (light) spreads, as Sound does, by spherical surfaces and waves: for I call them waves from their resemblance to those which are seen to be formed in water when a stone is thrown into it, and which present a successive spreading as circles, though these arise from another cause, and are only in a flat surface.(p. 4)*

Christiaan Huygens, *Treatise on Light.* (Translated from French by Silvanus P Thompson). Macmillan, London, 1690/1912). http://www.gutenberg.org/ebooks/14725

Figure 1.52 shows examples of successive spreading of circles from raindrops falling on water.

FIG. 1.52. Example of circular waves formed by rain falling on water. Image by Ruth Hartnup *https://www.flickr.com/photos/ruthanddave/5713878850*

Envisioning light as such successive spreading of circular waves also occurs today. Light waves can be represented as shown in Figure 1.53, which presents the primary colors of the spectrum of light from the sun. Red light has the largest wavelength, violet the smallest.

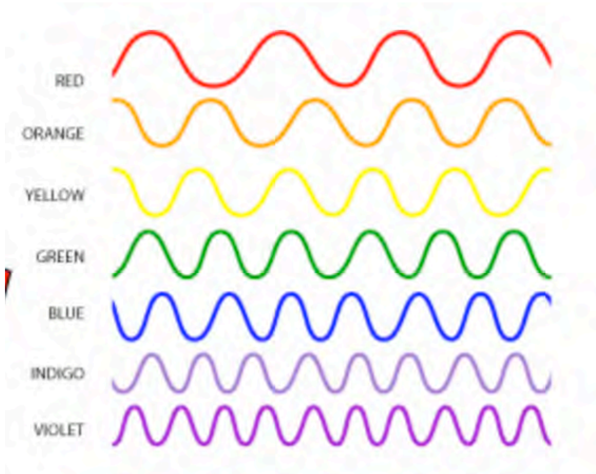


FIG. 1.53 Primary colors of the spectrum of light from the Sun as represented by waves with different wavelengths. [National Aeronautics and Space Administration, Science Mission Directorate. (2010). Visible Light. http://science.nasa.gov/ems/09_visiblelight , accessed May 28, 2019.]

As shown in Fig. 1.54, a *wave length*, often represented by the Greek letter *lambda* can be measured from crest to crest, midpoint to midpoint, or trough to trough. The wave's *amplitude* is the distance from the midpoint to the crest or trough.

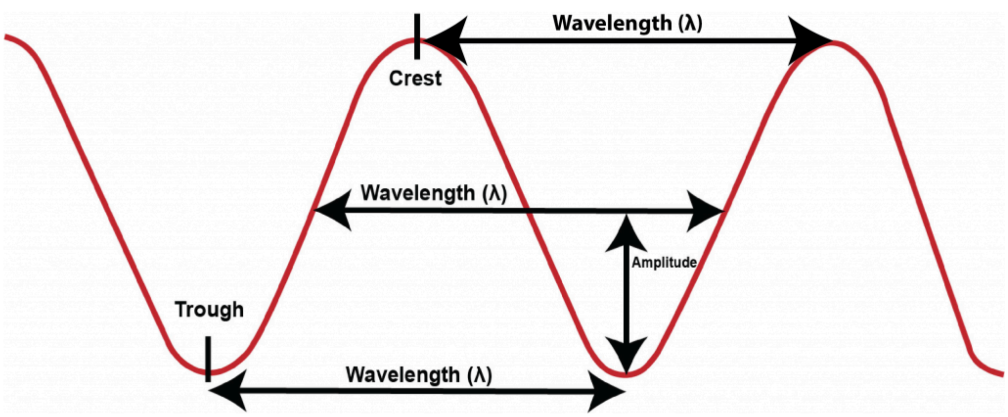


FIG. 1.54 Wave diagram showing wave length and amplitude. Modified from Phil Stoffer http://geologycafe.com/images/wavelength.jpg

The light's *frequency*, often represented by f or the Greek letter *nu* is the number of waves that pass a point each second. The *speed* of a wave depends on both the wavelength and the frequency: $(\mathrm{speed}) = (\mathrm{wavelength})(\mathrm{frequency})$.

These two perspectives on what light IS, whether particles or waves, were evident in the writings of Newton and Huygens in the 17th century. They continue today in the "wave-particle duality" to which physicists refer. Sometimes it is helpful to think of light as a stream of particles, sometimes as a spreading wave. Each perspective is useful, depending upon the context within which one is asking questions about light.

X. Making Connections to Educational Policies

What does it mean *to do* science? What should every person know about science? How should science be taught? These are questions that every community decides by what and how children learn science, or not, in its schools.

This section completes this unit. As an informed citizen, you should become aware of your community's standards for teaching science, particularly if you are a teacher, preparing to become a teacher, or a parent advocating for more science to be taught in elementary schools.

Question 1.25 What are the current standards for teaching science at various grade levels in your community?

- Contact the department of education in your community to find out about the current standards for teaching science at various grade levels. The Oregon Department of Education's announcement, for example, is at https://www.oregon.gov/ode/educator-resources/standards/science/Pages/Science-Standards.aspx . This state adopted the US *Next Generation Science Standards* (NGSS Lead States, 2013) in 2014.

A. Learning about the US *Next Generation Science Standards: Science and engineering practices*

The *Next Generation Science Standards* (NGSS) website is at https://www.nextgenscience.org . This website describes three dimensions of what it means to be proficient in science and engineering. These dimensions are *science and engineering practices, crosscutting concepts, and disciplinary core ideas* that NGSS recommends for students to learn at various grade levels.

This unit began, for example, with the scientific practice of *asking questions* about the nature of light such as *How does light seem to travel from a source to a screen*? By exploring light and shadows, students developed a model for thinking about light, that *light can be envisioned as rays traveling in straight lines*. Students next used that model to explain the *cause* of a surprising *effect*, that the projection on the screen of a pinhole camera is upside down. Searching for the *cause of an effect* is a *crosscutting concept* characteristic of the many domains of science and engineering. During explorations in this unit, students inferred and used a *disciplinary core idea* that *objects can be seen when light reflected from their surfaces enters our eyes.*

Development of the *Next Generation Science Standards* was based on an earlier document, A *Framework for K-12 Education: Practices, Crosscutting Concepts, and Core Ideas* (https://www.nap.edu/read/13165/chapter/1). The NGSS website includes a series of appendices that discuss various aspects of the *Framework*'s recommendations.

- NGSS Appendix F describes eight scientific and engineering practices at https://www.nextgenscience.org/resources/ngss-appendices . Scan these to see what they are and read about any that you find particularly interesting.
- Complete Table I.4 by indicating with a check mark your perception of participating in some way in some of the eight NGSS science and engineering practices during your exploration of light phenomena.

Table I.4. Science and engineering practices (NGSS Lead States, 2013)

Table I.4. Science and engineering practices (NGSS Lead States, 2013)

Practices	Exploring light and shadows	Exploring pinhole phenomena and estimating the size of an object	Exploring reflection, refraction, dispersion and explaining rainbows
1. Asking questions (for science) and defining problems (for engineering			
2. Developing and using models			
3. Planning and carrying out investigations			
4. Analyzing and interpreting data			
5. Using mathematics and computational thinking			
6. Constructing explanations (for science) and designing solutions (for engineering)			
7. Engaging in argument from evidence			
8. Obtaining, evaluating, and communicating information			

- Provide an example by choosing one of the practices and describe how you did this.

Complete your entries into Table I.4 and description of participating in one of the practices before reading an example of student work.

1. Example of student work about relevant educational policies

As shown in Fig. 1.55, a student indicated that many of the NGSS science and engineering practices had been used during this unit.

Science and Engineering Practices (NGSS, 2013)

Practices	Exploring light and shadows	Exploring pinhole phenomena and estimating the size of an object	Exploring reflection, refraction, dispersion and explaining rainbows
1. Asking questions (for science) and defining problems (for engineering	✓	✓	✓
2. Developing and using models	✓	✓	✓
3. Planning and carrying out investigations	✓	✓	✓
4. Analyzing and interpreting data		✓	
5. Using mathematics and computational thinking		✓	
6. Constructing explanations (for science) and designing solutions (for engineering)	✓	✓	✓
7. Engaging in argument from evidence	✓	✓	✓
8. Obtaining, evaluating, and communicating information	✓	✓	✓

FIG. 1.55 Student's response indicating use of science and engineering practices in this unit.

(The table) indicates with a check mark my perception of participating in some way in some of the eight practices specified during my exploration of light phenomena…One of the practices that we have participated in during class is developing and using models and we did this when we developed the idea that light can be envisioned as rays traveling in straight lines. In order to do this, we used a lamp, a barrier, a white piece of paper, and a meter stick. The light shined directly on the barrier, so the barrier made a shadow on the white paper. The meter stick was placed at the edge of the lamp and it went straight past the edge of the barrier. The meter stick represents a ray of light traveling from the lamp. The shadow of the meter stick was lined up with the edge of the barrier's shadow on the paper, which we inferred means that the light travels in a straight line because the shadows lined up perfectly in relation to the actual objects, so we assume that light can always be envisioned as rays traveling in straight lines. Developing and using a model allowed us to develop a very important idea.

Physics student, Spring 2016

B. Reflecting upon this exploration of light phenomena

This unit began with exploring light and shadows in order to develop ways to think and talk about the nature of light. The first demonstration involved turning on a lamp in a dark room and observing light shining all around on the ceiling, the floor, and people's faces. The first central idea to emerge from discussing this demonstration likely seemed obvious, that *light leaves a source in all directions*. This central idea needed refinement, however, to acknowledge that directional sources like lasers exist and that not all directions might occur. The refined central idea became *light leaves most sources in many directions*. Small group explorations with a light source, barrier, and screen included using a meter stick (or ruler) to serve as a physical model representing the central idea that *light can be envisioned as rays traveling in straight line*s.

These two central ideas formed a conceptual model useful in explaining an intriguing phenomenon: if one looks at a light bulb through a pinhole camera, the projection of the light bulb is upside down! A good way to start thinking about such puzzling phenomena is to make a sketch of the situation, in this case, to draw a picture of the light bulb and a picture of its upside-down projection. The next step is to think about what one knows that is relevant to the situation shown in the sketch. For example, how can envisioning light as rays leaving a source in straight lines help here? In particular, how can the physical model, the meter stick (or ruler), help to think about how light from the top of the light bulb can travel through the pinhole toward the bottom of the screen?

Laying one end of the meter stick (or ruler) near the sketch of the top of the bulb and the other end of the meter stick (or ruler) near the sketch of the bottom of the projection suggests a useful insight: that if light rays from any <u>point</u> on the bulb can be envisioned as leaving the source in many directions, some rays from the top of the bulb can be thought of as traveling straight through the pinhole toward the bottom of the screen; some rays from the middle of the bulb can be thought of as traveling straight through the pinhole to the middle of the screen; and some rays from the bottom of the bulb can be thought of as traveling straight through the pinhole toward the top of the screen. This insight implies that an alternative explanation is not needed, that something happens to the rays to "flip" the projection. The physical model of the meter stick (or ruler) suggests that <u>nothing</u> happens to the rays forming the projection; they just keep traveling in the same direction they happen to be going, straight through the pinhole. The aluminum foil around the pinhole blocks other rays from the source from shining on the screen.

Simplifying a sketch can help make important aspects of a situation more prominent.

Drawing a vertical line representing the bulb and a parallel vertical line representing an upside-down projection, for example, provides a useful visual model for pinhole phenomena, the *ray diagram*. Tracing the rays with one's finger while telling the story represented by a ray diagram can be a compelling way to communicate to others what one is envisioning to be happening.

The ray diagram for pinhole phenomena consists of two similar triangles. Interpreting these geometrically leads to a mathematical model for pinhole phenomena, an algebraic equation that expresses the direct relationship between ratios of the corresponding lengths of the similar triangles. This mathematical model made possible estimating a quantity that could not be directly measured. Students held a pinhole in a sheet of aluminum foil one meter away from a screen, traced the Sun's projection on the screen, measured the diameter of the projection, and used the equal ratios of corresponding lengths of similar triangles as well as information about the distance from the Earth to the Sun to estimate the Sun's diameter.

Exploring reflection phenomena with a mirror and two meter sticks or rulers in a dark room prompted a refinement of this ray model for light. *Light rays can be envisioned as traveling in straight lines until they hit a mirror and bounce away, with the angle of reflection equaling the angle of incidence*. Balls also bounce off walls and floors in this way, which suggests an elaboration of this model for light, that *rays can be envisioned as an on-going flow of particles, called photons, in straight lines*. An alternative model, representing light as waves, also can be helpful in explaining complex phenomena, as discussed in Unit 4.

Exploring refraction and dispersion phenomena prompted an additional refinement of this conceptual ray model for light. *When light rays move from one medium into another, such as from air into water or from water into air, the rays can be envisioned as traveling in straight lines that bend at the point of entering or leaving a medium. White light from the Sun can be envisioned as composed of many colors, with the degree of bending related to the color of the ray*. This refined conceptual model of light was powerful in explaining a complex phenomenon: rainbows!

C. Making connections to NGSS understandings about the nature of science

This unit has provided many examples of the nature of science as articulated in Appendix

H of the *Next Generation Science Standards* (NGSS, Lead States, 2013) https://www.nextgenscience.org/resources/ngss-appendices . Appendix H includes tables that provide insights about the development of these understandings about the nature of science across grade spans of K-2, 3-5 (elementary), 6-8 (middle school), and 9-12 (high school). Four NGSS understandings about the nature of science are related to the science and engineering practices.

One NGSS understanding about the nature of science, for example, is that s*cientific investigations use a variety of methods.* Children in grades K-2, for example, should understand that *scientists use different ways to study the world.* In this unit, for example, students have made observations using lamps, barriers, pinhole cameras, mirrors, cups of water, and prisms to explore what happens when light moves from one place to another.

Another NGSS understanding is that s*cientific knowledge is based on empirical evidence.* Students in grades 3-5, for example, should learn that *science findings are based on recognizing patterns.* In this unit, for example, students have explored patterns in what happens to shadows when someone moves a barrier closer or farther away from a light source.

Students experience in several ways the NGSS understanding that s*cientific knowledge is open to revision in light of new evidence.* Students in grades 6-8 (middle school), for example, should learn that *science explanations are subject to revision and improvement in light of new evidence.* In this unit, the central idea that *light can be envisioned as rays traveling in straight lines*, for example,was modified as the students explored what happens when light reflects from a mirror, refracts when entering and leaving a new material, and disperses if the light is composed of more than one color

K-8 development of the NGSS understanding that s*cience models, laws, mechanisms, and theories explain natural phenomena* ranges, for example, *from* s*cientists use drawings, sketches, and models as a way to communicate ideas* (K-2) to s*cience theories are based on a body of evidence developed over time* (middle school). In this unit, for example, students have learned how to use ray diagrams and central ideas based on evidence to explain a variety of phenomena. They also have had access to original descriptions of investigations of light conducted over several centuries.

XI. Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 1

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 1

***Exploring Physical Phenomena*: Summary of Equipment and Supplies for Unit 1**			
When used	For instructors and demonstration	For each group of 3	
Often	4 large whiteboards Set of white board markers and erasers 2 meter sticks Chart paper Masking tape Large whiteboard for class moon observations	1 large whiteboard, 1 meter stick, 1 plastic bin with set of magic markers; Example NSTA journal, NSTA newsletter, Children's books about light, thermal phenomena, weather, climate change (Need second meter stick for each group for exploring reflection in Unit 1)	Small w Whitel Whitel Half with w name p ____ /____
Unit 1 **Week 1** Day 1 **Q1.1 Exploring ways to foster science learning**	2 sheets chart paper on which volunteers alternately record findings reported by small groups about ways to foster science learning	Bin with above materials 1 sheet of chart paper on which group members draw pictures and record ways that fostered their own science learning	U1H1 W U1H2 S
If weather permits, go on field trip outside to start sky journals	Sky journal (see Unit 5, Question 5.6)		B U1H8 I about Sky J Questi
Q1.2 Diagnostic Question about Light	Bright lamp, no shade; Basketball with "stand" (masking tape roll)		U1H7 D Light H
Q1.3 – Q1.7 Exploring light and shadows	Large whiteboard Sheet of chart paper to cover whiteboard to serve as opaque screen Lamp with clear bulb so can see filament if available; otherwise frosted LCD bulb	Large whiteboard Sheet of chart paper to cover whiteboard to serve as an opaque 'screen' Shaded table lamp with bendable stem Barrier (board, book, or hand) U1H3 Exit ticket	U1H4 P Explana 2 U1H5 U1H9 Shadov Near cutout explor with fr

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 1			
Day 2 **Q1.9 – Q1.2 Exploring pinhole phenomena**:	Bright lamp with bulb that is not a sphere, no shade	Pinhole Exploration Envelope: (2 paper cups, 1 paper towel roll; 1 Al foil square, 3 wax paper squares, 6 rubber bands, 1 pin) (paper cups replace previous use of empty toilet paper rolls – they are clean, only need one rather than 2 ends added, and provide a larger projection) U1H3 Exit ticket	U1H5 P If remo empty or snac trans cereal Al fo bar wr paper 1 or 2 pin c U1H1 Pinhol end of
Week 2 Day 3 **Q1.16 Using pinhole phenomena to estimate diameter of Sun:**	Sunny day If not a sunny day: Bright lamp with bulb that is not a sphere, no shade Extra physics notebook pages if students have not brought their own	Pinhole Math Envelope (White paper on cardboard screen, cardboard holder with Al foil with pinhole; cardboard holder with wax paper screen if not a sunny day) U1H3 Exit Ticket	U1H11 S stated; U1H13 Proble U1H1 Hando end of
Day 4 **Q1.18 – Q1.20 Exploring reflection phenomena**:	(If there is a holiday during the term, combine reflection and refraction explorations)	Flashlight 2 meter sticks, yard sticks, rulers, or pencils Mirror Computer (provided; or laptop brought in by group member) Logger lite software TI Light Probe or other light sensor* ($16) or cell phone APP: LUX meter Interface** ($61) Reflectivity Envelope (samples of Al foil, cardboard, wax paper, colored paper including black, paper towel, dark cloth) U1H3 Exit Ticket	U1H1 (use ne
Week 3 Day 5 **Q1.21 Exploring refraction phenomena**		2 paper cups, one with dot Tray, straw or wooden stirrer U1H3 Exit Ticket	U1H1 (use ne

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 1			
Day 6 **Q1.23-1.24 Exploring dispersion phenomena and explaining rainbows**	Sunny day or bright lamp	Prism (note: CDs can make rainbows but this involves a different mechanism than dispersion) (sunny day or bright light) Red, blue, and black whiteboard markers U1H3 Exit Ticket	If remo prism glass p or acc water U1H (use ne U1H
* **https://www.vernier.com/products/sensors/tilt-bta/50/** **For example: Go!Link https://www.vernier.com/products/interfaces/go-link/**			

UNIT 2: EXPLORING THE NATURE OF THERMAL PHENOMENA

Exploring Physical Phenomena: What happens when light from the Sun shines on the Earth?

Unit 2 Table of Contents

Figures

Tables

I. Introduction

When light from the Sun shines on the Earth, things often get hot. This unit explores the nature of such thermal phenomena. Why, for example, do some things feel hot or cold? What is the difference between heat and temperature? How is energy conserved when mixing hot and cold water? While exploring the nature of thermal phenomena, you will be:

- ***identifying resources*** such as relevant language you use and experiences you have had
- ***developing central ideas based on evidence*** that you record in exploring how energy flows from hot to cold objects
- ***explaining an intriguing phenomenon*** such as why you might prefer sitting on wooden rather than metal risers in watching a soccer game late in the fall
- ***developing mathematical representations*** of the transfer of energy in various contexts
- ***using mathematical representations to estimate a quantity of interest*** such as how much cold water to add to a cup of tea too hot to drink and
- ***making connections to educational policy***, such as the *Next Generation Science Standards* (NGSS Lead States, 2013), the science standards adopted by many US departments of education.

During this unit, you will be learning about learning processes as well as about physics as you summarize and reflect upon your explorations. Also important will be integrating science and literacy learning such as speaking clearly, listening closely, writing coherently, reading with comprehension, and creating and critiquing media.

The main sections of the text present questions with suggestions for exploring topics and for writing reflections about your findings. Text in gray font indicates that these are suggestions; you may think of other ways to explore the topic. You are encouraged to ask and explore your own questions about thermal phenomena as well as those posed here. Check with your instructor if you choose to devise an alternative approach.

Much of the learning will occur within small groups as you and your group members talk with one another about what you are thinking and why. Keeping track of what one is doing and thinking is important. This course uses a template for a physics notebook page on which to record notes during class. The physics notebook page can help you remember your thoughts *before*, *during*, and *after* an exploration. An experienced elementary teacher, Adam Devittt, designed this notebook page to mirror the structure of *before*, *during*, and *after* reading strategies.

Before starting an exploration, think about and discuss with your group members what you know already about the topic, what questions you are asking, how you plan to conduct the exploration, and what you think you might find out.

During your exploration, record what is happening, what you are observing, and what you are thinking about what you are observing. Include sketches of equipment and observations. Note any words that are new and their definitions.

After your exploration, record any central ideas that have emerged from your observations and discussions. Also note the evidence on which you have based these ideas. In addition, provide a rationale that states explicitly how the evidence is relevant and supports the claims you are making in stating the central ideas. Also explain why this result is important. Then write a reflection about whatever you want to remember about this experience. In addition, briefly state what you are still wondering in this context.

After class, use your physics notebook pages and any handouts to write a summary of your exploration and findings. Writing such a summary after every class is a good way to prepare for the midterm and final examinations.

Next, to be sure you have understood the physics involved, read this text and some examples of student work. The student authors first wrote drafts, received feedback for ways to enhance content and clarity, and submitted these final versions. Also read about some nuances to consider when explaining the phenomena explored.

You also may find helpful student reflections about teaching a friend or family member about what they had just learned in class, historical information about ways knowledge about the topic developed, and some relevant aspects of the nature of science in the context of the topic explored. These sections of the text may broaden your understanding of science and of science learning and teaching.

II. Identifying Student Resources

Young children learn to stay away from hot stoves, to get mittens when going outside to play in the snow, and to sip carefully before drinking from a cup of hot cocoa when they come back inside. Such experiences can serve as resources on which to build when studying about thermal phenomena.

A. Connecting to what one already knows about thermal phenomena

One way to begin learning about a topic is to consider relevant everyday experiences and the language used to describe them:

Question 2.1 What are some everyday experiences you have had with thermal phenomena?

- How do you keep things hot or cold for a picnic?
- Adjust the temperature of water for a bath?
- Cook dinner?

Like many English words, the adjective *thermal* derives from a Greek root, in this case: *thérme*, which refers to *heat*.

- What words with the root thérme do you know?
    - What do you use to measure temperatures?
    - How do you keep a liquid hot or cold?
    - What controls how much heat a furnace delivers to a room?
    - What is the medical condition in which a person loses heat faster than the body can produce heat?

Everyday experiences with thermal phenomena may include using *thermometers* to measure temperatures, storing hot or cold liquids in a *thermos*, adjusting a *thermostat* to increase or decrease the amount of heat delivered to a room, and taking care to avoid *hypothermia* while hiking in cold and/or wet weather.

The formal name for the focus of this unit is *thermodynamics*. This is the study of energy in the form of heat (*thermo*) and ways such energy flows within a system (its *dynamics*). Thermodynamics is the study of what happens when things warm up or cool down.

- Record some of your experiences with thermal phenomena before reading examples of student work.

1. Examples of student work identifying everyday connections to thermal phenomena

A student reflected on relevant resources as follows:

> *The elementary students in my classroom will experience thermal phenomena in their everyday lives. They will experience the warmth of the sun on their faces, the coldness of metal handrails in the winter, and hot pavement in the summer. Students who take baths may also be aware of what happens when you combine a lot of hot water with some cold water – the water temperature lowers, but is still on the warmer side.*

Physics Student, Spring 2015

Another student wrote about an early experience that she had had:

> *I can remember being a young child and running to be the first in my classroom so that I could get a good seat. The good seat was not only close to the front, but it was a wooden chair, so it did not feel as cold as some of the metal and plastic chairs in the room.*

Physics student, Fall 2015

Such memories provide useful examples of thermal phenomena to be explained.

B. Documenting initial ideas with diagnostic questions about thermal phenomena

One way we make sense of the world is through observations, what we see, hear, smell, taste, and feel. These observations provide evidence that we can think about and interpret in different ways. The diagnostic questions below document some of your initial ideas about thermal phenomena and will not be graded.

Name_________________________________ Date______________

Diagnostic Questions about Thermal Phenomena

1. Consider (without touching) materials you may have at home such as an aluminum pie pan, steel can opener, Styrofoam or paper cup, and wooden salad fork – or four blocks made of such materials: an aluminum block, a steel block, a Styrofoam block or pad of paper, and a wooden block.

   Rank these in order of temperature. Explain the reasoning for your predicted ranking.

2. Touch the four materials. Rank these in order of temperature.

   Explain the reasoning for your ranking.

III. Developing Central Ideas Based on Evidence

What does it mean to develop an idea based on *evidence*? This is a practice central to doing science, to observe phenomena closely, record findings, and make sense of these results in ways that explain what is happening. Why, for example, would a child seek as a "good seat" a chair made out of wood rather than metal?

A. Developing central ideas about thermal phenomena

Some things feel cool when you touch them; other things not so much. How do their temperatures compare when measured with a thermometer?

Question 2.2 How would you rank different materials in order of temperature?

- Without touching, consider different kinds of materials often found in kitchens:

FIG. 2.1 *Examples of aluminum, steel, Styrofoam or paper, and wooden materials*

Equipment: Kitchen items such as aluminum pie pans, steel can openers, Styrofoam or paper cups, and wooden salad forks are often accessible but all have difference sizes and shapes. To simplify thinking about these materials, also consider using four blocks of about the same size and shape made out of aluminum, steel, Styrofoam or paper, and wood. Also obtain a bulb and tube thermometer, digital temperature probe, or cell phone APP that measures everyday temperatures (rather than just human body temperatures) to measure the items' temperatures after you have ranked them.

- Rank these materials in order of temperature.
- Explain the reasoning for your predicted ranking.

When all of your group members are ready:

- Touch the materials. Rank them in order of temperature.
- Explain the reasoning for your ranking.
- Talk with your group members about your rankings and reasoning.

If you want to record some of their ideas or change yours, leave your initial responses unchanged on the front of your paper and write instead on the back

- Try to come to consensus for ranking these materials in order of their temperatures. How do you as a group explain these observations based on touching the blocks?

- Measure the temperature of all of the items with a thermometer.

There are several ways to measure the temperature of objects. One simple way is to place a thermometer on each object in turn. One also can use a set of objects made out of different materials with a hole drilled in each to hold a thermometer as shown in Fig. 2.2

In using a regular glass bulb and tube thermometer, it is important to hold on to the thermometer near the top so one's hand does not affect the reading. Also keep holding the thermometer while waiting for the reading to stabilize so that the thermometer does not fall over and break.

Fig. 2.2 Styrofoam, wood, and two kinds of metal blocks and a thermometer.

- What is your ranking in order of temperature reading?
- Explain the reasoning for your ranking.
- Talk with your group members about your rankings and reasonings.

If you want to record some of their ideas or change yours, leave your initial responses unchanged on the front of your paper and continue writing instead on the back.

- Try to come to consensus for ranking these materials in the order of their temperatures.
  How do you as a group explain these observations based on measurement with a thermometer?

- Write a summary of your findings and explanation.

After completing your own summary, look at an example of student work

1. *Example of student work about how different materials feel to the touch*

Many students report feeling confident that the Styrofoam feels warmest and the metal feels coolest, based on prior experience with these materials as well with actually touching them now. There usually are some differences of opinion about how to rank the Styrofoam and wooden blocks and in what order to rank the steel and aluminum metal blocks.

One student described her experience in ranking the temperature of the four blocks after she touched them as follows:

> *Four blocks were laid out in front of me. I touched all four of the blocks and I noticed that they all felt like they were different temperatures. The two metal blocks felt the coldest, the wood block felt warmer than the metal blocks, and the Styrofoam block felt the warmest. Since these different materials all felt like they were different temperatures when I touched them, this is evidence that materials differ in how hot or cold they feel to the touch.*
>
> Physics Student, Spring 2016

Another student described what happened when her group used a thermometer to measure the temperatures of the four blocks. The scale of the thermometer was marked in degrees Celsius. This temperature scale is named after Anders Celsius (1701-1744), a Swedish scientist who defined a scale of a hundred degrees between the freezing and boiling points of water. On the current Celsius scale used world-wide, the freezing point of water is 0°C, room temperature is in the neighborhood of 20°C, human body temperature is about 37°C, and the boiling point of water is at 100°C at standard atmospheric pressure. For a summary of the history of measuring temperatures, see https://www.britannica.com/technology/thermometer#ref227799.

The student reported the following experience:

> *Students were then asked to flip over the plates and found that each one had a small hole drilled into it. Each table was then given a thermometer and asked to measure the temperature of the plates. Our table measured first the wood and Styrofoam and found both to be 24 ^{O}C. I thought that potentially there was something wrong with my thermometer, so I warmed it up to 30 ^{O}C and then placed it into a hole on one of the metal plates. The temperature went down and read 24 ^{O}C. I could*

not believe it. So I tried again with the thicker plate of metal and once again the temperature was measured to be 24 °C.

Physics Student, Fall 2015

Most groups are surprised to find that all the materials are at about the same temperature. The metal feels cool and the Styrofoam feels warm but the thermometer readings for the temperature of the metals, wood and Styrofoam are nearly or exactly the same! How can this be!

One possibility is that the thermometer is broken. That is readily tested by holding the thermometer's bulb in one's hand. The liquid in the thermometer's tube usually rises quickly with a warm hand on the bulb. Another possibility is that the thermometer is working properly and that the blocks are actually at or nearly at the same temperature.

Question 2.3 Why do some materials feel warmer or cooler than others?

- Talk with your group members about some possibilities for why the materials are all at the same temperature even though some feel warmer or cooler than others.
- Share your ideas with other groups. Listen closely to ideas that other groups are proposing.
- Talk with your group members about any suggestions from the other groups that seem helpful. Refine your group's ideas or pursue some new possibilities for explaining what was happening when you touched the different materials.
- Share your current ideas with the other groups. Listen closely to ideas that other groups are proposing now.
- Keep talking and refining ideas until your group and the other groups reach a consensus on some central ideas about what must be happening in order for the materials to have the same temperature but to feel so different when touched.
- Write a summary of the central ideas based on evidence that emerged from the small group conversations and whole group discussions.

After completing your own summary, look at an example of student work about thermal phenomena, nuances in exploring how hot or cold different materials feel to the touch, and some thoughts about the nature of science in this context.

1. Example of student work about developing central ideas based on evidence about

A student interpreted the surprising finding that materials can feel different even if at the same temperature as follows:

> *…the thermometer did not read a different temperature for any of the four plates. This made students realize that since each of the plates was found to have the same temperature, that they were all at room temperature. Essentially each of the plates had been left for a long time untouched in the room and had not had a heat source or sink that would have affected them. This means that they all were the same temperature.*

Physics Student, Fall 2015

Usually while discussing why the blocks are all at the same temperature, someone eventually utters the phrase *room temperature*. Occasionally someone will use the phrase *ambient temperature*. This has a more general meaning referring to the temperature of surroundings, sometimes used to refer to the temperature of the air surrounding a big computer. Once uttered, the phrase *room temperature* shifts most students from puzzlement to acceptance of the finding that the four blocks are all at the same temperature.

What remains is puzzlement about why the blocks feel so different even though they are all at room temperature.

The small group reports of current thinking may range from "I have no idea" to thoughts that hint at the next step. Someone, for example, may say something about hands being warmer than all of the blocks and someone else may struggle to express an idea about the materials of the different blocks being different in some way, hinting at the idea of a particular property of the materials that is making a difference.

Having heard these still-emerging ideas hesitatingly expressed, the small groups may make some progress if given another opportunity to talk with one another. Another round of reporting out may yield a well-articulated explanation that the class as a whole then adopts. This student, for example, continued with such an explanation:

> *Students were surprised to find that all of the plates were the same temperature, because when they placed their hands upon them, they could feel that the plates were colder or warmer than one another. What students came to realize is that what they were feeling was energy transfer by conduction. Essentially the metal objects are conductors of heat, which means that the energy from the students' hands was*

flowing from their palm into the metal…which left our hand feeling colder as the energy was leaving.

In this experiment, the students found that metal was a conductor, meaning that the metal transfers energy more quickly and has a high thermal conductivity. However, the Styrofoam, a substance often used for coolers, is an insulator, meaning that it has a low thermal conductivity, meaning that it transfers energy more slowly so it can keep hot things hot and cold things cold.

Physics Student, Fall 2015

The rounds of conversations that result in such a clear statement of what is happening take time, but they seem to help students make sense of what may have been a very puzzling experience. A goal of this course is to raise issues but to have students resolve these issues through small group conversations and whole group discussions. The intent is to create opportunities for students to experience science in ways similar to the ways that scientists experience science, as both interesting and comprehensible.

2. Nuances in exploring how hot or cold different materials feel to the touch

Students who held the bulb of their thermometer in their hands noted that the temperature indicated by the thermometer was higher than the temperature that the thermometer indicated for the four materials. They observed that there was a *temperature difference* between their hands and the blocks and inferred that *energy flowed from their hotter hands into the metal blocks*, which lowered the temperature of their hands.

The inference that energy flows only from hot to cold can be hard to accept because prior experiences may suggest a different direction. When one is sitting on a metal bleacher at a late fall soccer game, for example, the perception likely is that cold is seeping into one's body. However, the inference here is that what is actually happening is that one's body heat is flowing out into that entire metal bleacher!

The metal blocks felt cold; the Styrofoam felt warm. The inference is that the metal blocks differed from the Styrofoam in the *property of how easily the metal blocks conducted energy away from the students' hands*, the property of *thermal conductivity*.

The inference is that more energy flowed out of the students' hands into the metal blocks than into the Styrofoam block. The energy flowing into the metal blocks spread rapidly throughout the blocks; the metal blocks had a higher thermal conductivity. The students' hands lost more energy to the metal blocks and therefore felt cold when touching the metal blocks.

Another inference is that the energy flowing into the Styrofoam blocks did not spread throughout the Styrofoam blocks but stayed near where the hands were touching the blocks. The students' hands lost very little energy to the Styrofoam blocks and therefore their hands continued to feel warm

This introduces central ideas about the *transfer of energy* from hot to cold objects and the ease with which such energy transfer occurs. The inference is that energy flows quickly through materials that are *conductors*, which have a high *thermal conductivity*; energy flows slowly through materials that are *insulators*, which have low thermal conductivities.

Note that both judgments about the four blocks were based on evidence. Students produced rankings that differed based on observations made by touching the blocks. Students produced rankings that were the same based on observations made with a thermometer.

The usefulness of the rankings would depend upon the purpose. If one is choosing a material on which to sit on a cold day, rankings in terms of *thermal conductivities* would be helpful. If one is interested in the temperature of a room (without a heat source or sink), one could choose to use a thermometer to measure the temperature of an object made with any of these materials, the number obtained would be the same, or close to the same, for all. (Holding the object for a long time while making the measurement might change its temperature if the object has a high thermal conductivity.)

3. Some thoughts about the nature of science in this context

Science involves making judgments based on evidence. One needs to be aware, however, both of the nature of the evidence and its appropriateness for answering a question. When puzzlements occur, one may need to clarify ambiguities in formulating the question as well as in designing an exploration. Asking *How would you rank different materials in order of temperature?* turns out not be answerable by ranking materials by how they feel to the touch. Underlying the mismatch of that question with the suggested procedure is a conceptual distinction between heat and temperature.

B. Clarifying distinctions between closely related ideas

If something seems puzzling, one way to seek a better understanding is to ponder ideas that seem closely related, are they the same or different?

Question 2.4 What is the difference between the concepts of heat and temperature?

A useful way to organize outcomes is to review the set up, evidence, and relevant vocabulary for central ideas that emerge from explorations and discussions, as in Table II.1

- Clarify for yourself the difference in the meaning of the words *heat* and *temperature* in the context of physics by completing the following table:
    - Make a sketch of the set up with the four different materials
    - Note the evidence of how the materials felt when touched and what their temperatures were as measured by a thermometer
    - Define any relevant vocabulary.
    - Then write a summary of the central ideas about thermal phenomena developed so far in this unit.

TABLE II.1 Developing central ideas about thermal phenomena.

TABLE II.1 Explorations of Thermal phenomena			
Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
		Materials differ in how hot or cold they feel to the touch	
		Temperature is measured by a thermometer	
		Materials left for a long time without a heat source or sink in the room come to the same temperature, room temperature	Room temperature

		A temperature difference implies a flow of energy from hotter objects to colder objects. When the objects are touching, this process is called *energy transfer by conduction.*	Conduction
		Materials differ in their thermal properties such as how well they conduct energy throughout the material, their *thermal conductivity*. Conductors have high thermal conductivities. Insulators have low thermal conductivities.	Thermal Conductivity Conductors Insulators
		Heat and temperature are different ideas	

After completing the table above and summarizing your understanding of each central idea, look at an example of student work.

1. Example of student work clarifying the meaning of the words heat and temperature

Figure 2.3 shows one student's notes for the table above. Also presented is this student's summary of the central ideas about thermal phenomena developed so far in this unit.

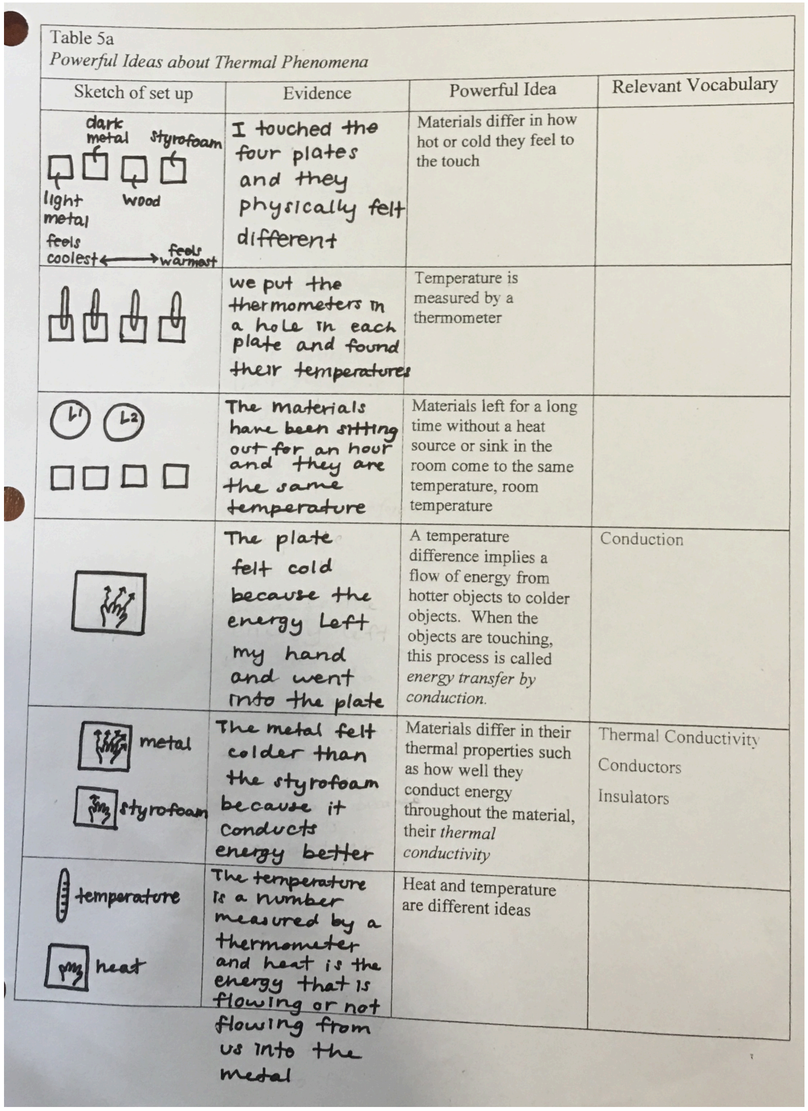


Table 5a
Powerful Ideas about Thermal Phenomena

Sketch of set up	Evidence	Powerful Idea	Relevant Vocabulary
dark metal, Styrofoam, light metal, wood; feels coolest ⟷ feels warmest	I touched the four plates and they physically felt different	Materials differ in how hot or cold they feel to the touch	
	we put the thermometers in a hole in each plate and found their temperatures	Temperature is measured by a thermometer	
L1, L2	The materials have been sitting out for an hour and they are the same temperature	Materials left for a long time without a heat source or sink in the room come to the same temperature, room temperature	
	The plate felt cold because the energy Left my hand and went into the plate	A temperature difference implies a flow of energy from hotter objects to colder objects. When the objects are touching, this process is called *energy transfer by conduction.*	Conduction
metal, styrofoam	The metal felt colder than the styrofoam because it conducts energy better	Materials differ in their thermal properties such as how well they conduct energy throughout the material, their *thermal conductivity*	Thermal Conductivity Conductors Insulators
temperature, heat	The temperature is a number measured by a thermometer and heat is the energy that is flowing or not flowing from us into the metal	Heat and temperature are different ideas	

FIG. 2.3 Student's entries describing the initial exploration of thermal phenomena.

For "sketch of the set up" in the first row, this student drew the four blocks in order from "*feels coolest*" on the left to "*feels warmest*" on the right and labeled the blocks "*light metal*, *dark metal*, *wood*, *Styrofoam*." For evidence, the student wrote "*I touched the four plates and they physically felt different.*"

In the second row, the student drew four blocks with four thermometers and wrote "*We put the thermometer in a hole in each plate and found their temperatures.*"

In the third row, the student drew the four blocks and two wall clocks showing the times of 1 and 2 o'clock. The student wrote, "*The materials have been sitting out for an hour and they are the same temperature.*"

In the fourth row, the student drew a picture of a block and hand, with a representation of energy flowing out of three of the fingers of the hand into the block. The student wrote, "*The plate felt cold because the energy left my hand and went into the plate*."

In the fifth row, the student drew a picture of two blocks, each with a hand touching the block. The hand touching the metal block has a representation of energy flowing out of four fingers; the hand touching the Styrofoam block has a representation of energy flowing out of only one finger. The student wrote, "*The metal felt colder than the Styrofoam because it conducts energy better*."

In the sixth row, the student drew a picture of a thermometer and labeled it "*temperature*" and a picture of a block with a hand on it and labeled "*heat*". The student wrote : "*The temperature is a number measured by a thermometer and heat is the energy that is flowing or not flowing from us into the metal*."

The student wrote the following rationales for the central ideas claimed in the third column of the table:

> ***Materials differ in how hot or cold they feel to the touch***. *Four blocks were laid out in front of me. I touched all four of the blocks and I noticed that they all felt like they were different temperatures. The two metal blocks felt the coldest, the wood block felt warmer than the metal blocks, and the Styrofoam block felt the warmest. Since these different materials all felt like they were different temperatures when I touched them, this is evidence that materials differ in how hot or cold they feel to the touch.*
>
> ***Temperature is measured by a thermometer.*** *The thermometer that we used to measure the temperatures of the four blocks was long and narrow and had rounded edges. The thermometer was made out of glass and it measured the temperatures in degrees Celsius.*
>
> ***Materials left for a long time without a heat source or sink in the room come to the same temperature, room temperature***. *The four blocks of different materials were laid out for a long time without being touched at all. There were no heat sources or sinks in the room. This allowed the blocks time to sit in room temperature.*
>
> *Each of the four blocks had a small hole in it that allowed the thermometer to sit inside of the material. To measure the temperature of each of the blocks, I held the thermometer in the hole for a minute by holding it at the top so that my hand did not affect the temperature. After waiting for a minute for the thermometer to finish reading the temperature of the material, I recorded the temperature of each of the blocks.*
>
> *The light-colored metal block was 18°C, the dark-colored metal block was*

18.25-18.5°C, the wood block was 18.5-18.75°C, and the Styrofoam was 19°C. Even though the blocks differed in how hot or cold they felt to the touch, the readings are all within 1°C of each other. Because the readings on a thermometer for the four blocks of different materials were all relatively the same temperature, room temperature, this is evidence that materials left for a long time without a heat source or sink in the room come to the same temperature, room temperature.

A temperature difference implies energy is flowing from hot objects to colder objects. *Four blocks that are room temperature were laid out in front of me. We know that the blocks are room temperature because they were left for a long time without any heat source or sink in the room.*

When students touched the blocks, they noticed that some felt colder or warmer than others. Human body temperature is warmer than room temperature, so my hand is warmer than the blocks. When I touched the metal block it felt cold. There is a difference in temperature between my hand and the metal block, which is what allowed energy to flow from the warmer object, my hand, to the colder object, the metal block. Energy leaving from my hand to the metal block made my hand feel cold. Metal has high thermal conductivity, so energy is quickly transferred from my hand and I feel the temperature difference right away.

The wood and the Styrofoam are insulators, so they have lower thermal conductivity. Because the transfer of energy takes longer for these materials, there is less energy flowing, and as a result my hand does not feel as much of a temperature difference.

Energy transfer by conduction, in this context, refers to the rate that energy is transferred by touch between two objects, such as a hand and a metal block. Energy is transferring from my hand to the blocks, because they are different temperatures. My body temperature is warmer than the metal block and when I touch the metal block my hand feels cold, which is evidence that a temperature difference implies energy is flowing from hot objects to colder objects.

Materials differ in their thermal properties such as how well they conduct energy throughout the material*. Thermal conductivity is referring to the rate or speed that energy is transferring between two objects when they touch. First of all, metal is a conductor. When I felt the metal, it felt the coldest out of the four blocks. Since the metal has high thermal conductivity, it rapidly transfers energy. So, when I touch the metal, energy leaves my hand quickly, so there is a lot of energy flowing, therefore leaving me to feel a big temperature difference between the object and my hand.*

Next, the wood and the Styrofoam are insulators. The wood and the Styrofoam have low thermal conductivity, so they slowly transfer energy. Styrofoam transfers energy slowly so that it can keep hot things hot and cold things cold, which is why it is often used for coolers. Since it takes a while for all of the energy to transfer from my hand to those materials, there is less energy flowing and I feel less of a temperature difference between the object and my hand.

So, because metal which is a conductor and wood and Styrofoam which are insulators feel like they are different temperatures to the touch, this tells us that they conduct energy at different rates. This difference in rates for conducting energy is evidence that materials differ in their thermal properties such as how well they conduct energy throughout the material.

Heat and temperature are different ideas. *…Temperature is a number measured in degrees. In class we used a thermometer to measure the temperature of the different blocks. According to the thermometer, the temperature of the light- colored metal block was 18°C, the dark colored metal block was 18.25–18.5°C, the wood block was 18.5–18.75°C, and the Styrofoam was 19°C. So, the numbers measured by the thermometer were the temperatures of the blocks.*

Heat can be thought of as a feeling, for instance the metal blocks felt colder than the other blocks, however what the students are feeling is the transfer of energy. Heat is the energy that is flowing or not flowing from us into the metal. So, when I touched the metal with my hand, the energy from my hand rapidly transferred to the metal because it is a conductor. The heat is what one feels because of the transfer of energy from one thing to another. Less energy was flowing from my hand to the wood, and even less to the Styrofoam, because they are insulators and are slower at conducting energy.

Because the different materials felt like they were different temperatures, the rate of the energy flow of each of the materials is different. Even though the rate of the energy flow of each material is different, the temperatures on the thermometer are all within 1°C of each other. So, since the thermal conductivity of the materials are different while the temperatures of the materials are about the same; this is evidence that heat and temperature are different ideas.

Physics student, Spring 2016

This student recognized that even though the measured temperatures were in the expected direction, with the Styrofoam block's temperature slightly higher than the light-colored metal block's temperature, a measured difference within 1°C could not explain the very large difference felt when touching these materials. The inference is that the large difference in how these materials felt to the touch was due to a large difference in a property of the materials, in how well they conducted energy from warm hands, their *thermal conductivities*.

Styrofoam is an insulator; it has a low thermal conductivity. Energy flowing from a warm hand to the Styrofoam stayed where the hand was touching the Styrofoam; therefore, energy stopped flowing from the hand to the Styrofoam when the hand and the small place where the hand was touching the Styrofoam became the same warm temperature. The rest of the Styrofoam remained near room temperature.

The metals, however, are conductors; they have high thermal conductivities. Energy flowing from a hand to the metal continued flowing and spreading throughout the metal block. Energy continued to flow from the hand, noticeably cooling the hand so the metal felt cool.

IV. Using Central Ideas about Thermal Phenomena to Explain an Intriguing Phenomenon

One aspect of the nature of science is its use of central ideas based on evidence in developing explanations of intriguing phenomena. The central idea that materials differ in the property of thermal conductivity can explain why some materials feel cooler than others even though they are the same temperature.

A. Applying the property of thermal conductivity in an everyday context

Question 2.5 Why do the metal legs of a chair feel cooler than its plastic seat?

- Use the central idea about thermal conductivity to explain this observation.
- Also engage a friend or family member in learning about such thermal phenomena.

Complete your responses before reading an example of student work.

1. Example of student work explaining an intriguing thermal phenomenon

After discussing the difference between heat and temperature, a student wrote:

> *The ideas above can help explain why metal parts of a chair feel colder than the plastic seat even though both parts of the chair have been in the same room for the same amount of time. One important idea to remember is that the metal part and the plastic part are the same temperature, regardless of how they feel. The metal part of the chair is a conductor so the heat from our bodies transfers quickly to the metal,*

leaving our hand feeling cold. However, plastic is not as conductive; the heat from our bodies takes longer to transfer to the plastic so our hand feels warmer.

I invited my friend to explore thermal phenomena with me. I engaged my friend in thinking about the difference between heat and temperature by adapting the activity we did in class with materials that I had in my house. I provided her with a metal spatula, a wooden spoon, and a Styrofoam coffee cup. I asked her to feel each of the objects and rank these materials by temperature and to roughly estimate what the temperature of each object was. She, like many of us in class, gave a clear ranking and suggested that the temperatures of each object were dramatically different.

I then explained, because I did not have a thermometer to prove it, that each of the materials was the same temperature. She looked at me puzzled and bluntly asked why they felt so obviously different. I explained to her, like it is stated above, that the materials act as conductors, some better than others, and that the rate the heat is transferred determines how it feels to us.

She then told me that she had learned about this before, but it had not stuck with her. So hopefully this will.

Physics student, Spring 2016

This is a typical report, that the friend or family member ranks the items by how hot or cold the items feel, expresses surprise when shown or told that the items are at the same temperature, recognizes the explanation that all are at room temperature but differ in how well they conduct energy throughout the material, and notes a lack of retaining learning that had occurred earlier.

V. Developing Additional Central Ideas about Thermal Phenomena

There are many ways to explore thermal phenomena. Thermometers are useful tools and come in many forms, based upon many different physical processes that depend upon how some change occurs with a change in temperature. This course uses digital temperature probes. Students can use regular bulb and tube thermometers that measure everyday temperatures (rather than only warm body temperatures), however, such as those that are typically available in schools.

A. Exploring thermal phenomena with technology

Students can see visually what is happening moment-by-moment on a graph of temperature versus time when using digital temperature probes connected to a computer. Students also can use regular bulb and tube thermometers in the explorations that begin with Question 2.7 below. Students using regular thermometers can become aware of what is happening moment-by-moment by viewing the figures below.

Equipment for each group:

• Provide two digital temperature probes that can be connected to a computer loaded with the relevant software, two regular bulb and tube thermometers and a stop watch, or a cell phone temperature app. Several technology companies such as pasco.com and vernier.com provide digital temperature probes. For example, we use Go!Temp probes (see https://www.vernier.com/products/sensors/temperature-sensors/go-temp/) that connect to a computer or other electronic device through free software, such as Logger Lite (http://www.vernier.com/products/software/logger-lite/#download).

•Provide a computer to use with the digital temperature probes. In our course, usually at least one student in a group can bring a laptop on days a computer is needed. We also have two netbooks that students can use or two groups can work together with one computer if necessary.

• To begin explorations, provide each group with a cup of cold water to cool the probe

quickly. The students can use their hands to warm up the probe or a cup of hot water. Place the cup(s) of water on a tray well away from the computer.
• Also provide a towel in case of spills.

The first exploration is very open-ended, in order to help students become familiar with using the temperature probes.

Question 2.6 What can you find out about thermal phenomena with a temperature probe connected to a computer?

This initial open-ended exploration provides time to learn how to set up the computer, download the software, plug in the temperature probe, and *play*. You and your group members have access to yourselves as heat sources and whatever is around you as materials.

- What questions can you ask and answer by playing in various ways with a temperature probe connected to a computer? Use a physics notebook page to keep track of what you are asking, doing, and thinking.

As shown in Fig. 2.4, the computer will be plotting a graph of temperature in degrees Celsius versus time in seconds. To start the computer program using Go Temp! probes, click on the little green box near the middle of the top of the screen.

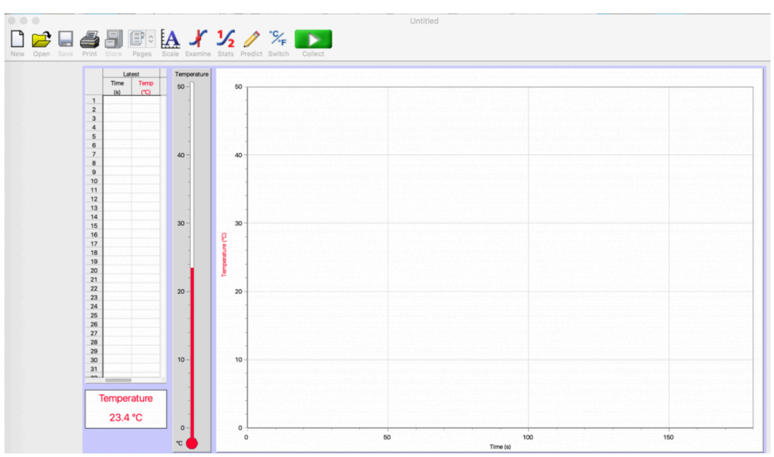


Fig. 2.4 Computer screen for displaying thermal explorations. ©Vernier Software & Technology-used with permission.

- How can you make letters on the screen as in Fig. 2.5: A letter *m*? A broad curvy *m*? A narrow sharp peaked *m*? A letter *w*? Any other letters? Use your hand to warm the probe and a cup of tap water to cool the probe quickly.

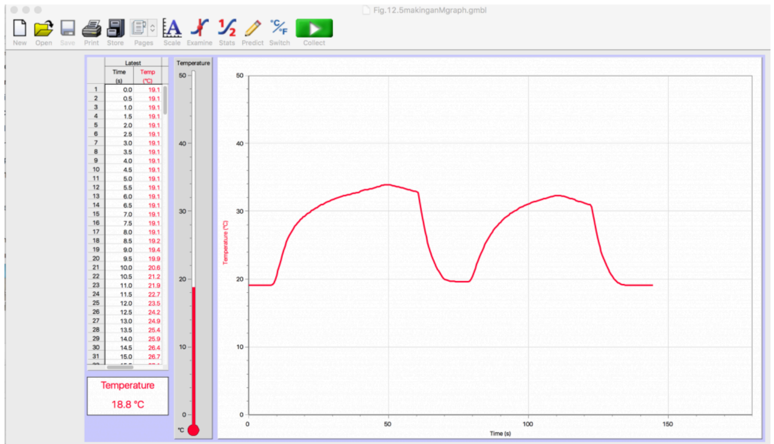


Fig. 2.5 Using a temperature probe to make a letter m on the computer screen. ©Vernier Software & Technology-used with permission.

After a while, add a second probe and a cup of hot water as well as cold.

- What questions can you ask and answer by varying the temperatures of the two temperature probes?

Artists may enjoy creating colorful designs with one probe drawing a red line and the other probe drawing a blue one to represent temperatures changing in different ways.

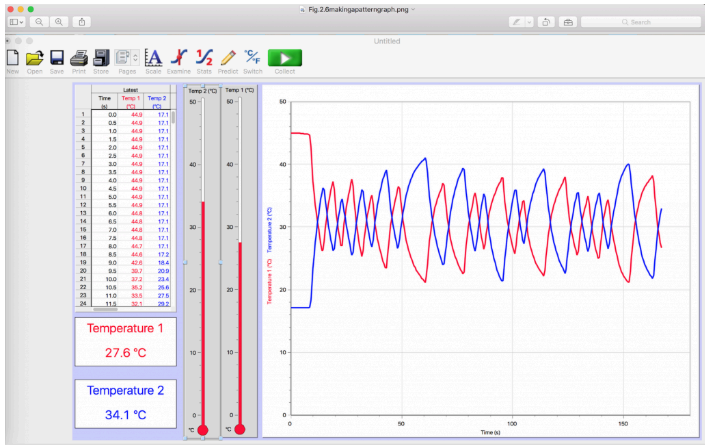


FIG. 2.6 Making a design with two temperature probes and hot and cold water. ©Vernier Software & Technology-used with permission.

- Discuss with your group members how to interpret the graph that you are seeing. How, for example, might students have made the graph shown in Fig. 2.6?

B. Exploring thermal phenomena with everyday materials

One activity most children enjoy at home, at school, and at the beach is playing with water. Explorations that involve mixing hot and cold water can be a logistic challenge but provide an engaging context for additional explorations of thermal phenomena.

For a series of explorations in mixing hot and cold water, use for each group of students:

- two temperature probes (or regular thermometers)
- clear plastic cup with lines indicating 1, 2, 3, or 4 parts for measuring (or a set of measuring cups),
- large Styrofoam cup or ceramic coffee mug for hot water,
- clear plastic cup for cold water,
- quart Styrofoam or plastic containers for storing hot and cold water,
- large container for storing water when finished with a trial

- tray large enough for holding the cups involved in mixing hot and cold water,
- towels in case things spill.

Place the tray and containers of water on a separate area or table from the computer to protect the computer in case of spills.

Question 2.7 What happens when you mix various amounts of hot and cold water?

- Explore thermal phenomena more systematically by mixing hot and cold water. In the *Before* section of a new physics notebook page sketch predictions for graphs that will appear on the computer screen when you mix hot and cold water in the following ways:

  a: Equal amounts at same temperature

  b: Equal amounts at unequal temperatures

  c: Unequal amounts at same temperature

  d: Unequal amounts at unequal temperatures: more hot than cold

  e: more cold than hot

- Discuss and agree on the details of how you will be doing the mixing:
  - What type of cup will you use for the hot water. Why?
  - Will you pour the cold water into the hot water or pour the hot water into the cold? Why?
  - How will you measure how much hot and cold water you are using?
- Place one temperature probe in the hot water; the other in the cold water.
  Click on the green box at the top of the computer screen to start the program.

As you pour the cold water into the hot water, also transfer its temperature probe so

that both temperature probes are now in the mixture of hot and cold water.
If you are using bulb and tube thermometers, place one in the hot water and one in the cold water. Record both temperatures. Also record the temperature of the mixture of hot and cold water.

- In the *During* section of your physics notebook page, record the graphs obtained by mixing the various amounts of hot and cold water specified above.
- Also record and define any new vocabulary relevant to this exploration.

- Discuss with your group members how to describe these graphs in words.
  What central ideas about mixing hot and cold water can you generate from this exploration?

- In the *After* section of your physics notebook page, state central ideas that have emerged from this exploration and the evidence on which they are based.
- State a rationale that explains how the evidence supports these ideas and why these are important.
- Add a reflection about what you want to remember about this exploration, how you might use this in your own classroom, what you learned about science learning and teaching…
- What are you still wondering?

A useful way to organize outcomes is to record the set up, evidence, and relevant vocabulary for central ideas that emerge from explorations and discussions, as in the continuation of Table II.1.

TABLE II.1 Developing central ideas about thermal phenomena (continued)

TABLE II.1 Explorations of thermal phenomena (continued)			
Sketch of set up/ graph	Evidence	Central Ideas	Vocabulary
		When liquids are mixed, they reach an equilibrium temperature.	
	Report findings for: • equal amounts, same T • equal amounts at different temperatures • unequal amounts, same T; • unequal amounts at different temperatures: • more hot than cold • more cold than hot	The equilibrium temperature depends on the initial temperatures and amounts of the liquids.	

- Complete the continuation of Table II.1 and write a summary of what you learned from this exploration.

After completing Table II.1 and your summary, look at an example of student work, nuances about exploring thermal phenomena by mixing hot and cold water, and some thoughts about the nature of science in this context.

1. Example of student work about mixing hot and cold water

A student summarized the exploration involving mixing hot and cold water as follows:

(The table) shows the experiments that we conducted in order to answer our questions and it also displays the ideas that were developed based upon these experiments.

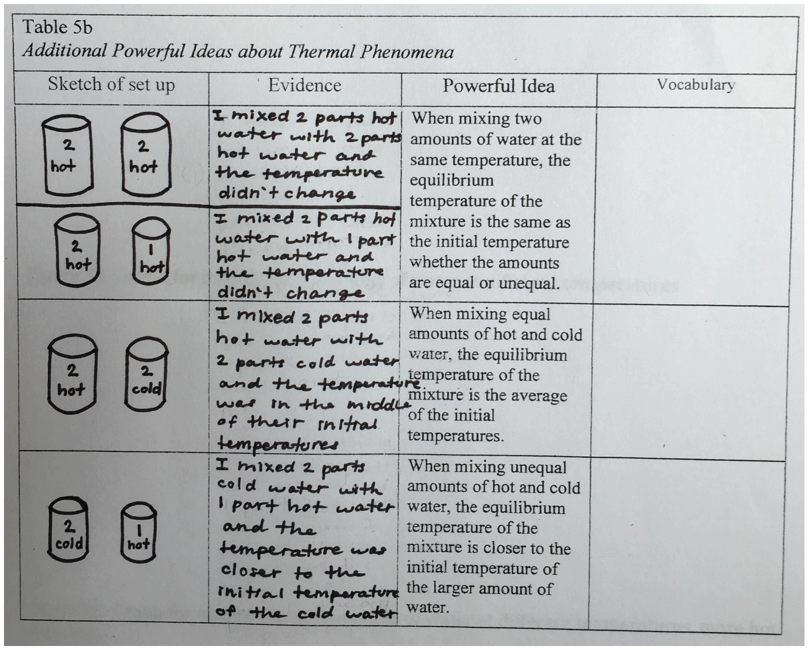


Table 5b
Additional Powerful Ideas about Thermal Phenomena

Sketch of set up	Evidence	Powerful Idea	Vocabulary
2 hot, 2 hot	I mixed 2 parts hot water with 2 parts hot water and the temperature didn't change	When mixing two amounts of water at the same temperature, the equilibrium temperature of the mixture is the same as the initial temperature whether the amounts are equal or unequal.	
2 hot, 1 hot	I mixed 2 parts hot water with 1 part hot water and the temperature didn't change		
2 hot, 2 cold	I mixed 2 parts hot water with 2 parts cold water and the temperature was in the middle of their initial temperatures	When mixing equal amounts of hot and cold water, the equilibrium temperature of the mixture is the average of the initial temperatures.	
2 cold, 1 hot	I mixed 2 parts cold water with 1 part hot water and the temperature was closer to the initial temperature of the cold water	When mixing unequal amounts of hot and cold water, the equilibrium temperature of the mixture is closer to the initial temperature of the larger amount of water.	

FIG. 2.7 Student's entries describing the mixing of hot and cold water exploration.

For the sketch of the set up in the first row, this student drew two containers representing cups of water and labeled them "2 *hot*" and "2 *hot* ." The student wrote, "I *mixed 2 parts hot water with 2 parts hot water and the temperature didn't change*."

In the second row, the student drew two containers and labeled them "2 *hot*" and "1 *hot*." The student wrote, "I *mixed 2 parts hot water with 1 part hot water and the temperature didn't change*."

In the third row, the student drew two containers and labeled them "2 *hot*" and "2 *cold*." The student wrote, "I *mixed 2 parts hot water with 2 parts cold water and the temperature was in the middle of their initial temperatures*."

In the fourth row, the student drew two containers and labeled them "2 *cold*" and "1 *hot*." The student wrote, "I *mixed 2 parts cold water with 1 part hot water and the temperature was closer to the initial temperature of the cold water*."

The student wrote the following rationales for the ideas claimed in the third column of the table:

> ***When mixing two amounts of water at the same temperature, the equilibrium temperature of the mixture is the same as the initial temperature, whether the amounts are equal or unequal.*** *(Figure 2.8) shows the graphs for mixing equal and unequal amounts of water at the same temperature. The first graph shows mixing*

equal amounts of water at the same temperature. I mixed 2 parts hot water with 2 parts hot water and the temperature of the water did not change from the initial temperature of the hot water. The second graph shows mixing unequal amounts of water at the same temperature. I mixed 2 parts hot water with 1part hot water and the temperature of the water did not change from the initial temperature of the hot water. The graphs in (Figure 2.8) *are evidence for the idea that when mixing two amounts of water at the same temperature, the equilibrium temperature of the mixture is the same as the initial temperature, whether the amounts are equal or unequal.*

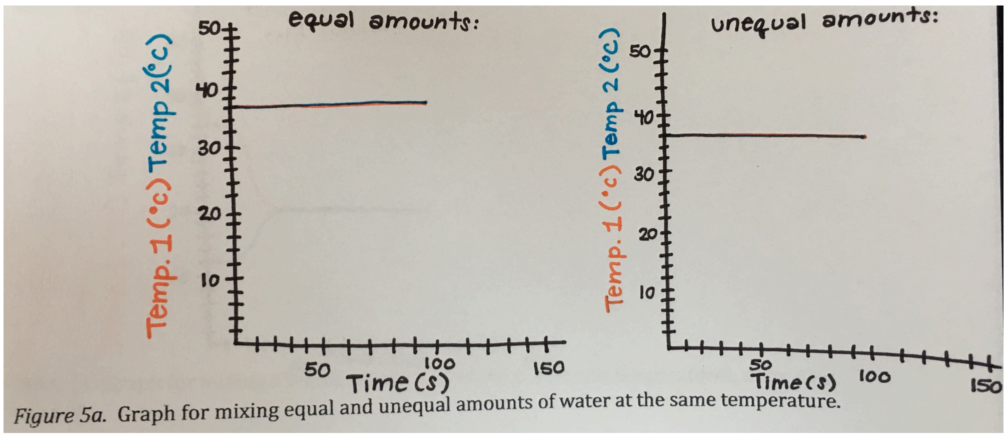


FIG. 2.8 *Mixing equal and unequal amounts at the same temperature.*

When mixing equal amounts of hot and cold water, the equilibrium temperature of the mixture is the average of the initial temperatures. (Figure 2.9) *shows the graph for mixing equal amounts of hot and cold water. I mixed 2 parts hot water with 2 parts cold water and the temperature of the water was right in the middle of their initial temperatures. The graph in* (Figure 2.9) *is evidence for the idea that when mixing equal amounts of hot and cold water, the equilibrium temperature of the mixture is the average of the initial temperatures.*

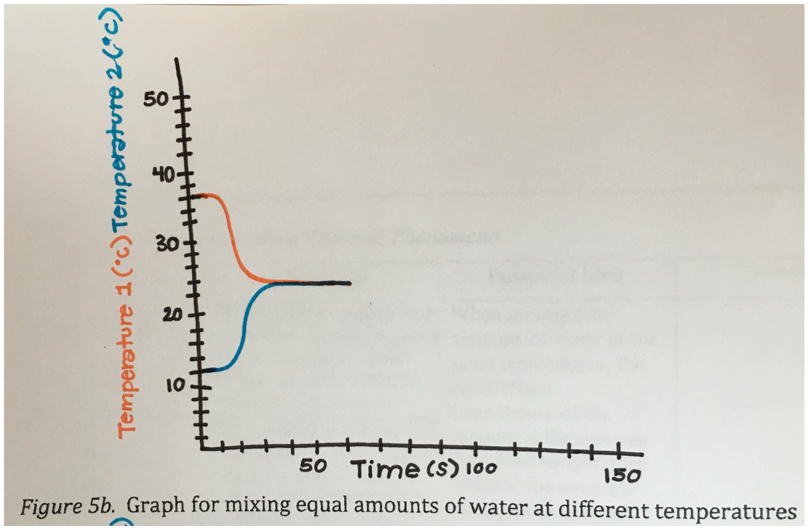


Figure 5b. Graph for mixing equal amounts of water at different temperatures

FIG. 2.9 *Mixing equal amounts of hot and cold water.*

When mixing unequal amounts of hot and cold water, the equilibrium temperature of the mixture is closer to the initial temperature of the larger amount of water. **(***Figure 2.10) shows the graph for mixing more hot water than cold water. I mixed 2 parts hot water with 1part cold water and the temperature of the water was closer to the initial temperature of the hot water. (Figure 2.11) shows the graph for mixing more cold water than hot water. I mixed 2 parts cold water with 1part hot water and the temperature of the water was closer to the initial temperature of the cold water. The graphs in (Figs. 2.10 and 2.11) are evidence for the idea that when mixing unequal amounts of hot and cold water, the equilibrium temperature of the mixture is closer to the initial temperature of larger amount of water.*

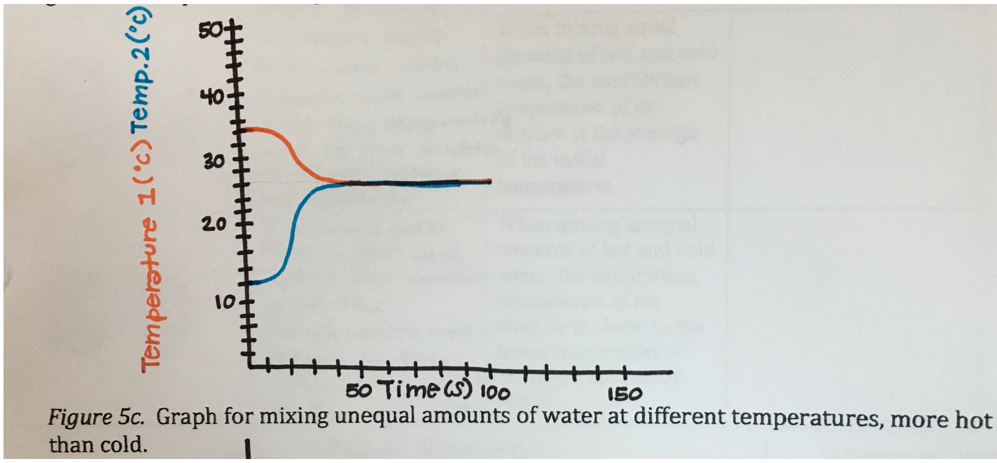


FIG. 2.10 *Mixing more hot than cold.*

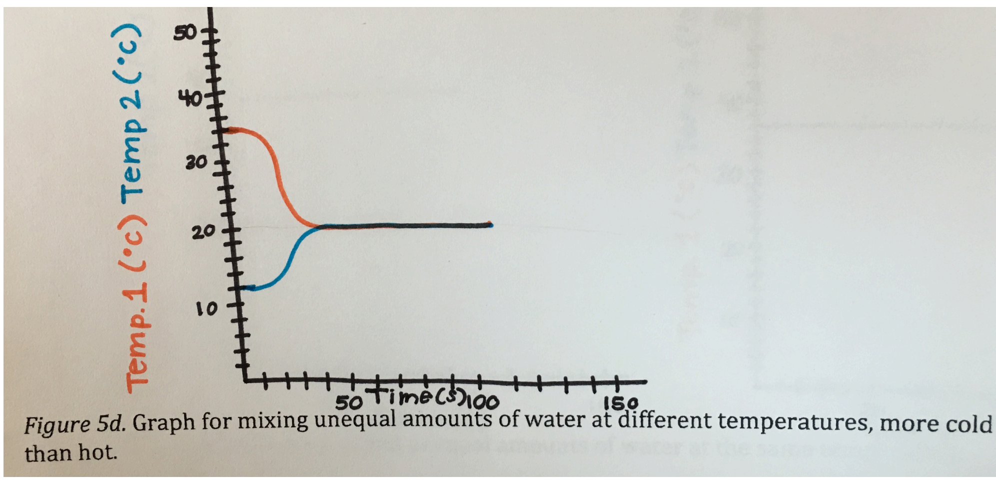


FIG. 2.11 *Mixing more cold than hot.*

Physics Student, Spring 2016

This was the first experience for these students in drawing and interpreting temperature graphs in this course. This student was careful to label the vertical axis with equal-distant marks representing a temperature scale and to color code the lines representing the changing temperatures for the two temperature probes. The student also indicated on the horizontal axis the time in seconds that the mixing took place.

2. Nuances about exploring thermal phenomena by mixing hot and cold water

Adults are unlikely to have difficulty understanding that mixing equal or unequal amounts of water at the same temperature will result in a mixture at that same temperature. These scenarios are included here because this does not necessarily seem obvious to children. They may be so accustomed to adding numbers that they may predict that they need to add the two temperatures if they are adding the two amounts of water together. The flat line on the resulting graph also is helpful even for adult students in that it makes clear that such a flat line represents something that is not changing, in this case the temperature of the water.

Mixing equal amounts of hot and cold water can be problematic. One needs to take care in measuring the equal amounts. With small amounts, such as a half of cup each, small errors in measuring can bias the result. The expectation is that the final temperature, called the **equilibrium temperature,** will be half way between the two initial temperatures when mixing equal amounts at unequal temperatures.

In Fig. 2.12, does it look like the hot water changed temperature a little more than the cold? Why might that have happened?

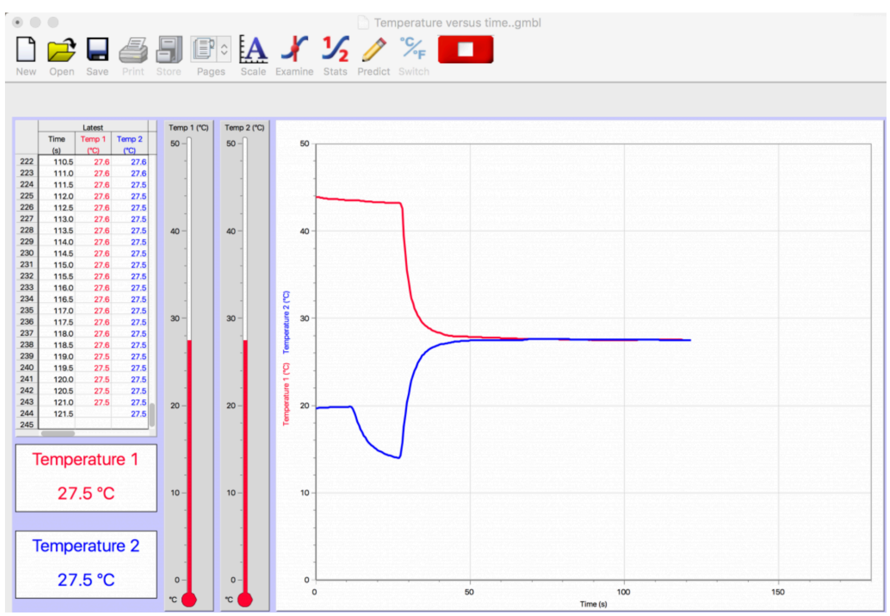


FIG. 2.12 Mixing intended equal amounts of water at unequal temperatures. ©Vernier Software & Technology-used with permission.

It may be that there were not exactly equal amounts of hot and cold water. Another possibility is that the amounts were equal but the hot water was poured into the cold water so some of the energy in the hot water flowed into the air and container as well as into the cold water. This would reduce the energy transferred to the cold water and look like a slightly smaller amount of hot water was used.

Figure 2.13 and Fig. 2.14 show the result of mixing different amounts of hot and cold water at different temperatures.

- In each of these experiments, which had the bigger temperature change? Which the smaller temperature change?
- In each of these experiments, which do you think was the bigger amount of water? The hot or the cold water?

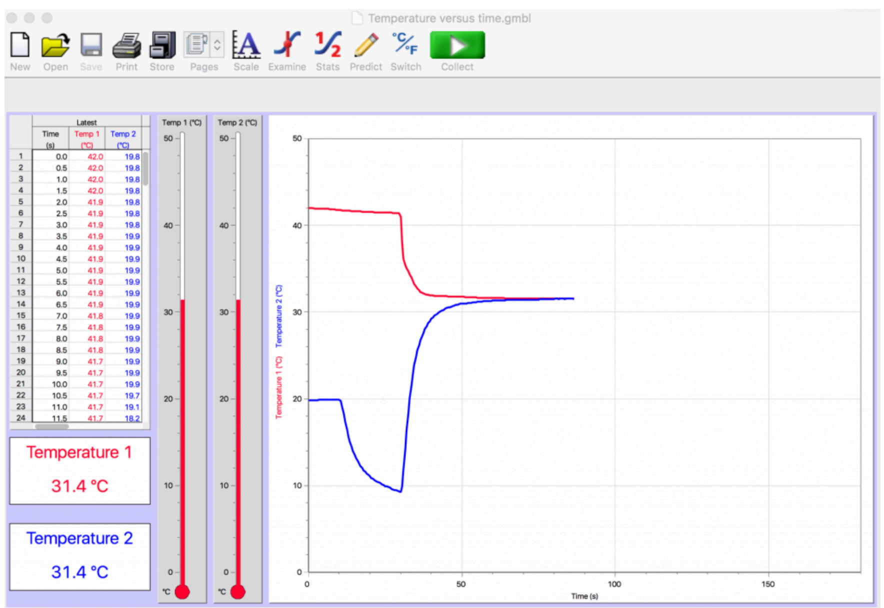


FIG. 2.13 *Mixing unequal amounts of water at unequal temperatures. ©Vernier Software & Technology-used with permission.*

In Fig. 2.13, it looks like the change in temperature of the hot water was smaller than the change in temperature of the cold water. Consider a bathtub with very hot water, much too hot for a bath. What to do? Add some cold water to cool things down, but not too much! If you mix a little cold water with a lot of hot water, which will change temperature the most?

The temperature of this small amount of cold water will change a lot as it mixes in with a large mass of hot water. The change in temperature is smaller for the larger mass of hot water. The change in temperature is larger for the smaller mass of cold water. Therefore, there must have been more hot water than cold in this scenario.

Figure 2.14 also shows the result of mixing different amounts of hot and cold water. Which had the bigger temperature change here? Which had the smaller temperature change? Which do you think was the bigger amount of water? The hot or the cold water?

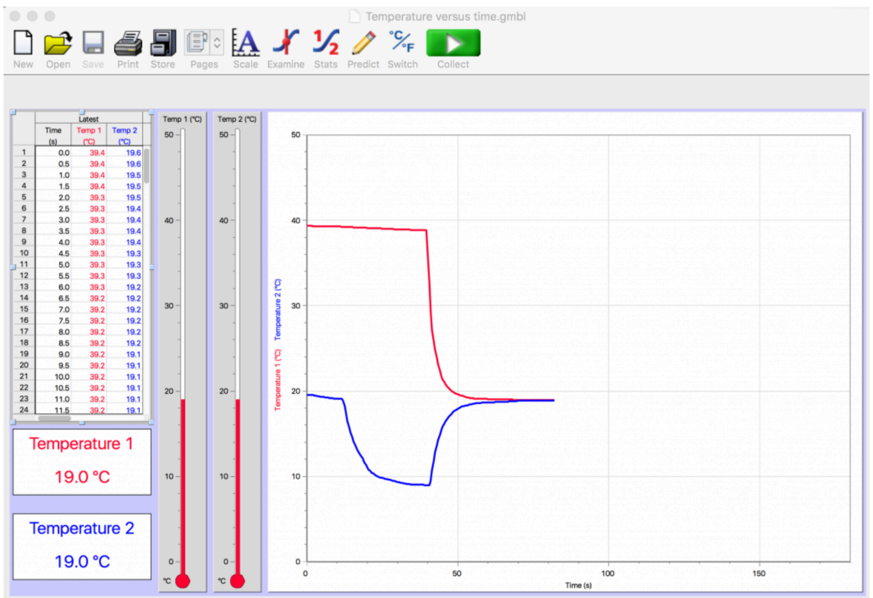


FIG. 2.14 Mixing unequal amounts of water at unequal temperatures. ©Vernier Software & Technology-used with permission.

In Fig. 2.14 the hot water had the bigger temperature change and the cold water had the smaller change in temperature. In this scenario, there must have been more cold than hot because the equilibrium temperature was nearer to the initial cold temperature.

A goal of this course is to build skills in interpreting line graphs in this way, to be able to “tell the story” of what happened by looking at the shapes of the lines and interpreting what must have happened in order for the lines to have formed in that way.

In Figs. 2.12 – 2.14, for example, the horizontal axis is representing the increase in time from left to right. The vertical axis is representing the temperature of the temperature probes.

- What does the red line at the beginning of the experiment indicate was happening to the temperature probe for the hot water?
- What does the blue line at the beginning of the experiment indicate was happening to the temperature probe for the cold water?
- What does the overlapping of the red and blue lines near the end of the mixing process indicate about what happened when these cups of hot and cold water were mixed together?

The almost flat red line at the beginning of the experiment suggests that the temperature of the hot water was not changing much as the temperature probe was sitting in the cup of hot water. There is a slight slant downward of the red line indicating that the hot water was cooling slightly in its cup. Then there is a very sharp change in the hot temperature recorded by this probe; the red line plunges almost instantly to a much lower temperature, suggesting that the sharp bend occurred the moment that the cold water was poured into the cup of hot water.

The straight blue line near the beginning of the experiment suggests that the temperature probe for the cold water was initially not in the cup of cold water but was outside of the cup, perhaps at room temperature when the computer program was started. The curved blue line represents the drop in temperature when the probe was then placed in the cup of cold water.

In Fig. 2.12 and Fig. 2.13, the temperature probe for the cold water was in the cold water long enough that the blue line has almost flattened out, indicating that the probe was near to reading the temperature of the cold water before mixing began. In Fig. 2.14, the blue line becomes almost flat. It is important to stir both cups of water and to wait until both lines are flat before pouring the cold water into the hot water. Record both temperatures just before mixing, in order to be sure that the initial readings of the temperatures of the hot and cold water are accurate.

The overlapping lines for both temperature probes at the end of the mixing process indicate that the two temperature probes were reading the same temperature, the *equilibrium temperature* reached after the mixing was complete. This assumes that the probes had been *calibrated*, that they had indicated the same temperature when placed in the same cup of water at the beginning of the experiment. If the two probes did not indicate the same temperature when placed in the same cup of water at the beginning of the experiment, the computer program needed to be instructed to change the calibration so that the readings of the two probes would agree when reading the same temperature.

Note how quickly the temperatures change as the mixing begins. Also note the shape of the curves as the temperatures change more gradually as the mixture comes to equilibrium. When drawing graphs, also take care to match the time when the lines start changing drastically, as temperature readings by both the hot and cold probes will start changing at the same instant, at the moment that the cold water is poured into the hot.

Figuring out how best to measure and mix the hot and cold water in order to maximize the accuracy of results is an example of an *engineering design* problem. The possible effects of pouring hot water into cold versus pouring cold water into hot, of stirring or not stirring before and after mixing, of calibrating the thermometers, and of timing the recording of initial conditions are all issues that need to be identified with solutions developed and optimized. (See Appendix I, *Engineering Design in the Next Generation Science Standards*, *https://www.nextgenscience.org/resources/ngss-appendices .)*

3. Some thoughts about the nature of science in this context

An important aspect of doing science is being able to represent and interpret changes that are occurring. Visual displays such as graphs can make aspects visible that might otherwise go unnoticed. Figures 2.13 and 2.14, for example, show dramatic differences in the stability of the initial temperatures of the hot and cold temperature probes. The initial almost flat line for the hot probe indicates a stable initial condition but the initial curved line for the cold probe indicates a dramatically changing initial condition. Such differences could affect the results. It is important in doing careful experiments that both the hot and cold temperature probes show a flat line, indicating a stable initial temperature, before mixing occurs.

These graphs show how the hot and cold water temperatures changed with time; such line graphs show how one quantity, represented by the vertical axis, changes with another quantity, represented by the horizontal axis. Learning to "tell the story" of such line graphs is an important skill in many fields. Being able to interpret such visual displays of data can enhance one's ability to influence and/or evaluate claims being made, whether in science, business, or personal contexts.

The use of digital temperature probes in this unit illustrate the affordances provided by technologies in collecting and interpreting data. As indicated in the US *Next Generation Science Standards*, *scientific knowledge is based on empirical evidence.* Third to fifth grade students, for example, should understand that *scientists use tools and technologies to make* *accurate measurements and observations* (NGSS, *Lead States*, 2013, *Appendix H*). (See: https://www.nextgenscience.org/resources/ngss-appendices.)

VI. Developing an Additional Central Idea about Thermal Phenomena and Its Mathematical Representations

Being able to tell a story about what is happening by looking at a graph is a useful skill whenever one is monitoring a numerical quantity. Graphs can show at a glance how something is changing, whether that involves finances, populations, sales, or some other quantity of interest. Being able to relate quantities algebraically also is helpful if one wants to make numerical predictions based on evidence rather than intuition. This section builds on skills in interpreting qualitative line graphs, such as those shown in Figs. 2.12-2.14. You also will develop quantitative skills for generating and justifying relevant equations, solving for an unknown, and calculating a quantity of interest.

A. Interpreting features of line graphs

"Telling the story" represented by a line graph involves looking at the shape of the graph and interpreting its features.

Question 2.8 How can you tell what is happening by interpreting the shape of a line graph?

Look at the shapes of the lines in the graphs shown in Figs. 2.15 and 2.16. What was happening if these graphs are representing the mixing of hot and cold water? Which of these graphs is intended to represent mixing more hot water than cold? Which is intended to represent mixing more cold water than hot?

For these graphs, an important feature is the length of the line representing the changing temperature of the hot water as compared to the length of the line representing the changing temperature of the cold water.

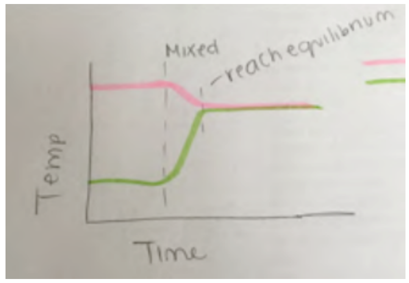


FIG. 2.15 Graph representing the mixing of hot and cold water. More hot water or more cold water?

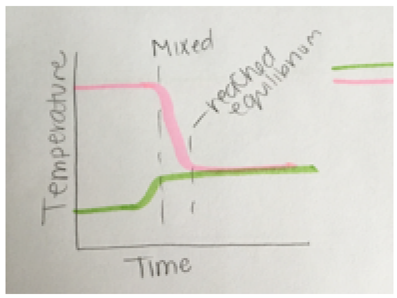


FIG. 2.16 Graph representing the mixing of hot and cold water. More hot water or more cold water?

Note that in Fig. 2.15, the student drew a long vertical dashed line to represent the time when the mixing of hot and cold water started, shown by the pink line bending down and the green line bending up. The initial bends are not as steep as shown in Fig. 2.13 but the lines start bending roughly at the same time, represented by the vertical line. The long vertical dashed line matches where both of the lines representing the hot- and cold-water temperatures started changing direction, representing that the temperatures of both the hot and cold water started changing at the same moment. The short vertical dashed line indicates roughly the time when the temperatures of the hot and cold water stopped changing as well, shown by the pink and green lines leveling off at about the same height above the horizontal axis, with that height representing the equilibrium temperature. The student wrote "*reach equilibrium*" to label what was happening there. The equilibrium is closer to the initial hot temperature, indicating that this was a case of more hot water mixing with cold.

In Fig. 2.16, however, the student did not match the lines representing times when the hot and cold water started changing direction. This graph suggests a story in which the cold water started warming up first and almost reached the equilibrium temperature before the hot water started cooling off. This is different from the story told by the lines in Fig. 2.14. It is important when drawing line graphs to check the story that your lines are telling. Are the details of your lines accurately telling the story of what is happening? The equilibrium temperature is closer to the initial cold temperature, indicating that this was a case of more cold water mixing with hot.

B. Identifying patterns in data

General thinking about a situation can help you decide how to set up a series of experiments to collect enough data to be able to perceive a pattern in the data. Once you have identified a pattern, try to represent that pattern mathematically. If the pattern can be expressed by an algebraic equation, you can use that the relationship to make predictions or to estimate a quantity of interest. That process is the focus of this section.

1. Designing a series of experiments to identify patterns in data

Question 2.9 When mixing hot and cold water, how are the amounts of hot and cold water related to how much their temperatures change?

- To explore what happens quantitatively when you mix various amounts of hot and cold water, first decide what data to record and how you want to keep track of these data.
    - If you want to double, triple, and quadruple an amount of water for a series of experiments, how might you do that?

    One way would be to use mass. If you have a balance, you could measure 100 grams, 200 grams, 300 grams, or 400 grams of water.

Another way would be to use volume. If you have a 500-milliliter measuring cup, you could measure 100ml, 200ml, 300ml, or 400 ml of water

Equivalently, use any container that you can mark with 1, 2, 3, 4 levels to measure multiples of the initial amount.

- How will you measure the initial and final temperatures?

  Two regular bulb and tube thermometers will work fine. Using two digital temperature probes connected to a computer, however, will allow you to build skill in interpreting the graphs that appear as you mix the various amounts.

- What combinations of hot and cold water will you try and how will you record your findings?

- Another issue is how best to carry out your experiments: What might affect how much the temperatures of the hot and cold water change?
  - How can you be sure that you are measuring the amounts of water consistently with your measuring devise?
  - How can you guard against some of the energy from the hot water flowing out into the cup and air instead of into the cold water?
  - How can you be sure that the temperatures you record for the hot and cold water are their actual temperatures at the moment just before you mix them?
  - How can you be sure the hot and cold water are well mixed before you record the equilibrium temperature?
- In the *Before* section of your physics notebook page, describe your experimental design – how you plan to conduct these experiments. This also is a place to record your initial thoughts about what to do with your data once obtained and to make predictions for the results.
  - What data do you plan to record and how do you plan to keep track of these data?
  - How might you use these data to predict the changes in temperature for each

experiment?

  - How might you use the amounts of hot and cold water and their initial temperatures to predict whether the equilibrium temperature is likely to be closer to the initial hot temperature, closer to the initial cold temperature, or half way in-between their temperatures?
  - How do you think the equilibrium temperature relates to the initial temperatures of the hot and cold water?
  - How might you use the amounts of hot and cold water to be mixed, their initial temperatures, and the likely equilibrium temperature in order to predict likely changes in temperatures of the hot and of the cold water?

- Explain your reasoning for the process you will use to make these predictions.

This process of designing your exploration by deciding on what to do, what data to record, how to use these data, and predicting what you expect to occur is an important aspect of learning to do science. This open-ended process contrasts with one in which a laboratory manual or teacher already has made most of those decisions for you. The intent here is to model the experimental process as well as the conceptual process of developing central ideas and the mathematical process of representing what is happening through graphs and algebraic equations.

- In the *During* section of your notebook page, create a table to record the findings for each experiment in a clear way.
- Also note any new words or familiar vocabulary that you have noticed as having special meanings in this context.
- Discuss your findings and formulate a relevant central idea.
- Sometimes one feels overwhelmed in the midst of an exploration, particularly if one is trying to figure out relationships among variables rather than simply following a lab manual's verification recipe. If that happens, it can be helpful to ask:
  - What are we doing?
  - Why are we doing this?
  - How is that helping us?

- In the ***After*** section of the physics notebook page, report this central idea and the evidence on which it is based.
- Write a rationale that explains how the evidence supports the central idea and why this is important.
- Also reflect upon this exploration such as what connections can you make to other experiences? How might you use what you learned in your own classroom?
- What are you still wondering?

After class, write a summary based on your physics notebook pages and handouts before reviewing the following discussion of comparing ratios of hot and cold water and their changes in temperature. To maximize learning, it is important to work through issues in conversation with your group members and with guidance as needed from your instructor in class before reading this text. The purpose of the sections below is to help clarify any details that may be puzzling.

2. Recording and analyzing data

There are many ways to record and analyze data. As an example, consider Fig. 2.14, repeated from above, for an experiment in which two parts of cold water were mixed with one part of hot water.

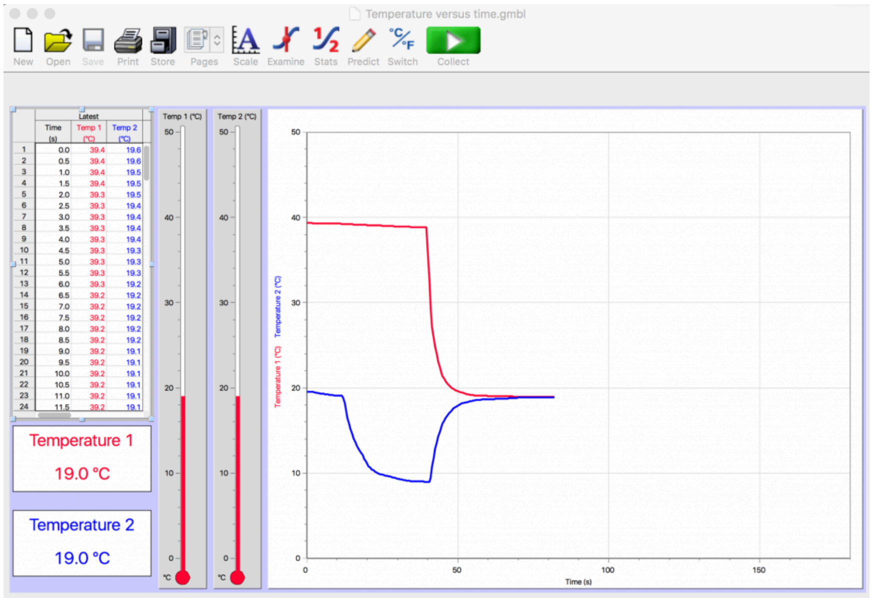


FIG. 2.14 (repeated). Mixing unequal amounts of water at unequal temperatures. ©Vernier Software & Technology-used with permission.

The vertical axis represents temperature in degrees Celsius; the horizontal axis represents time in seconds. The computer display indicates that the mixture of the hot and cold water reached an equilibrium temperature of 19.0 °C. The precision of the digital thermometers is nice but not necessary. If we had been using regular thermometers rather than digital thermometers, probably both regular thermometers would have indicated an equilibrium temperature of about 19°C. That level of precision would be enough for the purposes of this experiment. The graph on the computer is useful, however, in providing an informative visual display of what is happening.

Looking at the initial red line, which is just below the 40°C grid line, what is an estimate of the initial temperature of the hot water?

Looking at the lowest point of the initial blue line, which is just below the 10°C grid line, what is an estimate of the initial temperature of the cold water?

The ratio of parts of cold water to hot water is 2/1. The final temperature of the hot water was about 19°C; the initial temperature of the hot water was about 39°C. The final temperature of the cold water was about 19°C; the initial temperature of the cold water was about 9°C. Although the digital temperature probes provide more precise readings, we are choosing to record readings at ± 1°C here to ease visual inspection of the calculations in Table II.2.

A table would be helpful in recording and analyzing such data.

Table II.2 Reporting data and analyzing experiments mixing hot and cold water

TABLE II.2 Reporting data and analyzing experiments mixing hot and cold water									
Exp.	Part hot	Part cold	Ratio parts hot to cold	Final T hot in °C: T_{hf}	Initial T hot in °C: T_{hi}	Change in T hot water: ΔT_h	Final T cold in °C: T_{cf}	Initial T cold in °C: T_{ci}	Change in T cold water: ΔT_c
Fig. 2.14	1	2	1/2	19°C	39°C		19°C	9°C	

A similar table can be made for other combinations, such as mixing 1 part hot water with 4 parts cold, 2 parts hot water with 1 part cold, or 4 parts hot water with 1 part cold. Assembling such data for multiple experiments makes possible looking for patterns in the data across multiple contexts.

For the experiment represented in Fig. 2.14, what are the changes in temperature for the hot and cold water? When describing changes in temperature in everyday life, we usually indicate whether the temperature increases or decreases: "it will be 5 degrees *warmer* today than yesterday," "the cake *cooled* to room temperature," or "her temperature is *back down* to normal." Mathematically, we describe whether a temperature change is hotter or colder with a positive or negative sign. Therefore, we mathematically define a change in temperature as the final temperature T_f minus the initial temperature T_i and use ΔT, delta T, to represent a change in temperature:

$$\text{change in temperature} = \Delta T = T_f - T_i$$

When the temperature increases, the change in temperature is positive. When the temperature decreases, the change in temperature is negative. When mixing hot and cold water, the final temperature for both the hot and the cold water is the equilibrium temperature T_e so for both changes in temperature, subtract the initial temperature from the equilibrium temperature:

$$\text{change in temperature} = \Delta T = T_e - T_i$$

Figure 2.17 provides a visual way to think about the relationships among the initial, final, and equilibrium temperatures when mixing hot and cold water.

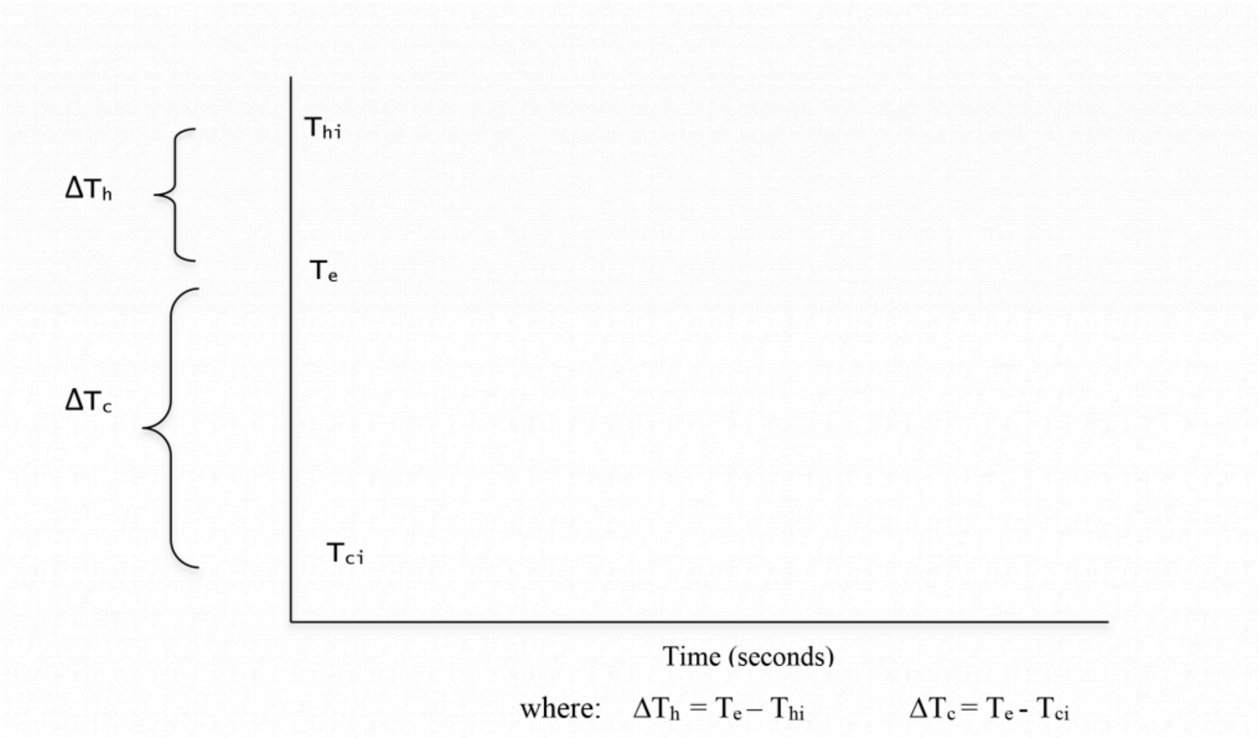


Fig. 2.17a. Graph of ***temperature versus time*** *for mixing more hot- than cold- water*

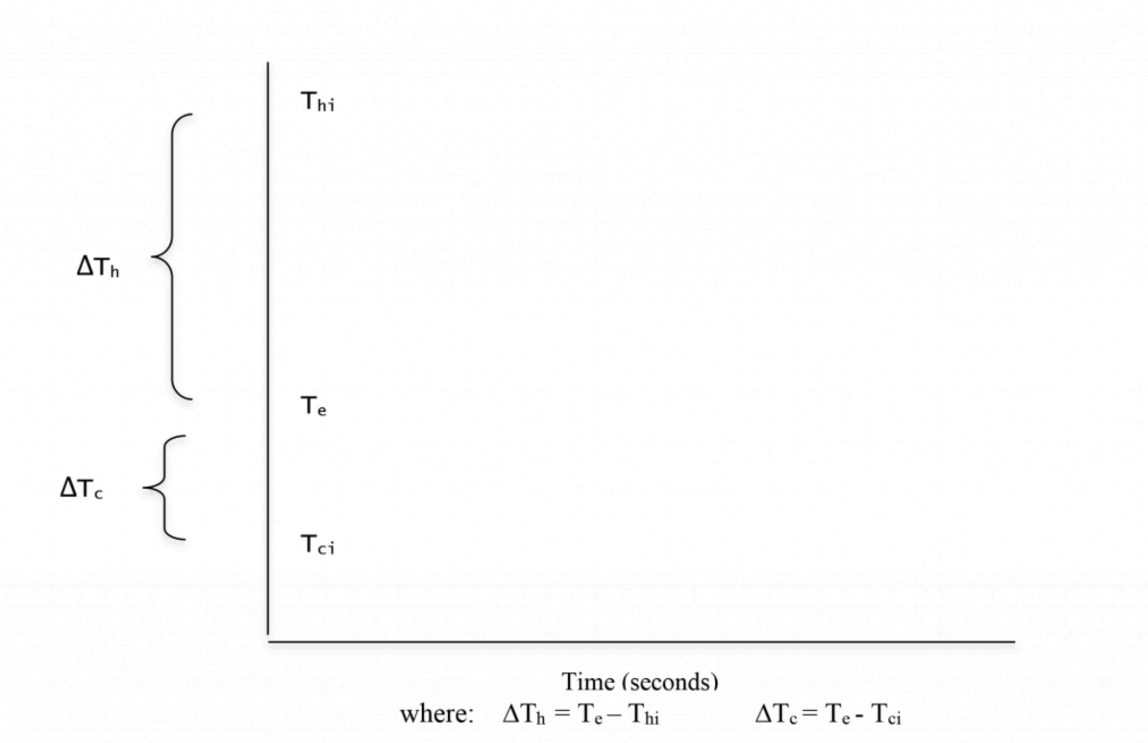


*Fig. 2.17b. Graph of **temperature versus time** for mixing more cold- than hot- water*

For the hot water:

$\Delta T_h = T_{hf} - T_{hi} = T_e - T_{hi} = 19°C - 39°C = -20°C$

The minus sign indicates that ΔT_h, the change in the hot water temperature, was a decrease in temperature. All ΔT_h in these mixing hot and cold water experiments will have a negative value as the hot water will always be at a higher initial temperature than the equilibrium temperature. Subtracting the higher initial temperature from this lower equilibrium temperature will always yield a negative value.

For the cold water:

$\Delta T_c = T_{cf} - T_{ci} = T_e - T_{ci} = 19°C - 9°C = +10°C$

The plus sign indicates that ΔT_c, the change in the cold water temperature, was an increase in temperature. All ΔT_c in these mixing hot and cold water experiments will have a positive value as the cold water will always be at a lower initial temperature than the equilibrium temperature. Subtracting the lower initial temperature from this higher equilibrium temperature will always yield a positive value

It can be helpful, when working with problems involving mixing hot and cold water, to sketch a graph that illustrates what is happening as in Fig. 2.18.

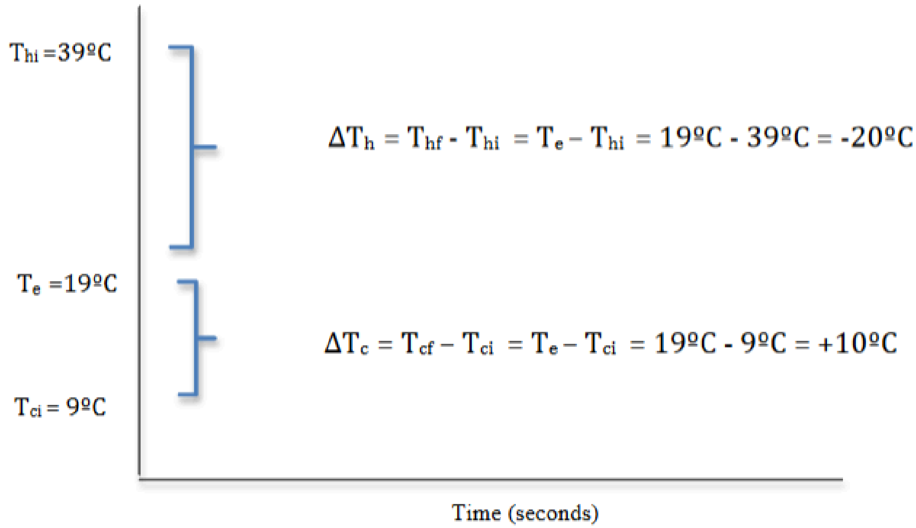


FIG. 2.18 Form of graph of temperature versus time for mixing 1 part hot and 2 parts cold water.

Entering these findings in the table and highlighting these changes in temperature and the parts of hot and cold water creates a visual display that can help identify patterns in these data. The magnitude of the change in temperature of the hot water would be twice as much as magnitude of the change in temperature of the cold water.

Calculating the change in temperatures of the hot water and the cold water completes Table II.2:

Table II.2 (continued) Reporting data and analyzing experiments mixing hot and cold water

Table II.2 (continued) Reporting data and analyzing experiments mixing hot and cold water

Exp.	Part hot	Part cold	Ratio parts hot to cold	Final T hot in °C: T_e	Initial T hot in °C: T_{hi}	Change in T hot $\Delta T_h = T_e - T_{hi}$	Final T cold in °C: T_e	Initial T cold in °C: T_{ci}	Change in T cold $\Delta T_c = T_e - T_{ci}$
Fig. 2.14	1	2	1/2	19°C	39 °C	– 20 °C	19 °C	9 °C	+10 °C

3. Interpreting findings

How are the highlighted quantities in Table II.2 related mathematically?

Given that we have been comparing what happens when mixing various ratios of the amounts of hot and cold water, it seems reasonable to compare the changes in temperatures as ratios as well:

$\frac{\text{Part hot}}{\text{Part cold}}$ equals: $\frac{\text{Change in temperature hot}}{\text{Change in temperature cold}}$ or

\frac{\text{Change in temperature cold}}{\text{Change in temperature hot}} ?

For the experiment represented in Fig. 2.14, what does the ratio $\frac{\text{Part hot}}{\text{Part cold}}$ equal ?

$$\frac{\text{Part hot}}{\text{Part cold}} = \frac{1}{2} = \frac{-20^o C}{+10^o C} \ ?$$

or

$$\frac{\text{Part hot}}{\text{Part cold}} = \frac{1}{2} = \frac{+10^o C}{-20^o C} \ ?$$

The results of this experiment indicate that the **ratio** of the amount of hot water to the amount of cold water (1 to 2) seems to be related to the **inverse ratio** of the change in cold temperature to the change in hot temperature.

There is a problem, however, in that the ratio of the temperatures is negative but the magnitudes match; they are both of magnitude 1/2. The magnitude of a quantity is its numerical value without reference to whether the value is positive or negative.

Sometimes students also are puzzled by what their results seem to be saying. Most ratios that students have worked with in other contexts seem to have been *direct proportions*, as in the pinhole camera, where the entities are in the same order: H/D = h/d or expressed another way: h/H = d/D, the ratio of corresponding heights in similar triangles is equal to the ratio of corresponding distances.

This new relationship between ratios is representing an *inverse proportion*:

$$\frac{\text{Property 1 of Top Entity}}{\text{Property 1 of Bottom Entity}} \text{ is related to } \frac{\text{Property 2 of Bottom Entity}}{\text{Property 2 of Top Entity}}$$

If a result seems wrong, consider whether something has gone wrong or whether this experimental result is what is really happening. Based on the data presented above, the ratio of a small amount of hot water to a large amount of cold water is related to the magnitude of the ratio of a small change in temperature of the large amount of cold water to the magnitude of a large change in temperature of the small amount of hot water. This is a description of what the graph showed in Fig. 2.14. In this case, the temperature of a large amount of cold water changed a little; the temperature of a small amount of hot water changed a lot.

In addition to considering whether a puzzling result seems logical and in agreement with other ways to represent the data obtained in an experiment, it is helpful to test whether the same result occurs in other contexts. This result was based on an experiment mixing one part hot water and two parts cold water. Would the same pattern occur with other combinations such as two parts hot water and one part cold? What about 4 parts hot water and 1 part cold? Or 1 part hot and 4 parts cold water. Such multiple trials make possible looking for patterns in data and testing whether the relationships one infers are valid. Looking for patterns in data is an example of a *crosscutting concept* that occurs across many different science domains as discussed in Appendix G of the *Next Generation Science Standards* (NGSS Lead States, 2013) https://www.nextgenscience.org/resources/ngss-appendices .

4. *Developing an algebraic representation of the findings*

There are several steps needed to express this relationship appropriately in symbols. We have chosen to express the amounts of water in terms of their masses. For the experiment shown in Fig. 2.14, the ratio of the mass of hot water to the mass of cold water was 1 to 2:

$$\frac{\text{mass of hot water}}{\text{mass of cold water}} = \frac{m_h}{m_c} = \frac{1}{2}$$

which is a positive number.

The ratio of the changes in temperatures can be written as:

$$\frac{\text{Change in temperature of the cold water}}{\text{Change in temperature of temperature of the hotwater}} = \frac{\Delta T_c}{\Delta T_h} = \frac{+10^oC}{-20^oC} = \frac{-1}{2}$$

which is a negative number.

Because ΔT_h is always negative and ΔT_c is always positive, the ratio of changes in temperature will always be a negative number. In order to set it equal to a positive number, a minus sign needs to be added to the expression. Therefore, the results of this experiment can be expressed algebraically as:

$$\frac{m_h}{m_c} = \frac{-\Delta T_c}{\Delta T_h}$$

The results also can be expressed as

$$\frac{m_c}{m_h} = \frac{-\Delta T_h}{\Delta T_c}$$

The magnitudes of the ratios in the experiment represented by the graph in Fig. 2.14 turned out to be exactly equal at the level of precision we used. That is unusual in these experiments. Typically these experimental results are only approximately equal. Therefore we choose to represent these experimental results with the symbol ≈ that represents "approximately equal":

$$\frac{m_h}{m_c} \approx \frac{-\Delta T_c}{\Delta T_h}$$

and

$$\frac{m_c}{m_h} \approx \frac{-\Delta T_h}{\Delta T_c}$$

The ratio of the mass of the hot water to the mass of the cold water is approximately equal to minus the ratio of the change in temperature of the cold water to the change in temperature of the hot water where change in temperature equals the final temperature minus the initial temperature ($\Delta T = T_f - T_i$).

One also can refer to the *magnitude* of the changes in temperature, the numerical values of the changes, without reference to whether they are an increase or decrease in temperature. The magnitude of a quantity is represented by vertical bars on both sides of its symbol: $|\Delta T_h|$ represents the magnitude of the change in temperature of the hot water, 20°C in this case. The ratio of the mass of hot water to the mass of cold water is approximately equal to the ratio of the magnitude of the change in temperature of the cold water to the magnitude of the change in temperature of the hot water. If stated in terms of magnitudes, the minus sign is not needed but vertical bars should be placed of both sides of the expressions with ΔT symbols:

$$\frac{m_h}{m_c} \approx \frac{|\Delta T_c|}{|\Delta T_h|}$$

and

$$\frac{m_c}{m_h} \approx \frac{|\Delta T_h|}{|\Delta T_c|}$$

If you choose to use "magnitudes" be sure to indicate that with both the verbal and symbolic statements of this relationship.

C. Recognizing the importance of systems thinking

Comparing the results for several experiments mixing various amounts of hot and cold water can increase confidence in the interpretation developed above, that the amounts of hot and cold water are inversely proportional to the magnitudes of their changes in temperature. Any differences in findings from multiple experiments would need consideration: what are the components of the system, how might they be interacting, how might the processes involved be affecting what is happening?

Question 2.10 What is the role of systems thinking in interpreting experimental results?

A student reported four experiments in which one set of ratios were equal but three of the four had slightly lower changes in temperature by the cold water than expected. The student reflected upon the role of systems thinking in explaining these findings.

1. *Example of student work reflecting upon the role of systems thinking*

> *In class, we mixed varying unequal amounts of hot and cold water. Our goal was to find a pattern in order to develop a mathematical representation of thermal phenomena…First, I mixed 2 parts hot water with 1 part cold water…Next, I mixed 1 part hot water with 2 parts cold water…Next, I mixed 4 parts hot water with 1 part cold water…Finally, I mixed 1 part hot water with 4 parts cold water…The experimental evidence that I found is evident in all four of the different unequal amounts of hot water and cold water that I experimented with. These four different trials all produced approximately equal ratios, which is experimental evidence that when mixing unequal amounts of hot and cold water, the ratio of the amount of hot water to the amount of cold water is approximately equal to the ratio of the (magnitude of the) change in temperature of the cold water to the (magnitude of the) change in temperature of the hot water..*
>
> *Various aspects of the situation may affect how close the mathematical model matches what actually happened. The cups of hot and cold water form a system with energy flowing from the hot water to the cold water. If it is a closed system, all of the energy lost by the hot water will be gained by the cold water. If it is an open system, some of the energy may flow out and into the environment, such as into the air or the material of the containers. Also, if there is an energy source nearby, some energy may flow into this system. Because we are trying to understand what is happening within our system of the cups of hot and cold water, it is important for us to keep the system as closed as possible.*
>
> *Because we were trying to find a pattern revolving around how the masses of the*

hot and cold water related to their changes in temperature when they were mixed, the most accurate results were found when as little energy as possible flowed out of the hot water and into the environment. So, the importance of system thinking in this exploration is that in order to move from the general claim that we developed to the precise mathematical statements, we needed to isolate the system of hot and cold water as much as possible.

Physics student, Spring 2016

In three of the four experiments discussed, the cold water did not change temperature quite as much as expected. This was a consistent effect, suggesting that the system was not a closed system consisting only of the hot and cold water. Some of the energy from the hot water likely flowed into the surrounding air and material forming the containers rather than into warming the cold water. This flow of energy into the surroundings, rather than into the cold water, would reduce the change in temperature for the cold water.

This is an example of the development of systems thinking, that one needs to consider all elements of a system and to observe carefully what is occurring. According to the *Next Generation Science Standards* (*NGSS Lead States*, 2013), thinking about *systems and systems models* is common across many science disciplines as described in Appendix G – Crosscutting Concepts (https://www.nextgenscience.org/resources/ngss-appendices).

What seems remarkable is that the ratios found in these experiments can be so close, given how simple the equipment and procedures are. We have not asked students to take the next step of doing multiple trials of each experiment in order to estimate uncertainties. The emphasis in this course has been on fostering conceptual understanding of the shapes of qualitative graphs while briefly modeling here a quantitative approach to looking for patterns in the data. With limited time available, our choice has been to balance this experimentally obtained insight about the inverse relationship between the amounts of hot and cold water and their changes in temperature with one based on theoretical considerations.

VII. Developing a Mathematical Representation of Thermal Phenomena Based on Theoretical Considerations

The experimental approach discussed above focused only upon the relative masses of the hot and cold water and their relative changes in temperature. No mention was made of the energy flowing from the hot to the cold water. An earlier section in this unit (II.B, Table II.1, page 194) had developed the following central idea:

A temperature difference implies a flow of energy from hotter objects to colder objects.

In this section, we consider how to express theoretical ways of thinking about that transfer of energy from the hot water into the cold water. This involves use of the Law of Conservation of Energy, that the total energy in a closed system does not change, that energy lost by the hot water is gained by the cold water and its surroundings.

A. Considering what happens when energy flows from hot water into cold

Question 2.11 What theoretical considerations can provide insights into what is happening when energy flows from the hot water into the cold water?

Energy is measured in different units in different contexts. (see https://www.aps.org/policy/reports/popa-reports/energy/units.cfm . In this course, we use the energy unit of a *calorie*.

A calorie is the amount of energy needed to change the temperature of one gram of water by one degree Celsius at standard atmosphere pressure and 20°C. This amount of energy is very small; the calories typically discussed in the context of food are kilocalories, 1000 of the calories discussed here. A kilocalorie is the energy needed to change the temperature of one kilogram of water by one degree Celsius at standard atmospheric pressure and 20°C.

There are many different materials one could use in exploring thermal phenomena. **The amount of energy needed to raise the temperature of one gram of a material by one degree Celsius is called the material's *specific heat*.**

Water is the standard. **One calorie of energy is needed to raise a mass of one gram of water by one degree Celsius** at standard atmospheric pressure and 20°C. The symbol for specific heat is c. In this course, water's specific heat is written $c_W = 1.0$ cal/(g°C).

Note that the units for mass and temperature both are in the denominator of this expression for specific heat. This is a mathematical way of stating that the change in energy for water is one calorie to change each gram by one Celsius degree. The dimensions of specific heat, c, are:

Dimensions of specific heat: $\dfrac{(\text{energy})}{(\text{mass})(\text{temperature})}$

The units are: $\dfrac{(\text{calories})}{(\text{grams})(\text{degrees Celsius})}$

To express mathematically how much energy is gained or lost when something is warmed or cooled:

- What might be the effect of how much "stuff" is involved?
- What might be the effect of the kind of "stuff" one has?
- What might be the effect of how much the temperature changes?
- How can you combine measures of these effects mathematically to estimate the energy lost by the hot water?

Complete Table II.3 and write a summary about expressing these theoretical considerations mathematically.

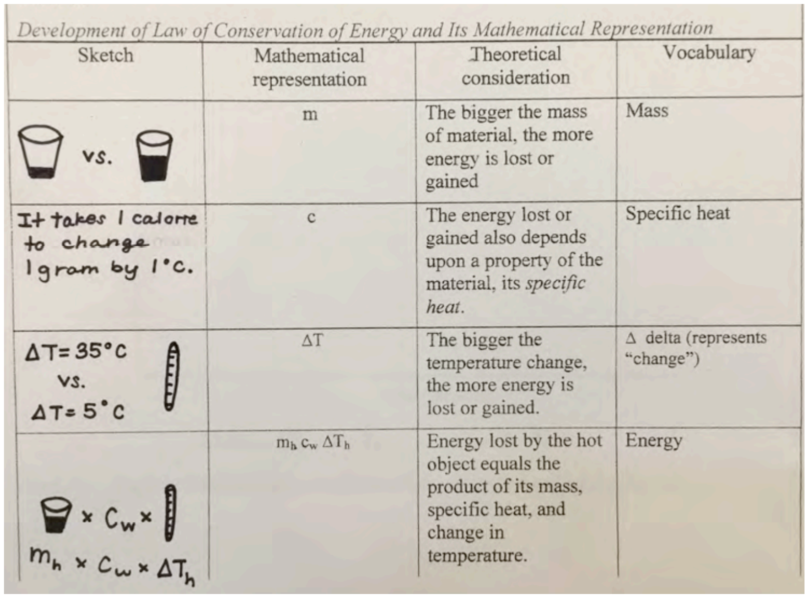
Table II.3 Developing a mathematical expression for change in energy

Table II.3 Developing a mathematical expression for change in energy			
Sketch	Mathematical representation	Theoretical consideration	Vocabulary
	m	The bigger the mass of material, the more energy is lost or gained	Mass
	c	The energy lost or gained also depends upon a property of the material, how much energy is needed to change the temperature of a mass of one gram by one degree Celsius, its *specific heat*.	Specific heat
	ΔT	The bigger the temperature change, the more energy is lost or gained.	ΔT, delta T, represents "change in temperature" $\Delta T = T_f - T_i$
	m c ΔT	The change in energy equals the product of mass, specific heat, and change in temperature.	Change in energy

After completing Table II.3, look at an example of student work and consider nuances about mathematical representations of thermal phenomena based upon theoretical considerations.

1. Example of student work about developing a mathematical expression for a change in energy

This section is an example of using mathematics to express some theoretical insights. The ratios above do not directly address what is happening conceptually in terms of energy transfers when mixing hot and cold water. The considerations that one must make, including how much material one has, what kind of material this *is, and how much the temperature changes, are indicated in (the table shown in Fig. 2.19 below.)*



Development of Law of Conservation of Energy and Its Mathematical Representation

Sketch	Mathematical representation	Theoretical consideration	Vocabulary
vs.	m	The bigger the mass of material, the more energy is lost or gained	Mass
It takes 1 calorie to change 1 gram by 1°C.	c	The energy lost or gained also depends upon a property of the material, its *specific heat*.	Specific heat
$\Delta T = 35°C$ vs. $\Delta T = 5°C$	ΔT	The bigger the temperature change, the more energy is lost or gained.	Δ delta (represents "change")
$\times C_w \times$ $m_h \times C_w \times \Delta T_h$	$m_h c_w \Delta T_h$	Energy lost by the hot object equals the product of its mass, specific heat, and change in temperature.	Energy

Fig. 2.19 Student's entries describing exploration of changes in energy.

The bigger the mass of material, the more energy is lost or gained. *The first row in (the table) presents this idea. For this experiment, the more water that there was, the more energy was lost or gained. This is because the more mass that a material has, the more energy it will take to change things about the material, such as its temperature. Since it takes 1 calorie to change 1 gram of water 1°C, the greater the mass of the material, the more calories were needed, which means that more energy was lost or gained.*

The energy lost or gained also depends upon a property of the material, its specific heat. *The second row in (the table) shows this idea. Specific heat is defined as, c = the amount of energy (lost or gained) to change the temperature of one gram of material by one degree Celsius. Water is the standard,* c_W *= one calorie of energy that is lost or gained when the temperature of one gram of water changes by one degree Celsius (at standard atmospheric pressure and 20°C).*

The bigger the change in temperature, the more energy is lost or gained. *This idea is displayed in the third row in (the table). Since it takes 1 calorie to change 1 gram of water 1°C, the greater the temperature change, the more calories were needed, meaning that more energy was lost or gained.*

Energy lost by the hot object equals the product of its mass, specific heat, and change in temperature. *This idea is presented in the fourth row of (the table). These variables are multiplied to express mathematically the energy lost by the hot water* $m_h c_w \Delta T_h$, *because in order to know how much energy is lost, you have to know how much material is losing energy, the specific heat of that material, and the change in temperature of that material. If you know all of that information, you are able to multiply the three values together in order to determine the amount of energy that is lost.*

Physics student, spring 2016

2. An analogy to specific heat and the mathematical expression for change in energy

This progression of mathematical thinking can seem challenging. However, exploring both experimental and theoretical approaches to relating quantities is an important part of modeling phenomena in science.

The process of developing such mathematical expressions can increase comfort with using subscripts, in interpreting expressions involving multiple symbols, and in deepening understanding of what multiplication represents in viewing $m_h c_w \Delta T_h$ as a meaningful expression for how much a mass m_h of hot water, with specific heat c_w, changes in energy when it cools by ΔT_h degrees in temperature when mixed with cold water.

Sometimes it helps to consider an analogous situation:

- How would you estimate the budget for a project if the basic cost, c, is the number of dollars paid for each hour worked by each person?

What would be the estimated budget for the project, for example, if you hired 5 people at a cost of $15/hour for each person who worked for 2 hours?

You would need: $(5 \text{ people})(\frac{\$\ 15}{\text{each person, each hour}})(2 \text{ hours}) = \$150$

Note that multiplication is indicated here by parentheses ( ) rather than by x's in order to avoid confusion with situations in which an x represents an unknown, which often occurs in algebraic equations.

In general, if n = the number of people, c = the cost for each person for each hour, and

Δt = the estimated duration (final clock reading − initial clock reading), i.e., the time in hours needed for this number of people to complete the project, the budget would be:

$$\text{Number of dollars needed} = \text{(number of people)}(\frac{\text{dollars}}{\text{person hour}})\text{(estimated number of hours)}$$

Budget needed for the project = $nc\Delta t$

The mathematical reasoning for energy transfer is exactly the same:

- How would you calculate the change in energy if the mass of the material was m, the specific heat of a material is “c,” which is the number of calories needed for an energy change of one gram for each degree C change in temperature, and the material changed in temperature ΔT?

If m = mass in the number of grams,

c = energy in calories needed for each gram for each degree C change in temperature, and

ΔT = change in temperature in number of degrees C,

the change in energy would be:

$$\text{change in energy} = mc\Delta T$$

Although it may be hard to view $mc\Delta T$ as a meaningful expression for change in energy, one can focus on dimensions and see this as:

$$\text{change in energy} = \frac{\text{(mass) (energy) (temperature)}}{\text{(mass)(temperature)}} = \text{energy}$$

or focus on units and see this as:

$$\text{change in energy} = \frac{\text{(\# of grams) (\# of calories) (\# of degrees C change in T) }}{\text{(gram)(degree C)}} = \text{\# of calories}$$

It can be helpful in working thermal problems, to step back and evaluate the dimensions on both sides of an equation to check that one has not made an algebraic mistake in manipulating an equation to solve for an unknown.

B. Considering the Law of Conservation of Energy

Question 2.12 How does the energy gained by the cold water compare to the energy lost by the hot water, assuming no energy is gained by the surrounding environment?

The total change in energy should equal the change in energy of the hot water plus the change in energy of the cold water plus any change in energy of the surroundings. This is a statement based on the *Law of Conservation of Energy*. The word "conservation" here means that the total amount of energy does not change when energy flows from one part of a system to another or from one form into another.

This means that the total change in energy when hot and cold water mix should equal 0. Total change in energy = change in energy of hot water + change in energy of cold water + any energy flowing into the surroundings.

If no energy flows into the surroundings:

$m_h c_w \Delta T_h + m_c c_w \Delta T_c = 0$ Law of Conservation of Energy

Note that because $\Delta T_h = T_{hf} - T_{hi}$ and the final temperature is always less than the initial temperature for the hot water, ΔT_h is always negative, and therefore $m_h c_w \Delta T_h$ is always negative, which can be interpreted as the energy lost by the hot water.

The energy lost by the hot water + energy gained by the cold water = 0, makes sense as long as none of the energy lost by the hot water flows into the air or the containers. This also means that the magnitude of the energy lost by the hot water equals the magnitude of the energy gained by the cold water as long as none of the energy lost by the hot water flows into the air or the containers.

Question 2.13 How are these experimental and theoretical approaches related?

According to the Law of Conservation of Energy, the total energy does not change: Total change in energy = change of energy for hot water + change in energy for cold water = 0 if no energy flows into the surroundings.

$m_h c_w \Delta T_h + m_c c_w \Delta T_c = 0$ Law of Conservation of Energy

This algebraic relationship also can be written as: $m_h c_w \Delta T_h = - m_c c_w \Delta T_c$

This equation tells us that the change in energy of the hot water is *equal and opposite* to the change in energy of the cold water

This equation can be simplified by dividing both sides by c_w, m_c and ΔT_h in order to make ratios of m's and ΔT's:

$$\frac{m_h}{m_c} = -\frac{\Delta T_c}{\Delta T_h}$$

This is the equation developed experimentally with approximate results! Thus the theoretical approach confirms the relationship evident in the patterns of data obtained by measuring temperature changes when mixing various configurations of hot and cold water.

One can work forwards from the experimental result by multiplying both sides by m_c and ΔT_h

and including the specific heat of water on both sides to obtain the theoretical result:

$$m_h c_w \Delta T_h = - m_c c_w \Delta T_c$$

One also can express this relationship in terms of magnitudes:

$$|m_h c_w \Delta T_h| = |m_c c_w \Delta T_c|$$

Any of these approaches can be used in estimating a thermal quantity of interest.

VIII. Using Mathematical Representations to Estimate a Quantity of Interest

Qualitative approaches, such as interpreting the shapes of graphs, were helpful in gaining a conceptual understanding about what is happening when mixing hot and cold water. Quantitative approaches make possible the making of predictions and estimation of quantities that may be of interest.

A. Solving a thermal math problem

In this section, we demonstrate how to solve thermal math problems in the context of mixing hot and cold water. We assume that the specific heat of water is the same over the range of temperatures between freezing at 0°C and boiling at 100°C. We also assume that the specific heat of water is the same as the specific heat of fluids such as tea, milk, and cocoa when working thermal energy problems involving mixing these substances. The same mathematical process also applies in more complex situations in which the specific heat of the hot material differs, however, from the specific heat of the cold material, when, for example, a piece of hot metal is submerged into a cooling bath.

Question 2.14 How can one use mathematical representations of thermal phenomena to estimate a quantity of interest?

After developing both experimental and theoretical ways to describe what happens when mixing hot and cold water, one can use that knowledge to generate and solve thermal math problems.

To make up a thermal math problem, decide on a scenario and specify three of the four variables involved if only considering changes in temperature: mass of hot water, mass of cold water, magnitude in change in temperature of hot water, or magnitude of change in temperature of cold water. Also include information about one of the initial temperatures or equilibrium temperatures. Use mass units (grams, kilograms) or parts rather than volume units. If the scenario involves materials with difference specific heats, be sure to include that information in stating the problem and in calculating the answer.

As with solving pinhole math problems, the goal in solving a thermal math problem is not the “answer.” The goal is to build your ability to help someone else understand what to do and why. Start by helping the learner to understand what is happening by describing the scenario verbally with words and visually with a sketch. Next review the physics involved by stating what the relevant central ideas are. Also draw a qualitative graph and use it and the central ideas to explain what is happening. Then describe the graph mathematically, being clear about what each symbol represents. Justify the equation that relates the quantities represented; write the equation in both words and symbols. Finally, solve for the unknown in symbols before substituting values. After calculating an answer, be sure to also discuss why that answer seems reasonable.

In facilitating a conversation with someone about thermal phenomena, ask questions rather than tell answers throughout this process. In solving a thermal math problem for homework, follow the format provided here:

Format for Solving a Thermal Math Problem

a. **State the problem** in words
b. **Make a sketch** of the amounts to be mixed
c. **Review what you know** about the physics of this phenomenon: summarize the conceptual model by stating the relevant central ideas
d. **Draw a graph representing the problem:** use a ruler to make straight perpendicular axes, draw flat horizontal lines to represent temperatures that are not changing before the two substances are mixed, add the shared equilibrium temperature after the mixing, check that you have drawn the appropriately shaped graph for mixing more hot than cold or more cold than hot or equal amounts. Draw the graph to indicate whether the changes in temperature happen very quickly or are gradual processes.
e. **Tell the ‘story’ of the graph** with the relevant central ideas to **explain** why the equilibrium temperature is likely to be where you have drawn it (nearer the temperature of the initial hot water, initial cold water, or in the middle.)
f. **Represent this scenario mathematically**: **State the equation in words** that relates the masses of the substances mixed and their changes in temperature. Use the

experimental form of the equation derived from your exploration, including specific heats if the materials differ, or the theoretical form based on the Conservation of Energy. **Justify the use of the equal sign** accordingly.

g. **Define symbols, state equation in symbols**, and express how you are envisioning this equation.
h. **Solve for the unknown** in symbols
i. **Record given values and estimate any needed**
j. **Substitute values and calculate answer**
k. **Check answer**: why does the number you get from the calculation seem reasonable?

- Complete the process of generating and solving a thermal math problem before looking at a slightly modified example of student work.

1. *Example of student work generating and solving a thermal math problem*

The problem stated in words is: If you have 180 grams of hot tea, and you want to cool it down by 20 degrees Celsius by adding 60 grams of cold water, how much will the temperature of the cold-water change? Assume all of the energy lost by the tea is gained by the cold water and that the specific heats of tea and water are the same. The initial temperature of the cold water is 15 degrees Celsius. After finding the change in temperature of the cold water, find the equilibrium temperature and the initial temperature of the hot tea.

(As shown in Fig. 2.20), below is a sketch of the situation.

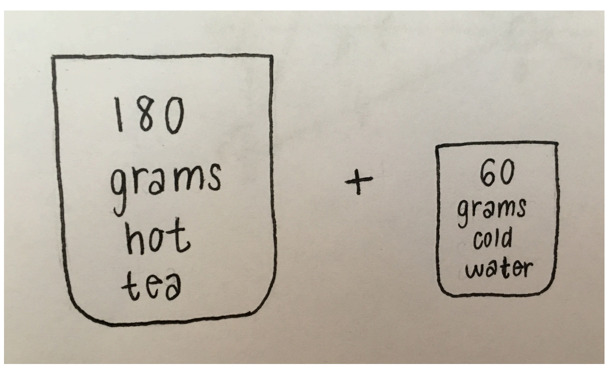


Fig. 2.20 Student sketch of the situation for this problem.

(As shown in Fig 2.21), below is a graph that represents the problem. The first relevant idea is, when mixing unequal amounts of hot and cold water, the ratio of the amount of hot water to the amount of cold water is approximately equal to minus the ratio of the change in temperature of the cold water to the change in temperature of the hot water. Next, the energy lost by the hot object equals the product of its mass, specific heat, and change in temperature. Finally, energy is conserved: energy lost = energy gained, so when mixing hot and cold water, the (magnitude of the) energy lost by the hot water equals (the magnitude of) the energy gained by the cold water.

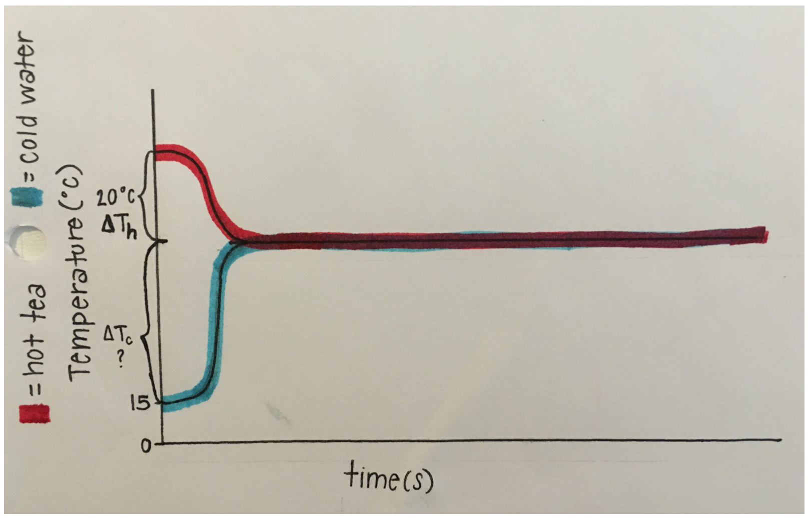


Fig. 2.21 Student representation of the problem graphically.

Symbols that are defined for the relevant quantities are m_h= *mass of hot tea,* m_c= *mass of cold water,* ΔT_c= *change in Temperature of cold water, and* ΔT_h= *change in Temperature of hot tea. An algebraic equation that relates these quantities in symbols is*

$$\frac{\text{m}_h}{\text{m}_c} \approx \frac{-\Delta T_c}{\Delta T_h}$$

The same equation in words is

$$\frac{\text{Mass of hot tea}}{\text{Mass of cold water}} \approx \frac{-\text{change in Temperature of cold water}}{\text{change in Temperature of hot tea}}$$

This equation is justified because it is equivalent to the theoretical statement of the Law of Conservation of Energy $-(m_h\, c_w\, \Delta T_h) = (m_c\, c_w\, \Delta T_c)$, *assuming that no energy is gained by the environment such as the cup and air.*

The unknown and the quantity to be calculated is the change in temperature of the cold water, ΔT_c. *The symbols for the quantities I have provided in the problem* *statement and their numerical values are* m_h= 180 *grams,* m_c= 60 *grams, and* ΔT_h= – 20°C.

The equation solved algebraically for the unknown is $\Delta T_c = -\Delta T_h \frac{(\mathrm{m}_h)}{(\mathrm{m}_c)}$.

When I substitute the values above for the known quantities and then calculate the answer I get

$$\Delta T_c = -(-20^\circ C)\frac{(180 \text{ grams})}{(60 \text{ grams})} = 60^\circ C$$

This answer is reasonable because there was a lot more hot water than cold water which means that the temperature of the mixture will be closer to the initial temperature of the hot water than the initial temperature of the cold water. This means that the cold water should have a greater temperature change than the hot water. The hot water had a temperature change of -20°C, *so this answer of the cold water having a temperature change of* 60°C *is reasonable.*

The initial temperature of the cold water was 15°C. *Since we know the initial temperature of the cold water, we are able to use equations to solve for the initial temperature of the hot water and for the equilibrium temperature. I can now write an algebraic equation for the unknown of the equilibrium temperature,* T_e. *That equation is* $T_e = T_c + \Delta T_c$. *When I substitute the values in I get* T_e = 15°C + 60°C= 75°C.

Then, I can write an algebraic equation for the unknown of the initial temperature of the hot tea. That equation is ΔT_h. = $T_e - T_h$ so $T_h = T_e - \Delta T_h$ *When I substitute the values in I get* T_h = 75°C – (-) 20°C= 95°C. *This initial hot temperature is* 95°C *which is below boiling point and the initial cold temperature is* 15°C *which is above freezing, which both seem reasonable. Cooling tea down to* 75°C *also seems reasonable because this is below boiling point but above freezing. If a student spills the tea, it is not hot enough to burn them.*

Physics Student, Spring 2016

Actually 75°C is hot enough to burn one severely. Recommendations are for ‘hot’ liquids to be at 60°C or less. https://www.ncbi.nlm.nih.gov/pubmed/18226454

IX. Engaging Friends or Family Members in Exploring Thermal Phenomena

Question 2.15 What can you learn about science learning and teaching by engaging a friend or family member in learning about thermal phenomena?

- Invite a friend or family member to explore thermal phenomena with you.
- What does this person already know about thermal phenomena in the context of mixing hot and cold water?
- Help this learner do some systems thinking about how energy is conserved when energy flows from hot to cold water.
- Make up a conservation of energy problem and invite your learner to think aloud with you about how to solve it.
- Include the wording of your conservation of energy problem and its mathematical solution.
- Create an environment in which your learner feels comfortable enough to ask questions. Describe what this learner asked and said.
- Also describe what this learner did and found.
- In addition, discuss a NGSS science or engineering practice in which you engaged your learner while learning about thermal phenomena.
- Reflect on what you learn about teaching science through this experience in facilitating science learning.
- Post on the class electronic discussion board. Read your classmates' postings to learn from their experiences.

Complete this experience in learning and teaching physics before reading the examples of student work about designing and solving thermal math problems.

1. Examples of student work about designing and solving thermal math problems with friends and/or family members

A student engaged her roommate in some qualitative thinking to develop the relationship between masses of hot and cold water and their changes in temperature:

> *I explored thermal phenomena with my roommate M. Before experimenting, I asked her what she thought would happen when we mixed the hot and cold water and she said that it would become warm water. When I asked why her explanation was just that the cold cools down the hot water while the hot warms up the cold water.*
>
> *I asked her to try mixing different amounts of water and predict what would happen. We kept all of the results labeled in different cups to compare their temperatures. We did not have a thermometer so we just had to base everything on touch. I asked her to line up the cups from hottest to coldest based on feeling.*
>
> *M noticed that the hottest had the least amount of cold water in the mixture and the coldest had the least amount of hot water. Since we were not able to measure our temperatures at home, I showed Morgan the data we had collected in class. I did not give her the equation we came up with because I wanted to see where she would go with the information.*
>
> *She asked me if the temperature changes always need to add up to a specific number. I asked her to try it with different numbers than what we got to see if that was the case. She realized that was wrong because if there is a smaller gap between the temperatures, their temperature differences would be smaller.*
>
> *M was stumped so I tried having her look at the whole numbers without the decimals. She then realized the big numbers were double the small numbers. After looking at all of the data a little longer she realized that if the amount of hot water was double the cold water, that the temperature change of the cold water would be double that of the hot water.*
>
> *I then challenged her to imagine what the temperature change would be like if it was 4 parts hot water and 1 part cold water. Immediately M said that the temperature change of the cold water would be 4 times greater than that of the hot.*
>
> *I asked her if she could come up with an equation and she said it would be hot water divided by cold water would be equal to hot water temperature change divided by cold water temperature change. I asked her to test it with the data. She then*

realized the second equation would need to be cold temperature change over hot temperature change.

Once she had figured this out I asked her to figure out the temperature change of cold water when 2g of cold water was mixed with 8g of hot water. I also give her the temperature change of the hot water being 5C. She then figured out that the temperature change of the cold water would be 20C.

I used the same examples that had been used in class because I thought it was a good progression of testing understanding. I learned the importance of teaching in steps and building off previous knowledge.

Physics student, Fall 2016

Another student engaged her boyfriend in some interesting thinking about aspects that might affect what happens:

When I asked my boyfriend what happens when you add 4 parts cold water to 2 parts hot water, he said "the temperature increases and the mixture gets warmer, because it's closer to the cold water. The heat goes into the cold water". I said, "Right! Because energy transfers from hot water to cold water."

When I asked him what other factors might affect the transfer of hot water to cold, specifically when you pour the water in, he responded that the container, the air, and the surface the cups are sitting on all could affect the heat transfer.

Then we started talking about how these things may be affected. The amount both containers would take in heat, would matter on what the material it was made out of. M said, "If it was a thermos, it wouldn't take in much heat, because the heat would be insulated in the cup."

We also talked about the temperature of the air where you were pouring. Like if it was in Alaska, or Mexico the air surroundings would take in either more or less depending on which.

Next I gave him a word problem on solving for the change in heat of hot water. "What is the change of the hot water, when you have 30 g of hot tea and add 20g of cold water to make it drinkable and the change in temperature of the cold water is 15 degrees.

He was very confused by this complicated problem and thought that we should match the A temperature with A change in temperature and B temp with B change, to get a new temperature of C. But he did not know where to take it from there.

I asked him if he remembered anything about specific heat and showed him the equation to solve for the change in temp of hot water. He solved the algebra easily, *but said he probably couldn't come up with the equation on his own and I agreed that I wasn't able to come up with it on my own either.*

He was on the same page as me about this problem, that the algebra made sense and was easy, but it was the comprehending the bigger picture that was hard to grasp, and thinking up the equation on your own.

I learned that sometimes teachers and learners have the same questions, and that makes it easier to discuss and engage in thorough investigations. Also I learned both having questions lessens the "authoritarian" all knower- teacher type that teachers sometimes possess. We engaged in discussion, using math to solve problems, and analyzed and constructing explanations and designing solutions for the science and engineering practice standards.

Physics student, Fall 2015

X. Making Connections to Educational Policies

What does *doing* science and engineering involve? Unit 1 introduced common practices such as collecting, analyzing and interpreting data as well as engaging in argument from such evidence. *Doing* science and engineering also involves ways of thinking that bridge across different science domains. What concepts, for example, do biologists, physicists, and chemical engineers all use in their studies?

A. Learning about the US *Next Generation Science Standards: Crosscutting Concepts*

Many US states have adopted the *Next Generation Science Standards* (NGSS Lead States, 2013) for guiding science instruction in their schools. In addition to the science and engineering practices introduced in Unit 1, these standards articulate a group of concepts that are common across many science disciplines. Both the science and engineering practices and these crosscutting concepts are intended to help students learn about and participate in the nature of science.

Question 2.16 What relevant crosscutting concepts have you used in exploring light and thermal phenomena?

- Go to https://www.nextgenscience.org/get-to-know
- Click on Appendix G, scroll down the first page to the list of seven crosscutting concepts that scientists and engineers use across many different contexts:
  - **Patterns**. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
  - **Cause and effect**: Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and

explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

    - **Scale, proportion, and quantity**. In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.
    - **Systems and system models**. Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
    - **Energy and matter**: Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
    - **Structure and function**. The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.
    - **Stability and change**. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study
- Scan the discussion of these crosscutting concepts to see what they are and read about any that you find particularly interesting.
- Put a check in Table II.4 to indicate if you have used a crosscutting concept while exploring light and thermal phenomena in this course.
- For each context, choose one or more crosscutting concepts and describe an example of what you did and learned.

TABLE II.4 Crosscutting concepts (NGSS Lead States, 2013)

TABLE II.4 Crosscutting concepts (NGSS Lead States, 2013)

	Unit 1 Explaining pinhole phenomena and estimating the size of an object	Unit 1 Exploring reflection, refraction, dispersion and explaining rainbows	Unit 2 Distinguishing between heat and temperature	Unit 2 Exploring transfer of energy when mixing hot and cold water
1. Patterns				
2. Cause and Effect				
3. Scale, proportion, and quantity				
4. Systems and system models				
5. Energy and matter: Flows, cycles, and conservation				
6. Structure and function				
7. Stability and Change				

B. Reflecting upon this exploration of thermal phenomena

This unit began by considering what students already knew about thermal phenomena. Children and adults have many experiences in which high temperatures describe hot days and low temperatures describe cold days. They also have many experiences touching objects of many kinds in which some feel colder than others. These prior experiences often lead students to rank paper or Styrofoam, wood, aluminum and steel in order from higher to lower temperatures because these materials feel so different to touch. Most students are surprised to find that items made of these materials all are at the same temperature when measured by a thermometer, rather than by their hands, if the materials have been in the same room for a long time.

Understanding often emerges when someone mentions the idea of *room temperature*, that objects that have been in the same room for a long time are at the same temperature. A helpful nudge usually occurs when someone comments that maybe the materials differ in what happens when one touches them, that metal differs from paper or Styrofoam in some way.

Eventually someone articulates the idea that energy is flowing from one's hand into the metals, that metal is a conductor, and one's hand is losing energy quickly so one's hand feels cold. Paper and Styrofoam, however, are insulators; very little energy is flowing from one's hand into the paper or Styrofoam, so one's hand stays warm. The materials feel different because of their differences in the property of *thermal conductivity*, in how well energy flows into and throughout the material, but their temperatures are the same if left for a long time in the same room.

This process is an example of what scientists and engineers do when they observe something that seems puzzling. They try to figure out what might be happening in order to explain that puzzle; they ponder how to reconcile different ideas that seem applicable but do not agree. This process of refining one's ideas often involves separating and clarifying the differences between some closely related concepts that seem initially to be the same such as *heat* and *temperature*.

After developing relevant central ideas, this unit also modeled the next step, of figuring out how to represent mathematically the relationships one has been exploring with both experimental and theoretical approaches. A series of experiments led to the inference of an *inverse relationship* between the amounts of hot and cold water and their changes in temperature when mixed. Many students express surprise at this inverse relationship as their prior experiences with mathematical ratios typically have been with direct relationships, such as the equal ratios of heights and distances involved in pinhole phenomena. A theoretical approach based on the *Law of Conservation of Energy*, however, confirms this inverse relationship between the masses of hot and cold water and their respective changes in temperature when mixed together. A refinement involves recognizing that the property of *specific heat* also affects how much energy is absorbed or released when the temperature of a material changes. Development of an algebraic equation representing these relationships makes possible numerical predictions and estimates of quantities of interest.

Students may experience some of the frustration that scientists and engineers often face as they struggle to perceive the patterns in their data, particularly when our simple equipment does not yield precise relationships but only trends when the data are compared in various ways. Students also may experience, however, the pleasures that scientists and engineers experience when finally recognizing and confirming both the conceptual and mathematical models developed.

C. Making connections to NGSS understandings about the nature of science

The *Next Generation Science Standards* recommends that students engage in three dimensions of learning science by using science and engineering practices and cross cutting concepts while learning disciplinary core ideas. In this unit, for example, students used the science and engineering practice of *analyzing and interpreting data* when they tracked and interpreted initial and final temperatures while mixing various amounts of hot and cold water. They became aware of the importance of the crosscutting concepts of *systems and system models* while attempting to minimize energy flowing into the cups and air by pouring the cold water into the hot water rather than the hot water into the cold. During these explorations of thermal phenomena, students learned disciplinary core ideas about *conservation of energy and energy transfer.*

This unit also has provided additional examples of understandings about the nature of science as articulated in Appendix H of the *Next Generation Science Standards* https://www.nextgenscience.org/resources/ngss-appendices . The learning progression for the NGSS understanding that *science is a way of knowing*, *f*or example, includes that middle school students should learn that *science is both a body of knowledge and the processes and practices used to add to that body of knowledge*. In this unit, for example, students observed that materials left for a long time in the same room have the same temperature even though the materials may feel warmer or colder when touched. From this, the students gained new knowledge about the role of an object's property, its *thermal conductivity*, in the rate at which such energy transfers occur. By mixing various amounts of hot and cold water, the students developed mathematical ways of tracking the flow of energy in a relatively simple system. This unit thus initiated explorations of such energy transfer processes. This focus continues in considering more complex energy transfer phenomena during local weather in Unit 3 and during global climate change in Unit 4.

XI. Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 2

***Exploring Physical Phenomena*: Summary of Equipment and Supplies for Unit 2**

***Exploring Physical Phenomena*: Summary of Equipment and Supplies for Unit 2**			
When used	For instructor and demonstrations	For each group of 3	For each student
Unit 2 **Week 4** Day 7 **Q2.1 – Q2.5** **Exploring the difference between heat and temperature**		4 blocks (aluminum, steel, wood, paper pad or Styrofoam), or kitchen items made of these materials; Regular bulb and tube liquid thermometer that reads between 0 and 100 degrees C	U2H2. Diagnostic Question about Temperature
Begin Day 7, **Q2.6 – Q2.18** **Exploring energy transfer in the context of mixing hot and cold water**	If in a room without a sink: Big pot with cold water from tap Big pot with hot water from tap or on hot plate Dippers, hot pot holder Big bucket for waste water	Qualitative exploration: 2 digital temperature probes and related software (We use vernier.com probes and Logger lite software) or 2 bulb and tube thermometers); cup for hot water (ceramic or Styrofoam), Plastic cup for cold water, 1 clear plastic cup marked with 1,2,3,4 equal divisions, 2 quart containers for hot and cold water, 2 trays. (laptop computer, perhaps brought to class by group member if using digital temperature probes) U2H1 Exit Ticket	

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 2			
Day 8 Continue exploration of thermal phenomena (Additional time would be helpful for students needing to build skill with algebra) **Question 2.16** **NGSS crosscutting concepts used in Units 1 & 2**	Same equipment as Day 7	Quantitative Exploration: Same equipment as Day 7 (Group creates Table II.2) U2H1 Exit ticket	

U2.Solving a Thermal Math Problem

1. **State the problem** in words
2. **Make a sketch** of the amounts to be mixed
3. **Review what you know** about the physics of this phenomenon: the relevant central ideas
4. **Draw a graph representing the problem** (use a ruler to make straight perpendicular axes, draw flat horizontal lines to represent temperatures that are not changing before the two substances are mixed and the shared equilibrium temperature after the mixing, draw the appropriately shaped graph for mixing more hot than cold or more cold than hot or equal amounts. Draw the graph to indicate whether the changes in temperature happen very quickly or are gradual processes.**)**
5. **Tell the 'story' of the graph** with the relevant central ideas to **explain** why the equilibrium temperature is likely to be where you have drawn it (nearer the temperature of the initial hot water, initial cold water, or in the middle.)
6. **Represent this scenario mathematically**: **State the equation in words** that relates the masses of the substances mixed and their changes in temperature. Use the experimental form of the equation derived from your exploration or the theoretical form based on the Conservation of Energy and **justify the use of the equal sign** accordingly.
7. **Define symbols, state equation in symbols**, and express how you are envisioning this equation.
8. **Solve for the unknown** in symbols
9. **Record given values and estimate any needed**
10. **Substitute values and calculate answer**
11. **Check answer**: why does the number you get from the calculation seem reasonable?

UNIT 3: CONSIDERING THE INFLUENCE OF LIGHT AND THERMAL PHENOMENA ON LOCAL WEATHER

Exploring Physical Phenomena: What happens when light from the Sun shines on the Earth?

Unit 3 Table of Contents

Figures

Tables

I. Introduction

The theme for this course is *what happens when light from the Sun shines on the Earth?* In this unit, you will be exploring the effect of light and thermal phenomena on local weather. While exploring these phenomena, you will be:

- ***identifying resources*** such as everyday knowledge about water and weather
- ***developing central ideas based on evidence*** about the water cycle
- ***explaining intriguing phenomena*** such as why, during a sunny day at the beach, the sand is hot, the water cool, and cloudy skies as well as sea breezes often appear in the afternoon
- ***developing mathematical representations*** of the transfer of energy in various contexts
- ***using mathematical representations to estimate a quantity of interest*** such as predictions about "will it rain tomorrow"? and
- ***making connections to educational policy***, such as the *Next Generation Science Standards* (NGSS Lead States, 2013), the science standards adopted by many US departments of education.

This unit continues exploration of learning processes as well as of physical phenomena. Summarizing and reflecting upon these explorations will foster integrating science and literacy learning. This includes learning to speak clearly, listen closely, write coherently, read with comprehension, and create and critique media.

The main sections present questions with suggestions for exploring topics and for writing reflections about your findings. Text in gray font indicates that these are suggestions; you may think of other ways to explore the topic. Asking your own questions as well as those posed here will enhance learning both about physics and about learning. Check with your instructor if you choose to devise an alternative approach.

Keeping track of what one is doing and thinking is important. In this course, use a template for a physics notebook page on which to record your notes during class. The physics notebook page can help you remember your thoughts *before*, *during*, and *after* an exploration. An experienced elementary teacher, Adam Devittt, designed this notebook page to mirror the structure of *before*, *during*, and *after* reading strategies:

Before starting your exploration, think about and discuss with your group members what you know already about the topic, how you plan to conduct the exploration, and what you think you might find out.

During your exploration, record what is happening, what you are observing, and what you are thinking about what you are observing. Include sketches of equipment and observations. Note any words that are new and their definitions.

After your exploration, record any central ideas that have emerged from your observations and discussions. Also note the evidence on which you have based these ideas. State explicitly how the evidence is relevant and supports the claims you are making in stating the ideas. Also explain why this result is important. Then write a reflection about whatever you want to remember about this experience. In addition, briefly state what you are still wondering in this context.

After class, use your physics notebook pages and any handouts to write a summary of your exploration and findings. Writing such a summary after every class is a good way to prepare for the midterm and final examinations.

Next, to be sure you have understood the physics involved, read this text and some examples of student work. The student authors first wrote drafts, received feedback for ways to enhance content and clarity, and submitted these final versions. Also read about some nuances to be aware of in these contexts.

You may also find helpful students' reflections about teaching friends and/or family members about what they had just learned in class, historical information about ways knowledge about the topic developed, and some relevant aspects of the nature of science in the context of the topic explored. These sections of the text may broaden your understanding of science and of science learning and teaching.

II. Identifying Student Resources

Water is a central player in weather phenomena. The Greek stem *hydro* for water has formed the basis of many English words related to water.

- If a plant wilts, what can you do to revive it?
- If you forget your water bottle on a long hike, what might happen to you?
- What chemical element is a component of water?
- Where is water found on a planet such as the planet Earth?

To *hydrate* something, for example, means to supply a liquid, usually water, to someone or something that needs it; to be *dehydrated* means to be lacking water. The element *hydrogen* is a component of water: two atoms of hydrogen and one of oxygen form one molecule of water (H_2O). The word *hydrosphere* refers to everywhere that water is found on Earth.

A. Connecting to relevant knowledge and experiences

Thinking about how water moves from place to place can provide resources on which to build in learning about weather phenomena.

Question 3.1 What do you already know about water and weather?

- Look at a cup of water. How did the water get there?

  Trace the paths that the water in this cup might have followed to get to where you can see it here.

FIG. 3.1 Cup of water.

Discuss with your group members what you already know about water and how it moves from place to place. Record some of your ideas before reading an example of student work.

1. Example of student work about early experiences with water and weather

A student wrote:

> *In my early years of elementary school, I was taught about the water cycle. When I learned about the water cycle, I learned about the terms that could apply to experiences that I have previously had as a child. For example, I learned that condensation describes the droplets that form on the outside of my water bottle that has ice water in it. Next, I learned that precipitation is what describes that rain that I have seen falling from the sky. Finally, I learned that evaporation is what describes when a water puddle that I see is gone a few hours later. These are experiences that are likely to occur for students, so it is important that they understand what they observe.*
>
> Physics student, Spring 2016

Understanding the physical phenomena underlying the water cycle is the focus of this section.

B. Documenting initial ideas about changes in states of matter

Water exists on Earth in several *states of matter*: solid, liquid, and gas. These also are called *phases of matter*. Ice cubes melting, a puddle of water evaporating, water vapor condensing into fog, and the surface of a pond freezing over are examples of *changes in state* or *phase changes.*

1. Diagnostic Question about States of Matter

Responding to the diagnostic question below will document some of your initial knowledge about the roles of heat and temperature during changes in states of matter.

Name___________________________ Date_____________

Diagnostic Question about Changes in States of Matter

Some ice and a little liquid water are placed in a pot on a hot plate.
When the hot plate is turned on, the ice begins to melt.
After the ice melts, the liquid water warms, and eventually begins to boil.
The boiling continues until the pot is removed from the hot plate.

How does the temperature change during this process?
Illustrate your prediction with a graph of temperature versus time.

III. Developing Central Ideas Based on Evidence

Unit 2 developed the central idea that heat and temperature are different ideas. The next exploration extends this development to examine what happens when water changes state.

A. Exploring the difference between heat and temperature during changes in states of matter

Question 3.2 What happens when ice melts, liquid water warms, and the liquid water eventually boils?

To explore changes in state, assemble:

- rice cooker, pot and hot plate, or pot and stove
- tray of ice cubes
- thermometer
- large binder clip.

We use a digital temperature probe connected to a computer that displays a continuous record of the temperature (see https://www.vernier.com/product-category/?category=temperature-sensors). We set the duration for 1800 seconds (30 minutes) and the temperature scale from about -5 °C to about 110°C. A regular bulb and tube thermometer will work if the scale ranges at least from a little below the freezing point of water (0°C) to a little above its boiling point (100°C).

- In the ***Before*** section of your physics notebook page, predict how the temperature of water changes when a container of ice cubes is placed on a heater and the ice melts, the liquid water warms, and then boils. Sketch a graph of temperature versus time to illustrate your prediction.

- What happens when ice melts, warms, and boils?
- Put some ice and a little water in a container that can be heated such as in a rice cooker or in a pot on a hot plate or on a stove. Place a thermometer or temperature probe connected to a computer in the ice.
- You can use a binder clip to keep the temperature probe or thermometer from touching the bottom of the pan as shown in Fig. 3.2.

FIG. 3.2 Pot with thermometer

- Turn on the heat source and keep its level constant throughout this exploration so that energy is flowing at a constant rate into the system of the pot and the frozen, liquid, and finally boiling water.
- In the ***During*** section of your physics notebook page, record what happens to the temperature when you heat the ice.
- Be sure that the thermometer or temperature probe is not resting on the bottom of the rice cooker or pot but is measuring the temperature of the melting mixture of ice and liquid water. Stir occasionally to be sure the temperature is the same throughout the mixture of melting ice and liquid water.
- Leave the temperature probe in the warming liquid water, stirring as needed, and for a few minutes while the liquid water is boiling.
- If using a regular thermometer, stir and record the temperature repeatedly while the ice melts, the liquid water is warming, and boils.

- Draw and interpret a graph of the recorded temperatures as the ice melts, liquid water warms, and eventually boils.
- Discuss with your group members what the relation is between the energy flowing into the system and the temperature of the water in its various phases and phase changes. Formulate your insights into relevant central ideas.
- In the ***After*** section of the physics notebook page, report these ideas and the evidence on which they are based.
- Write a rationale that explains how the evidence supports the ideas and why these are important.
- Also reflect upon this exploration such as connections you can make to other experiences. How might you use what you learned in your own classroom?
- What are you still wondering?

Enter notes in Table III.1 to represent this exploration:

TABLE III.1 Central ideas about changes in states of matter

TABLE III.1 Central ideas about changes in states of matter			
Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
	Draw complete Temperature versus time graph	Water occurs in three states of matter: solid (ice), liquid, and gas (water vapor).	Solid phase Liquid phase Gaseous phase
	Draw complete graph and highlight relevant section	When solid water (ice) is melting, energy enters the system but the temperature does not change.	Melting Freezing Latent heat of fusion for water (about 80 calories/gram)
	Draw complete graph and highlight relevant section	When liquid water is heated and energy enters the system at a steady rate, the temperature increases at a steady rate.	c =specific heat in calories/(gram °C) specific heat of water = one calorie/(g °C) = energy needed to change the temperature of one gram of water by one degree Celsius.
	Draw complete graph and highlight relevant section	When liquid water is evaporating, energy enters the system but the temperature does not change.	Evaporation Heat of vaporization for water (about 533 calories/gram)

Complete documenting your exploration and writing a summary before looking at an example of student work and discussion of nuances about changes in states of matter.

1. Example of student work about changes in states of matter

Figure 3.1 shows a student's entries into a table about changes in states of matter. The student's summary of ideas about energy transfers during changes in states of matter also appears below.

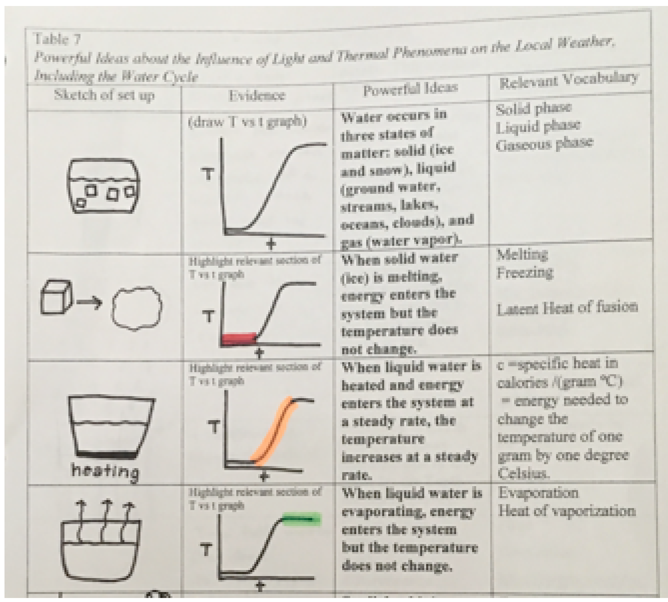


Table 7

Powerful Ideas about the Influence of Light and Thermal Phenomena on the Local Weather, Including the Water Cycle

Sketch of set up	Evidence	Powerful Ideas	Relevant Vocabulary
	(draw T vs t graph)	**Water occurs in three states of matter: solid (ice and snow), liquid (ground water, streams, lakes, oceans, clouds), and gas (water vapor).**	Solid phase Liquid phase Gaseous phase
	Highlight relevant section of T vs t graph	**When solid water (ice) is melting, energy enters the system but the temperature does not change.**	Melting Freezing Latent Heat of fusion
heating	Highlight relevant section of T vs t graph	**When liquid water is heated and energy enters the system at a steady rate, the temperature increases at a steady rate.**	c =specific heat in calories /(gram °C) = energy needed to change the temperature of one gram by one degree Celsius.
	Highlight relevant section of T vs t graph	**When liquid water is evaporating, energy enters the system but the temperature does not change.**	Evaporation Heat of vaporization

FIG. 3.3 Example of student's Table III.1 showing changes in state graph.

Water occurs on Earth in three states of matter: solid (ice and snow), liquid (ground water, streams, oceans, clouds), and gas (water vapor). *Water occurs on Earth in three states of matter. The first state of matter in which water occurs is as a solid. This is when water is in the form of snow or ice. When the same water is heated, it can be in the state of matter of a liquid. This is when water is in the form of ground water, streams, oceans, and clouds. When the same water is boiled, it can be in the state of matter of a gas. This is when the water is in the form of water vapor.*

When solid water (ice) is melting, energy enters the system but the temperature does not change. *(Row 1 of Fig. 3.1) shows a graph of Temperature vs. time. In row*

2, the relevant part of the graph is highlighted. The highlighted part shows what is happening when solid water (ice) is melting. When the ice is melting, energy is entering the system. In the graph, it is seen that the temperature does not change, even though energy enters the system.

When liquid water is heated and energy enters the system at a steady rate, the temperature increases at a steady rate. **(***Row 1 of Fig. 3.1) shows a graph of Temperature vs. time. In row 3, the relevant part of the graph is highlighted. The highlighted part shows what is happening when liquid water is heated. When liquid water is heated, energy from the heat of the rice cooker is entering the system at a steady rate. The graph shows that the temperature is also increasing at a steady rate.*

When liquid water is evaporating, energy enters the system but the temperature does not change. **(***Row 1 of Fig. 3.1) shows a graph of Temperature vs. time. In row 4, the relevant part of the graph is highlighted. The highlighted part shows what is happening when liquid water is evaporating. When liquid water is evaporating, energy is entering the system. The graph shows that the temperature does not change, even though energy enters the system.*

Physics student, Spring 2016

This student has interpreted the flat areas of the graph as phase changes that occurred in which energy continued to flow into the system but the temperature did not change while the ice was melting and while the liquid water was evaporating.

2. *Nuances about changes in states of matter*

This exploration provides an example of refining understandings about the difference between heat and temperature by considering the context of application. Many students draw a straight line when predicting the graph of temperature versus time for melting ice, warming liquid water, and boiling. Such a straight line can seem reasonable given prior experiences in warming things up. A straight line is appropriate for the context of warming the liquid water. When liquid water is warming up, adding energy to the system at a steady rate increases the temperature at a steady rate and a straight inclined line on a temperature versus time graph represents that regular increase in temperature with time.

In the context of changes in state, however, <u>the temperature does not change</u> when adding energy to the system if ice is melting or liquid water is evaporating. The heater is supplying a constant flow of energy into the system of the pot of melting ice or boiling water but the temperature does not change. The temperature does not change because the energy is going into the melting process or into the evaporation process.

According to the learning progression for the structure of matter (PS1.A) articulated in the *Next Generation Science Standards* (Lead States, 2013), in the early elementary grades students are to focus upon observable properties such as whether a substance is a solid, liquid, or gas. Young students are not expected to envision what is happening to particles too small to see. By middle school, however, students are expected to understand that materials are composed of atoms and molecules, that atoms and molecules vibrate while bound together firmly in solids and loosely in liquids, and that atoms and molecules are free to move around in gases.

Changes in temperature involve changes in the *kinetic energy* of the molecules. *Kinetic energy* refers to energy associated with motion. Higher temperatures are associated with higher vibration rates among molecules in solids and liquids and with higher speeds for molecules in gases. See https://phet.colorado.edu/en/simulation/states-of-matter-basics for a simulation for the movement of water molecules in solid, liquid, and gaseous states.

During melting and evaporating, the incoming energy goes into breaking bonds between the molecules in solids and liquids rather than into increasing the rates of vibration. During freezing and condensing, energy is released as such bonds form among atoms and molecules.

The energy involved in changing states is known as *latent heat*. The adjective *latent* refers to something that is hidden or concealed. *Latent heat* refers to incoming or outgoing energy that is not detectable by a change in temperature. The energy needed to melt a gram of ice, the *latent heat of melting*, is about 80 calories. The energy released when a gram of liquid water freezes, the *latent heat of fusion*, also is about 80 calories. The energy needed to evaporate a gram of liquid water, the *latent heat of vaporization*, is about 533 calories. The energy released when a gram of water vapor condenses, the *latent heat of condensation*, is also about 533 calories.

Scientists and engineers design and use *phase change materials* to cool buildings. Microscopic pellets of phase change materials added to insulation absorb energy as they melt during the day, for example, keeping a roof cool, and release energy as they freeze at night. See http://tll.mit.edu/help/latent-heat for a discussion of latent heat and its engineering application in designing ways to cool buildings. This is an example of *Identifying situations that people want to change as a problem that can be solved through engineering*, an aspect of *engineering design* that children as young as K-2 are expected to understand according to the *Next Generation Science Standards* (NGSS, Lead States, 2013) (See NGSS Appendix I https://www.nextgenscience.org/resources/ngss-appendices .

B. Exploring phase changes in which water absorbs or releases energy

The *water cycle*, sometimes called the *hydrologic cycle*, involves water in its many phases and phase changes. The phase changes occur both when water is absorbing energy as well as when it is releasing energy. Such phenomena are the focus of the next explorations.

Question 3.3 What are some everyday examples of water absorbing energy when water changes state?

Light from the Sun can supply energy for changing the phase of water.

You can explore such changes outside on a sunny day or inside with:

- lamp
- tray
- food coloring
- source of water
- large plastic bag
- houseplant
- access to the Internet.

- In the ***Before*** section of a physics notebook page, note some examples of phase changes of water that involve absorbing energy. What are some ways to explore these?

For example:

- What happens to puddles during a sunny day?
- Pour a little liquid water onto a tray. Add a drop of food coloring to make the puddle easier to see.
- Place the tray outside in sunlight or inside near a lamp shining on the puddle. What happens after 15 minutes? An hour?

FIG. 3.4 *Evaporating puddles by 四代目火影 CC BY-SA 4.0 https://commons.wikimedia.org/wiki/File:Puddle,_Vas%C3%BAt_utca,_Zichy%C3%BAjfalu_001.jpg*

This phase change from liquid to gas is called *evaporation*. Fig. 3.4 illustrates puddles that are in the process of evaporating. How quickly a puddle evaporates depends upon the temperature and how much water is already in the air. The warmer the temperature, the more moisture the air can hold. For more information, see https://water.usgs.gov/edu/watercycleevaporation.html and http://www.waterandclimatechange.eu/evaporation

- What happens on a hot dry day when you sweat? How does sweating cool you off?
- What happens on a hot humid day? Why does sweating not cool you then?

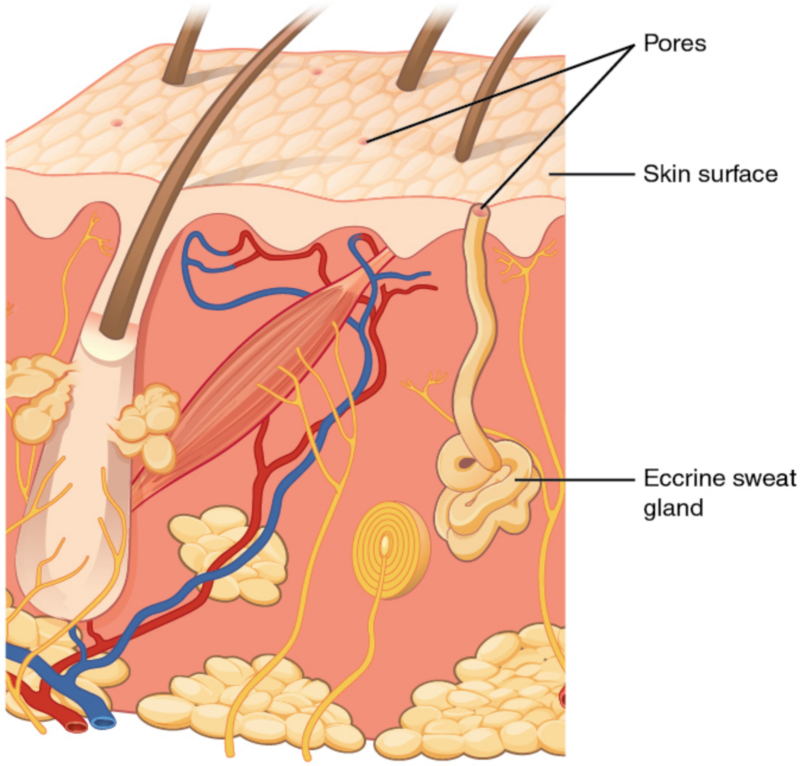


Fig. 3.5 Illustration of sweat glands that produce perspiration by OpenStax College [CC BY 3.0] https://commons.wikimedia.org/wiki/File:508_Eccrine_gland.jpg

Sweat is a form of moisture called*perspiration.* Fig. 3.5 illustrates the sweat glands in your skin. These help your body cool itself by producing perspiration that absorbs energy from your body when the moisture evaporates.

Relative humidity compares how much water vapor is in the air to how much water vapor the air can hold at a given temperature. A prediction of hot muggy weather with high relative humidity means that the air will be very humid, holding close to as much water vapor as possible. This means that very little perspiration will be able to absorb energy from your body and cool you by evaporating from your skin.

- What happens when sunlight shines on plants?
- Cover a houseplant with a plastic bag and place in sunlight outside or inside near a lamp so the lamp is shining on the plant as shown in Fig. 3.6. What happens after 15

minutes? An hour?

FIG. 3.6. Demonstration of transpiration.

This form of evaporation is called *transpiration.* The drops of water that form on the plastic bag have evaporated from the leaves and then condensed on the cooler inner surface of the bag. Plants use some energy from the Sun to grow via photosynthesis; some energy from the Sun, however, is absorbed by liquid water evaporating from the leaves. Transpiration from an acre of corn, for example, can total as much as three to four thousand gallons of water each day (see https://water.usgs.gov/edu/watercycletranspiration.html).

- What sometimes happens to ice and snow on high mountains?

FIG. 3.7 Example of sublimation on Mt. Everest. Image by Simon Steinberger from Pixabay https://pixabay.com/photos/mount-everest-himalayas-nepal-413/

Another form of evaporation occurs when ice or snow changes directly into a gaseous form of water without a liquid phase as shown in Fig. 3.7. This form of evaporation is called *sublimation*. See https://water.usgs.gov/edu/watercyclesublimation.html for additional information about sublimation directly from a solid to a gas.

Water also absorbs energy when changing from a solid phase to a liquid:

- What happens when ice warms?
- Place an ice cube outside in the sunlight or inside near a lamp so the lamp is shining on the ice cube as shown in Fig. 3.8. What happens after 15 minutes? An hour?

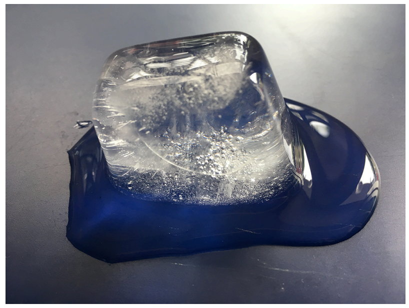


FIG. 3.8 Ice cube in a warm room.

This phase change is called *melting*. During the summer melt season in the Arctic, more sea ice has been melting than sea water has been freezing during winter in recent years. (See the National Snow and Ice Data Center Arctic Sea Ice News and Analysis at https://nsidc.org). For information about melting snow and ice, see: https://water.usgs.gov/edu/watercyclesnowmelt.html.

As shown in Fig. 3.9, melting sea ice forms fresh water *melt ponds* in depressions in the surface.

FIG. 3.9 Melting sea ice during summer in the Artic. Image by Kathryn Hansen | NASA Goddard Space Flight Center used under CC BY 2.0 https://earthobservatory.nasa.gov/images/51335/ponds-on-the-ocean

- Record your findings, including sketches, in the *During* section of the physics notebook page
- Discuss these examples of phase changes that absorb energy and formulate some central ideas that summarize your findings. Record these in the *After* section of the physics notebook page.
- Write a rationale that explains how the evidence supports the ideas and why these are important.

Phase changes also occur in the opposite direction, when phase changes of water release rather than absorb energy.

Question 3.4 What are some everyday examples of water releasing energy when water changes state?

To explore such phase changes, you can use:

- ice cold glass of water
- tray
- wide mouth jar
- hot water to fill jar about half way
- small cup that fits in opening of jar or jar lid
- ice to put in the cup or on lid

- In the ***Before*** section of a new physics notebook page, note some examples of phase changes of water that involve releasing energy. What are some ways to explore these?

For example:

- What happens if you are wearing eyeglasses when you walk inside during winter? Or get out of a hot bath and look at a mirror?
- What happens if you bring an ice-cold container of water into a warm room? For an

extra effect, use food coloring to make colored ice cubes and use those to cool the drink. What happens after 15 minutes? An hour? Are the water droplets that form on the outside of the container clear or the color of the melting ice cubes?

FIG. 3.10 Demonstration of condensation.

This phase change is called *condensation*. For more information, see https://water.usgs.gov/edu/watercyclecondensation.html. Read about the role of latent heat released from condensing water droplets in thunderclouds and hurricanes at http://climate.ncsu.edu/edu/Heat . As water vapor condenses into droplets, the heat released warms the surrounding air, causing instability in the cloud as the warm air rises.

What happens sometimes if liquid water in the atmosphere coalesces into very large droplets?

- Place a wide mouth jar on a tray. Pour some hot water into the jar, about half full. Place a cup of ice into the mouth of the jar so it just fits or simply put some ice on the upside-down lid on top of the jar. What happens after 15 minutes? An hour?

FIG. 3.11 Demonstration of precipitation.

This is called precipitation. For more information, see https://water.usgs.gov/edu/watercycleprecipitation.html . The higher the average temperature of the atmosphere, the more water evaporates; the more water in the atmosphere, the more rainfall can occur. For information about changes in heavy rainfall events in the U.S, see http://climatesmartfarming.org/changing-climate/ .

What happens if liquid water gets cold enough?

FIG. 3.12 Illustration of freezing liquid water to make ice cubes.

FIG. 3.13 Freezing winter weather. CC0 Public Domain. [*https://www.maxpixel.net/Leann-Snow-Coldly-Winter-Weather-Landscape-3077971*](https://www.maxpixel.net/Leann-Snow-Coldly-Winter-Weather-Landscape-3077971)

If the temperature gets cold enough, a liquid freezes into a solid form. This can occur in a controlled situation in a refrigerator or in nature during a winter storm. As liquid water freezes, energy is released. Some farmers spray crops like oranges with water to protect the crops from freezing. Why would this work? See: http://fruitgrowersnews.com/article/protecting-your-fruit-from-frost-and-freeze/

- Record findings, including sketches, in the *During* section of this physics notebook page.
- Discuss these examples of phase changes that release energy and formulate relevant central ideas. In the ***After*** section of this physics notebook page, report these ideas and the evidence on which they are based.
- Write a rationale that explains how the evidence supports the ideas and why these are important.
- Also reflect upon these explorations of phases changes, both those that absorb and those that release energy. What connections can you make to other experiences? How might you use what you learned in your own classroom?
- What are you still wondering?

C. Exploring convection phenomena

Liquids and gases are called *fluids*. Fluids can flow from one place to another. When streams of warm and cool liquid water are flowing nearby, *convection* phenomena occur. Convection also occurs with nearby streams of warm and cool air.

Question 3.5 What happens when convection occurs?

To explore convection phenomena, you can use:

- blue food coloring
- ice cube tray to make blue ice cubes in a freezer

- clear plastic rectangular container such as a shoe storage box or a clear glass loaf dish
- four paper cups and one cup that can hold almost boiling water
- source of water to fill container
- red food coloring in small bottle or eyedropper
- very hot water (close to boiling)

- In the ***Before*** section of a physics notebook page, predict what you think will happen when a stream of warm water and a stream of cold water are flowing in a clear plastic or glass container of water. Also describe a way to explore such convection currents.
- Set four paper cups upside down at four corners of a rectangle so that they can support a rectangular container such as a clear plastic shoebox or glass loaf dish.
- Fill the clear container with room temperature water and place it on the 4 cups.
- Carefully use an eyedropper or small bottle of food coloring to place a red drop on the bottom of the clear container at one end.
- Choose a cup that can hold very hot water so that you can slide it underneath the clear container.
- Fill this cup with very hot (close to boiling) water. Slide the cup of hot water under the container so that it is positioned underneath the dot of red food coloring on the bottom of the container
- What happens to the water above the red dot?
- Carefully add some blue ice cubes to the water at the other end of the container.
- What happens to the blue water melting from the ice cubes?
- What happens to the blue and red streams of water?

FIG. 3.14 Demonstration of convection currents.

- Record findings, including sketches, in the *During* section of this physics notebook page
- Discuss your findings and formulate a relevant central idea about convection currents. In the ***After*** section of the physics notebook page, report this idea and the evidence on which it is based.
- Write a rationale that explains how the evidence supports the idea and why this is important.
- Also reflect upon this exploration such as what connections can you make to other experiences? How might you use what you learned in your own classroom?
- What are you still wondering?

1. *Nuances about convection phenomena*

Convection phenomena occur when fluids differ in how dense they are. Density is a measure of how much mass a material has in a given volume. Something will sink in a fluid if it has more mass in a given volume than the fluid; something will rise in a fluid if it has less mass than the fluid in a given volume.

In this course, we measure mass in grams and volume in cubic centimeters. At standard atmospheric pressure, room temperature water (about 21°C) has a density of about 0.998 grams per cubic centimeter. Hot water close to boiling (about 93°C) has a density of about 0.963 grams per cubic centimeter, so it rises in the room temperature water. Cold water melting from an ice cube (about 4°) has a density of about 1.000 grams per cubic centimeter so it sinks in the room temperature water (see: https://water.usgs.gov/edu/density.html). These small differences in density of warm and cold water are enough to cause the convection currents observed.

Ocean currents are caused both by differences in temperature and by differences in salinity. Warm water from the tropics moves near the surface of the oceans toward the poles; cold water from the poles, being more dense, flows toward the tropics at a deeper level. Fresh water from melting glaciers reduces salinity; freezing sea ice leaves salt and other minerals behind in the ocean, increasing salinity with saltier water sinking and fresh water rising. Currents of water travel across the globe via the *Great Ocean Conveyor Belt*, which takes about 1000-1200 years for water to circulate throughout the global system (see: https://www.weather.gov/jetstream/circulation).

D. Summarizing the water cycle

A variety of physical processes underlie the phases and changes-in-phases of water known as the water cycle.

Question 3.6 What is the water cycle?

The water cycle includes the phases of solid (ice and snow), liquid (ground water, lakes, streams, rivers, ocean), and gas (water vapor), in addition to the changes-in-phases known as freezing, melting, sublimating, evaporating, transpiring, perspiring, and condensing. Briefly describe each exploration in Table III.2.

Complete documenting your explorations and writing a summary before looking at an example of student work about explorations of the water cycle.

TABLE III.2 Central ideas about the influence of light and thermal phenomena on local weather, including the water cycle

TABLE III.2 Central ideas about the influence of light and thermal phenomena on local weather, including the water cycle			
Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
		The Sun radiates energy in all directions, some of which shines on the Earth. This process is called *energy transfer by radiation.*	Radiation https://www.windows2universe.org/sun/spectrum/multispectral_sun_overview.html
		Sunlight shining on Earth sometimes supplies enough energy for some liquid water in the soil or bodies of water to evaporate.	Evaporation http://water.usgs.gov/edu/watercycleevaporation.html
		Sunlight sometimes supplies enough energy for snow and ice to sublimate directly into the gaseous phase.	Sublimation http://water.usgs.gov/edu/watercyclesublimation.html
		Water also evaporates from plants. This is called transpiration.	Transpiration http://water.usgs.gov/edu/watercycletranspiration.html

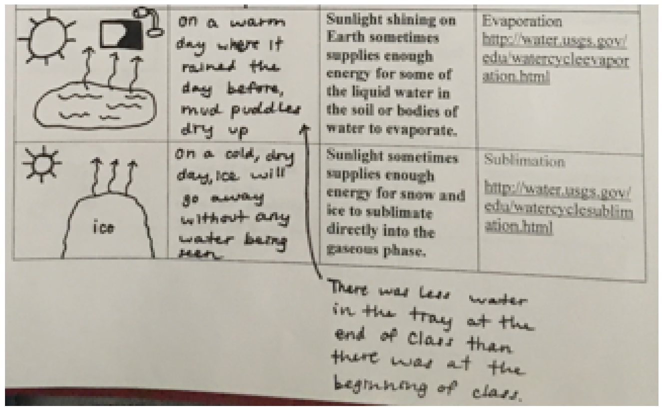
		Water also evaporates from people. This is called perspiration.	Perspiration http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/sweat.html
		Condensation occurs when warm moist air cools; gaseous water (water vapor) condenses into liquid water droplets to form clouds, fog, or dew.	Condensation http://water.usgs.gov/edu/watercyclecondensation.html
		Precipitation occurs when water droplets coalesce and fall to the Earth as rain, snow, or hail.	Precipitation http://water.usgs.gov/edu/watercycleprecipitation.html Coalesce http://scijinks.jpl.nasa.gov/rain/
		Rain falls to Earth and water flows downhill due to the force by the Earth known as *gravity*.	Force of gravity by the Earth https://spaceplace.nasa.gov/what-is-gravity/en/
		Temperature differences within fluids cause differences in density. Less dense warm regions rise and more dense cool regions sink. This process is called *energy transfer by convection.*	Fluid Convection current https://www.youtube.com/watch?v=IpHAj4R-Z8

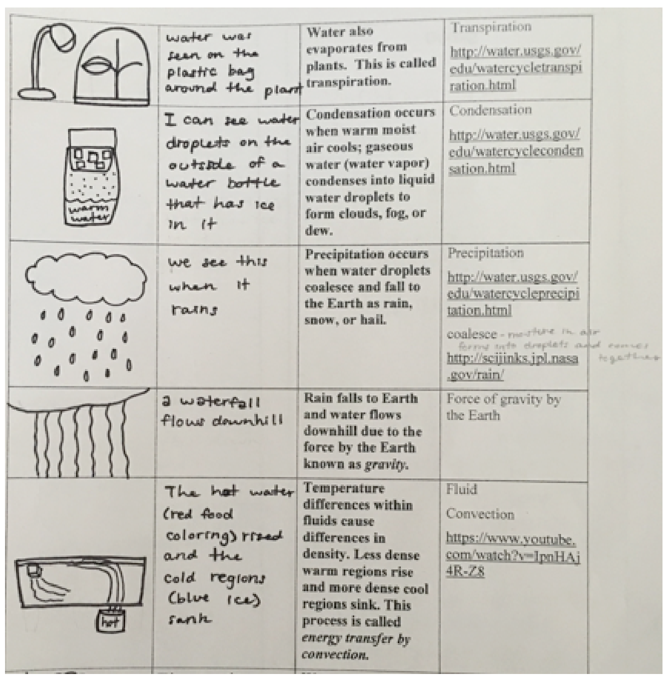
		Water cycles among land, bodies of water, and the atmosphere.	Hydrosphere http://water.usgs.gov/edu/watercycle.html

1. Example of student work about explorations of the water cycle

Figure 3.15 shows a student's entries into a table about phase changes and convection currents that occur during the water cycle.

Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary





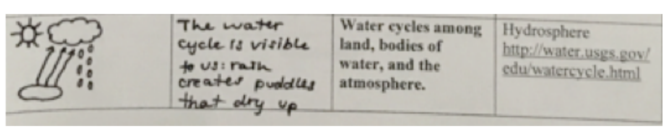


FIG. 3.15 Example of a student's entries into Table III.2 about the water cycle.

In row 1, which focused upon evaporation, the student drew a picture of a sun shining on a puddle with arrows pointing upward representing evaporating water, the natural phenomenon being modeled by the equipment drawn in the upper right corner, a tray with a puddle of water on which a lamp is shining. The student wrote, O*n a warm day where it rained the day before, mud puddles dry up* and added the statement, T*here was less water in the tray at the end of class than there was at the beginning of class*.

In row 2, which focused upon sublimation, the student drew a picture of the sun shining on ice on a mountain with arrows pointing upward representing water sublimating directly from ice into water vapor. The student wrote, O*n a cold, dry day, ice will go away without any water being seen.*

In row 3, which focused upon transpiration, the student drew a picture of a lamp shining on a plant enclosed in a clear plastic bag. The student wrote, W*ater was seen on the plastic bag around the plant*.

In row 4, which focused upon condensation, the student drew a picture of a large jar filled part way with warm water, with a cup with ice cubes sitting in its opening, and droplets of water on the bottle. The student wrote, I *can see water droplets on the outside of a water bottle that has ice in it*.

In row 5, which focused upon precipitation, the student drew a picture of a rain falling from a cloud. The student wrote, W*e see this when it rains*.

In row 6, which focused upon the force of gravity by the Earth, the student drew a picture of a waterfall and wrote, A *water fall flows downhill*.

In row 7, which focused upon convection, the student drew a picture of a clear plastic container filled with water, with a blue ice cube floating at the left end with melting blue water streaming down and with a hot cup under red food color at the right end with a stream of red water floating up and over toward the ice cube. The student wrote, T*he hot water (red food coloring) rised and the cold regions (blue ice) sank*.

In row 8, which focused on the water cycle, the student drew a picture of the sun, shining on a puddle with arrows, representing evaporating water, pointing up toward a cloud and with raindrops falling down. The student wrote, T*he water cycle is visible to us: rain creates puddles that dry up*.

The student wrote the following rationales for the central ideas claimed in the third column of the table:

> ***Sunlight shining on Earth sometimes supplies enough energy for some of the liquid water in the soil and bodies of water to evaporate.*** *My sketch of the evaporation demonstration is seen in (row 1of the table). For this demonstration, we had a tray of water, which represents some of the liquid water in the soil and bodies of water. There was also a lamp that was shining on the water, which represents the sunlight shining on the Earth. In this demonstration, we observed the water at*

the beginning of class and at the end of class. Since there was less water in the tray at the end of class than at the beginning of class, this shows that some water was evaporated. This model is a demonstration that shows that sunlight shining on earth sometimes supplies enough energy for some of the liquid water in the soil and bodies of water to evaporate.

Sunlight shining on Earth sometimes supplies enough energy for snow and ice to sublimate directly into the gaseous phase. *Sublimation occurs if snow or ice vaporizes directly into the gaseous phases without first melting and going through the liquid phase.*

Water also evaporates from plants. This is called transpiration. *My sketch of the transpiration demonstration is seen in (row 3 of the table). For this demonstration, a plastic Ziploc bag was placed around a plant. A lamp was shining on the plant. Some water droplets were able to be seen on the bag, which demonstrates this process of water evaporating from plants, which is called transpiration.*

Condensation occurs when warm moist air cools; gaseous water (water vapor) condenses into liquid water droplets to form clouds, fog, or dew. *My sketch of the condensation experiment is seen in (row 4 of the table). For this experiment, a jar was filled with warm water. Then, a container with ice in it was placed on the top of the jar. The warm moist air that is in the jar, below the container, cools because of the ice in the container on the top of the jar. Water droplets form on the bottom of the container and on the sides of the jar, which is the gaseous water that has condensed into liquid water droplets. This process of the gaseous water condensing into liquid water droplets is how clouds form.*

Precipitation occurs when water droplets condense, coalesce, and fall to the Earth as rain, snow, or hail. Rain falls to Earth and water flows downhill due to the force by the Earth known as gravity. *My sketch of a precipitation demonstration is seen on (rows 5 and 6 of the table). First, I drew water droplets falling to the Earth as rain, which shows the process of precipitation. Then, I drew the water flowing downhill in the form of a waterfall, due to the force of gravity.*

Temperature differences within fluids cause differences in density. Less dense warm regions rise and more dense cool regions sink. This process is called energy transfer by convection. *My sketch of the convection experiment can be seen in (row 7 of the table). For this experiment, a container of room temperature water was placed on four cups. Warm water was colored red by food coloring and was warmed by very hot water that was placed directly below the food coloring. The warm water* *first rose up from the bottom of the container toward the top, and then it started moving horizontally along the top of the water toward the ice cube. Then, the blue ice cube that was placed on the top of the water was observed. The blue melted water first sank down to the bottom of the water and then it moved horizontally along the bottom of the container toward the red food coloring. These movements set up a circular current within the container. The hot water rising and the cold water sinking created convection currents. This idea of warm regions rising and cool regions sinking can also be seen in ocean currents.*

Water cycles among land, bodies of water, and the atmosphere. *Figure* (3.3) *shows the water cycle.*

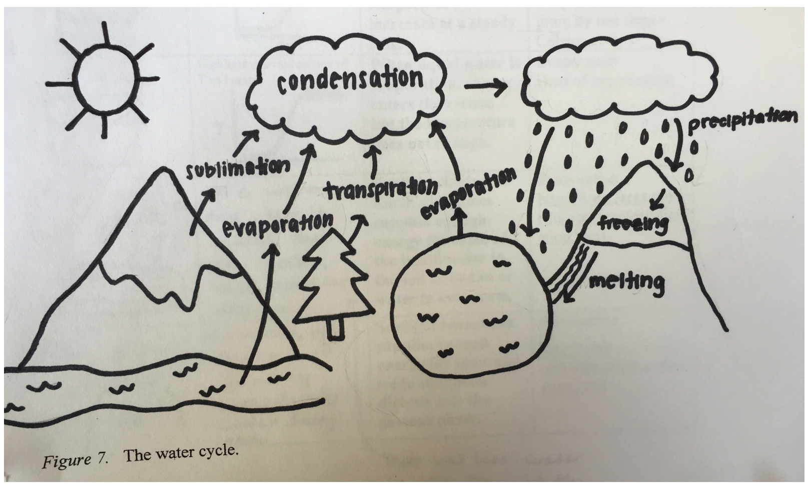


FIG 3.16 *Example student's diagram of the water cycle.*

The student has included labels with the phase changes of *evaporation*, *sublimation*, *transpiration*, *condensation*, *precipitation*, *freezing and melting* as well as illustrations of snow on the mountains, rain falling, clouds in the sky, and bodies of liquid water on the Earth. The student described the water cycle as follows:

First of all, the sun heats up the water and turns it into water vapor. The water vapor leaves the source and goes into the air. The water vapor comes from different forms of water on earth such as lakes and rivers through the process of evaporation, it comes from plants through the process of transpiration, and it comes straight from ice or snow without melting first through the process of sublimation. Once the water vapor rises, it goes through the process of condensation. Condensation is when the water vapor in the air becomes cold and turns back into a liquid, forming clouds. Once enough water has condensed and the clouds are full, the water falls to the *ground, which is known as precipitation. Some of the water falls back into oceans, lakes, rivers, or other water sources. Other parts of that water can be stored in ice or snow, which is known as freezing. Then, when that frozen snow or ice becomes liquid water again, this is known as melting. This process of the water cycle is continuous and will repeat itself again and again.*

Physics student, Spring 2016

The next section develops some additional central ideas useful in explaining intriguing phenomena that students may experience when enjoying a sunny day at the beach.

IV. Developing Additional Central Ideas Based on Evidence

A sunny day at the beach can be a lot of fun. Why does the sand get so hot, however, while the water is so cool when the sun has been shining on both the sand and the water in the same way for the same time? Sometimes the sky clouds over and a breeze comes up in the afternoon. Why does that happen? This section explores how light and thermal phenomena sometimes affect the local weather during a sunny day at the beach.

A. Exploring the effects of properties of materials

Question 3.7 What happens when light shines on sand and water?

Equipment: To explore the effects of various properties on what happens when light shines on sand and water, use:

- Lamp with bendable stem,
- Light probe connected to a computer with graphing software or cell phone app for reflectivity (LUX meter)
- Black paper, white paper
- Two identical clear cups
- Balance
- **Sand and water at room temperature**
- Two temperature probes, and a computer or two regular bulb and tube thermometers with a range from at least about 15°C to 35°C.

[In a remote learning situation, brown rice, split peas, or dried beans can serve as a substitute for sand if necessary. A simple balance can be made with a board (a ruler will do) and something on which to balance it like a playground teeter totter. Set this up so it is balanced and then use two identical clear cups to put about half a cup of water on one side and as much sand as you need to balance it on the other side.]

- What properties of sand and water might affect what happens when light from the Sun shines in the same way for the same time on both the sand and the water?
- In the ***Before*** section of a physics notebook page, record your ideas and predictions about the effect of properties explored in units 1 and 2: reflectivity, thermal conductivity, and specific heat. How can you explore the effects of these properties of sand and water on what happens when sunlight shines on a beach?
- To explore the property of reflectivity, move a light probe connected to a computer or a cell phone with a LUX meter app over black and white paper as well as over sand and water. Does the angle of reflection seem to matter?
- One way to explore differences in thermal conductivity and specific heat is to use equal amounts of the materials. Should one use equal amounts by mass or by volume?
- The property of specific heat is expressed in terms of the number of calories needed to change the temperature of one unit of mass by one degree Celsius so equal amounts by mass seem appropriate. Use a balance and identical clear cups to measure equal masses of sand and water at **room temperature**. Compare the volumes of the equal masses of sand and the water in the cups. What does this imply about the density of sand compared to the density of water?
- Set up a lamp with curved stem shining from the same distance away on cups with equal masses of sand and water at room temperature.
- Put both temperature probes in the same cup of water to make sure that they read the same number if put in the same container. If the probes do not read the same or close to the same number (within 0.2°C or so), calibrate them in the computer. If using regular thermometers, put both in the same cup of water and see if they read the same number; if they do not, record their temperatures and correct the final readings for this difference.
- Connect the two temperature probes to a computer and place one probe near the **top** of the cup of water and the other probe near the **top** of the cup of sand. Set the time on the computer for 900 seconds, about 15 minutes. (Or place regular thermometers near the tops of the sand and water and regularly read and record the temperatures while the lamp is shining on the cups of sand and water).
- Start the computer program (or use the regular thermometers) to record the initial

temperatures of the sand and water. If both the sand and the water have been sitting in the same room for a long time, these temperatures should be the same or close to the same (within a degree or so). If they are not the same, record the temperatures and include this difference in interpreting your results.

- Turn on the lamp. Monitor the temperatures of the sand and water, by looking at the temperature versus time graphs on the computer (or regularly record the regular thermometer readings at least every minute).
- What do you observe after at least 10 minutes?
- Move the temperature probes (or thermometers) to near the bottom of the cups. What do you observe?
- In the ***During*** section of the physics notebook page, record your findings. Draw a picture of the temperature versus time graph and indicate the parts of the graph that represent the different materials that you tested. Note any vocabulary that is new to you.

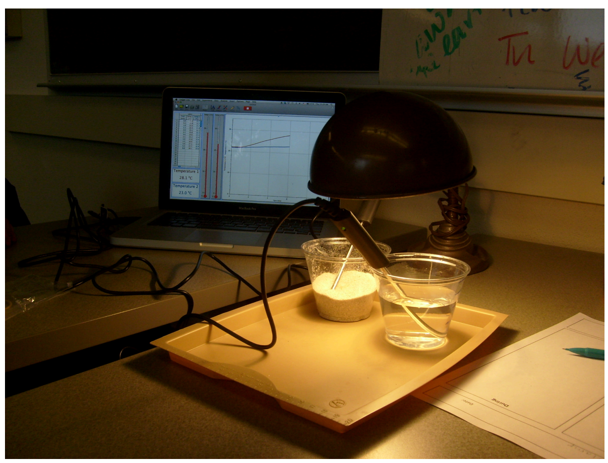


Fig 3.17 End of experiment to compare the way that energy from a lamp warms up sand and water. Line graph shows temperature versus time for sand (red) and water (blue). Note the difference in heights of the equal masses of sand and water. Which is more dense? ©Vernier Software & Technology-used with permission.

- Discuss your findings and formulate relevant central ideas. In particular, compare the slope of the graph for sand with the slope of the graph for water.
- Compare the change in temperature of the sand during ten minutes with the change

in temperature of the water during ten minutes. How is this result related to a comparison of how much the temperature changes for each unit of time (one minute)? How is this result related to a comparison of how much the temperature changes for each unit of incoming energy from the lamp?

- Also discuss findings about the reflectivity of black and white paper and of sand and water. Compare your findings with those by other groups. Do they agree?
- Formulate central ideas based on the findings.
- In the ***After*** section of the physics notebook page, report these central ideas and the evidence on which they are based.
- Write a rationale that explains how the evidence supports the central ideas and why these are important.
- Also reflect upon this exploration such as what connections can you make to other experiences? How might you use what you learned in your own classroom?
- What are you still wondering?

Enter notes in Table III.3 representing these explorations:

TABLE III.3 Central ideas about the properties of materials

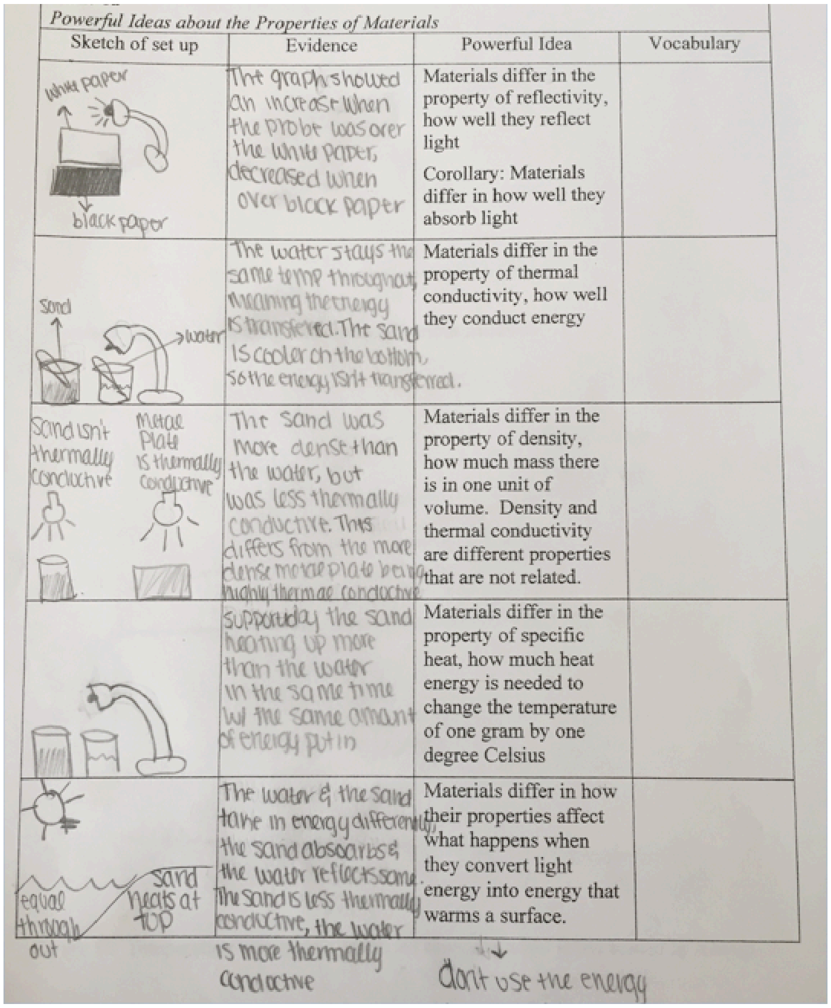
TABLE III.3 Central ideas about the properties of materials			
		Materials differ in the property of reflectivity, how well they reflect light Corollary: Materials differ in how well they absorb light	
		Materials differ in the property of thermal conductivity, how well they transfer energy	
		Materials differ in the property of density, how much mass there is in one unit of volume. Density and thermal conductivity are different properties that are not related.	

	Compare the change in temperatures, ΔT for sand and ΔT for water , during 10 minutes with the lamp shining equally on sand and on water.	Materials differ in the property of specific heat, how much energy is needed to change the temperature of one gram by one degree Celsius.	
		Materials differ in how their properties affect what happens when they convert light energy into energy that warms a surface.	

Complete documenting your exploration and writing a summary before looking at an example of student work. Also consider nuances about exploring the effect of thermal conductivity, specific heat, and reflectivity on what happens when light shines on sand and water.

1. Example of student work about what happens when light shines on sand and water

Figure 3.18 shows a student's entries into a table about ideas about properties of materials. The student's summary also appears below.


Powerful Ideas about the Properties of Materials

Sketch of set up	Evidence	Powerful Idea	Vocabulary
white paper; black paper	The graph showed an increase when the probe was over the white paper, decreased when over black paper	Materials differ in the property of reflectivity, how well they reflect light Corollary: Materials differ in how well they absorb light	
sand; water	The water stays the same temp throughout meaning the energy is transferred. The sand is cooler on the bottom, so the energy isn't transferred.	Materials differ in the property of thermal conductivity, how well they conduct energy	
sand isn't thermally conductive; metal plate is thermally conductive	The sand was more dense than the water, but was less thermally conductive. This differs from the more dense metal plate being highly thermal conductive	Materials differ in the property of density, how much mass there is in one unit of volume. Density and thermal conductivity are different properties that are not related.	
	supporting the sand heating up more than the water in the same time w/ the same amount of energy put in	Materials differ in the property of specific heat, how much heat energy is needed to change the temperature of one gram by one degree Celsius	
equal throughout; sand heats at top	The water & the sand take in energy differently, the sand absorbs & the water reflects some. The sand is less thermally conductive, the water is more thermally conductive	Materials differ in how their properties affect what happens when they convert light energy into energy that warms a surface. don't use the energy	

FIG. 3.18 Example of student's entries into Table III.3 about properties of materials.

In row 1, the student drew a picture of a light shining on white and black paper. The student wrote, *The graph showed an increase when the probe was over the white paper, decreased when over black paper*.

In row 2, the student drew a picture of a cup with sand and a cup with water, each with a temperature probe, and a light shining on the cups. (Note that the student indicated more rather than less sand than water.) The student wrote, *The water stays the same temp throughout, meaning the energy is throughout. The sand is cooler on the bottom so the energy isn't transferred.*

In row 3, the student drew a picture of a cup of sand and a metal plate, with a light shining on each, and notes *sand isn't thermally conductive* and *metal plate is thermally conductive*. The student wrote, *The sand was more dense than the water, but was less* *thermally conductive. This differs from the more dense metal plate being highly thermally conductive.*

In row 4, the student drew a picture of a light shining on a cup with sand and a cup with water. The student wrote, *Supported by the sand heating up more than the water in the same time with the same amount of energy put in*. (Note that the student again drew containers with higher rather than lower sand than water).

In row 5, the student drew a sun shining on a beach with sand and water, with labels *equal throughout* in the water and *sand heats at top* in the sand. The student wrote, *The water and the sand take in energy differently, the sand absorbs and the water reflects some. The sand is less thermally conductive, the water is more thermally conductive.* The student also drew a light and a dark arrow with the note *don't use the energy*.

The student wrote the following rationales for the ideas claimed in the third column of the table:

> ***Materials differ in the property of reflectivity, how well they reflect light. Corollary: Materials differ in how well they absorb light. …****The white paper showed an increase on the graph, because it has greater reflectivity and the black paper showed a decrease on the graph, because it has lower reflectivity. We also compared the reflectivity of the dry sand and water with a light sensor. The reflectivity of water depends upon the angle at which the light source is shining on the water. Water is highly absorbent when the Sun in high and more reflective when the sun is shining on it at an angle…*
>
> ***Materials differ in the property of thermal conductivity****. Thermal conductivity is how well a material transfers energy. The second row of (the table) shows the light source shining equally on the equal masses of water and sand. For ten minutes the light was shining over both cups with temperature probes in the cups.*
>
> *After ten minutes, the water warmed from an initial temperature of 21.6°C to 22.9°C throughout the cup of water. The temperature near the top of the sand was 31.1°C. The temperature near the bottom of the sand was the same as the initial temperature, which was 24.4°C. I would infer that the water has higher thermal conductivity because the temperature was the same throughout the substance, meaning energy was transferred from the top to the rest of the liquid.*
>
> *The same amount of light shined for the same amount of time on the same mass of water and dry sand, but the temperature of the sand was hotter on the top than the bottom. The water was the same temperature throughout, therefore the sand kept more of the energy it absorbed near the surface of the sand.*

Materials differ in the property of density, how much mass there is in one unit of volume. *The third row of (the table) describes this idea. When I was filling the cups with equal masses of sand and water I had to add some sand. I added a little bit of sand and put the cup on the scale, which showed the sand weighed much more than the water. I poured a little of the sand out and scale showed the sand cup was much lighter than the water. The little bit of the sand made a big difference, showing sand is dense. The sand was denser, so there was less sand (by volume) in the cup than water in the cup. If sand was added to water, the sand would sink to the bottom, demonstrating the sand is denser. Water is the standard, so the mass of one gram of water has a volume of one cubic centimeter at 4°C. The density of the sand is approximately 1.6 grams for each cubic centimeter.*

The metal plate appeared denser than the Styrofoam plate that we experimented with before. The metal plate had more thermal conductivity than the Styrofoam plate, which was demonstrated by the cool feeling we experienced when touching the metal plate. When touching the Styrofoam plate there was no temperature change felt. The sand was denser than the water, but as demonstrated above, the sand had lower thermal conductivity. This is evidence that there is no relation between the properties of density and thermal conductivity.

Materials differ in the property of specific heat, how much energy in calories is needed to change the temperature of one gram by one degree Celsius*. The fourth row of (the table) represents this idea. Water is the standard, meaning one calorie is needed to change the temperature of one gram of water by one degree Celsius, at standard atmospheric pressure and 20°C. This can be shown by* c_{water} *=1 cal/(g °C). The specific heat of sand is smaller; sand only needs approximately 0.2 calories to change one gram of sand by one degree Celsius. This can be represented by* c_{sand} *=0.2 cal/(g °C).*

These ideas can be used to decide which material changes temperature more. If the sand and the water have the same mass, the sand will change temperature more. Less energy is needed to change one gram of sand by one degree Celsius than is needed for water; it only takes 0.2 calories to change one gram of sand one degree Celsius while water needs one calorie to change one gram of water by one degree Celsius. One calorie of energy from the Sun will change one gram of water one degree Celsius. For sand, one calorie of energy from the Sun will change one gram of sand by five degrees Celsius. Therefore, sand will change temperature by five degrees more.

Materials differ in how their properties affect what happens when they convert

light energy into energy that warms a surface. *Two cups were filled with equal masses of water and dry sand. These cups were placed under a light where the light could shine on them equally for an equal amount of time. When light shined equally on the equal masses of the sand and water, the water heated evenly throughout the cup. The sand was warmer near the surface but remained the initial temperature near the bottom of the cup. The sixth row of (the table) shows this idea.*

Figure (3.19) shows the graph that represents our findings over ten minutes. The graph shows both water and sand increased in temperature gradually and constantly. The temperature of the sand increased more than the temperature of the water. The initial temperature of the sand was 24.4°C, which increased to 31.1°C. The initial temperature of the water was 21.6°C which increased to 22.9°C.

Water is more thermally conductive than sand. This is demonstrated by the temperature of the water being the same throughout the cup. Sand has a low thermal conductivity, demonstrated by the differences in temperature between the surface of the sand and the bottom of the sand.

The temperature of the sand (near the surface) increased more than the temperature of the water even though they were exposed to the same amount of energy for the same amount of time. This demonstrates that sand has a smaller specific heat. One gram of sand can change one degree Celsius with only 0.2 calories of energy, which means the sand needs less energy than water to change the same amount in temperature, which is shown on the graph.

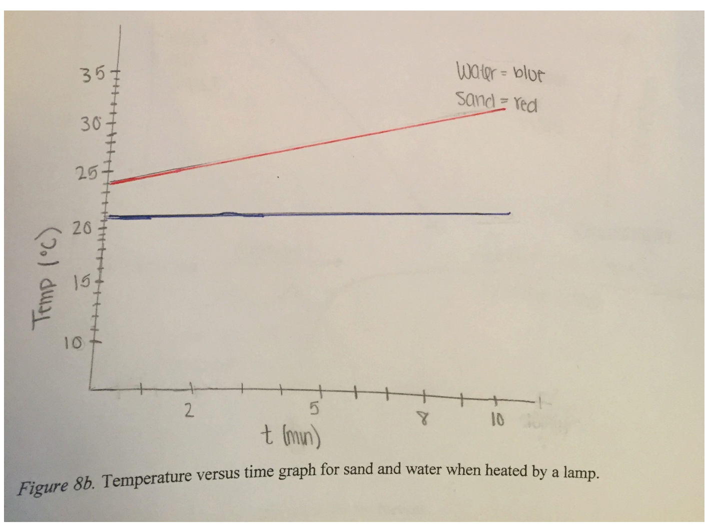


FIG. 3.19 *Student's graph of temperature changes for sand and water*

Physics student, Spring 2016

2. *Nuances about the exploration of effects of properties of materials*

(a) Noticing the lack of a relationship between the properties of thermal conductivity and density.

As this student noted clearly above, this exploration refutes the tempting inference that thermal conductivity and density are related. Although the more dense metal blocks were also more thermally conductive in the exploration in Unit 2, here the less dense water was more thermally conductive than the more dense sand.

The temperature of the sand near the bottom of the cup was lower than the temperature of the sand at the top of the cup. From this we inferred that the energy absorbed by the sand near the top of the cup stayed near the top of the cup rather that spreading throughout the sand, that sand has a low thermal conductivity. The temperature of the water near the bottom of the cup, however, was the same as the temperature of the water near the top of the cup. From this we inferred that some of the energy absorbed by the water near the top of the cup flowed throughout the water in the cup rather than staying on the surface, that water has a high thermal conductivity.

These results indicate that in this case the more dense material, sand, had a lower thermal conductivity than the less dense material, water. This is opposite to the earlier result in Unit 2 in which we inferred that the more dense materials, the 2 metals, had higher thermal conductivities than the less dense materials, wood and Styrofoam. These contradictory results indicate that there is no relation between the properties of thermal conductivity and density.

(b) Interpreting the difference in initial heights of the lines in Fig. 3.19. Visually it is clear from the graph that the temperature of the sand changed more rapidly than the temperature of the water. The lines do not start at the same height, however, as would be expected if the sand and water started at the same temperature. It is not clear whether the sand and water were at different temperatures at the start of the experiment, whether the temperature probes were not calibrated so they did not read the same temperature although the sand and water actually were at the same temperature, or whether the temperatures of the sand and water were already different at the instant in time that the computer started displaying the graph because the students turned on the light before they started the computer program recording the temperature probes. It is important to turn on the computer first, to document that the sand and water are starting out at the same temperature. Then turn on the light to start the warming process. It is clear from the graph, however, that the temperature probe in the sand increased in temperature much faster than the temperature probe in the water.

(c) Interpreting the slopes of the lines in Figs. 3.17 and 3.19. The vertical axes of the graphs shown in Fig. 3.17 and Fig. 3.19 represent the temperature of the sand (red line) and water (blue line). The horizontal axes represent the time that the lamp was shining on the sand and water. The *height* of the line at any point represents the temperature at that instant of time. The *slope* of the line represents how much the height changed during some time interval. The horizontal axis is marking off time in one-minute time intervals. For these graphs, the slope of the line represents how much the temperature was changing during one minute of time.

Because the lamp was the same distance away from the sand and water, the horizontal axis represents not only the time that the light was on but also the incoming energy shining on the sand and water. Therefore **the slopes of the lines also represent how much the temperatures of sand and water were changing for each unit of incoming energy**.

The straight lines indicate that these slopes were constant, that the temperature of the sand was changing at the same rate at the end of the ten minutes as it was changing at the beginning of the ten minutes that the light was shining on the cups of sand and water. The same was true for the water, that the rate of change of temperature for each unit of time was constant for the water.

(d) Comparing the slopes of the lines. How did the slope of the line for the sand compare to the slope of the line for the water? Clearly the slope of the red line, representing how much the temperature changed for sand for each unit of energy, was greater than the slope of the blue line, representing how much the temperature changed for water for each unit of energy absorbed.

(e) Relating the slopes of the lines to the specific heats of sand and water. How does this result for the slopes of the lines relate to a comparison of the specific heats of sand and water? As discussed in Unit 2, a material's *specific heat* is the amount of energy needed to change the temperature of a mass of one gram of the material by a temperature of one degree C. A table of specific heats (See http://www.engineeringtoolbox.com/specific-heat-capacity-d_391.html) lists the specific heat of sand as 0.19 cal/(g°C) and the specific heat of water as 1.00 cal/(g°C).

If the specific heat of sand is about 0.2 cal/ g°C, how much would the temperature of 1 gram of sand increase if it absorbed 1 calorie of energy? If a gram of sand increases in temperature by 1°C when it absorbs 0.2 cal of energy and the sand absorbs (0.2 cal + 0.2 cal + 0.2 cal +0.2 cal + 0.2 cal) of energy, how much does its temperature increase?

If the specific heat of water is 1.0cal/g°C, how much would the temperature of 1 gram of water increase if it absorbed 1 calorie of energy?

For each calorie of energy absorbed by a gram of sand, the temperature of the sand goes up about 5 degrees C compared to one degree C for each calorie of energy absorbed by a gram of water. This major difference in the properties of sand and water has major implications for what happens when light from the Sun shines on sand and water at the beach! The difference in their specific heats is the primary cause of why the sand gets hot and the water stays cool during a sunny day at the beach.

(*f*) *Considering the effect of the property of reflectivity.* In our course, students sometimes obtain different results for the property of reflectivity; some report the water reflects more than the sand and some less. It seems to depend upon the angle at which they hold the light probe. To what extent is this a problem for interpreting results?

The percent of incident light reflected is called a material's *albedo*. Water's albedo depends upon many aspects, including whether the sun is shining straight down (low albedo) or at an angle (high albedo) as shown in Fig. 3.20. The water absorbs more of the Sun's energy when the Sun is high in the sky than when the Sun is rising or setting.

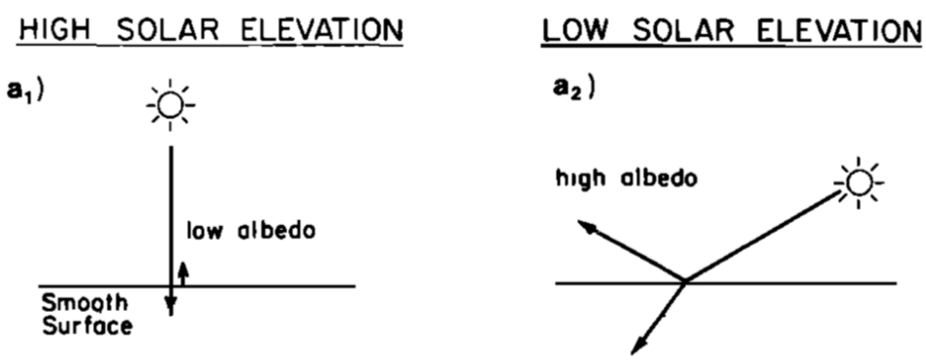


FIG. 3.20 Dependence of solar reflection upon angle of incidence. https://atmos.washington.edu/~mcmurdie/articles/katsaros_etal_1985.pdf, p. 7314. Kristina B. Katsaros, Lynn A. McMurdie, Richard J. Lind, and John E. DeVault, "Albedo of a water surface, spectral variation, effects of atmospheric transmittance, sun angle and wind speed," Journal of Geophysical Research, **90**(C4), 7313-7321 (July 20, 1985).

Water's albedo also depends upon its state, whether it is liquid in the ocean, bare ice, or ice with snow. Fresh snow reflects the most, about 90%, whereas liquid water in the oceans reflects very little, about 6% as shown in Fig. 3.21. Desert sand reflects about 40% (http://www.climatedata.info/forcing/albedo/).

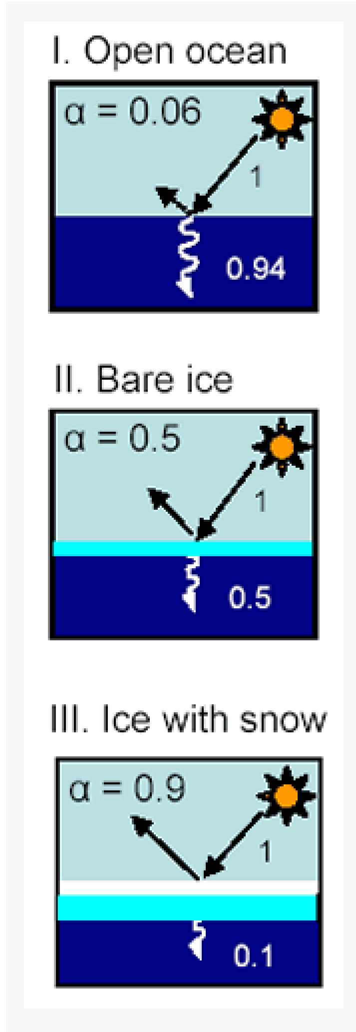


Fig. 3.21 Albedo of water in liquid and solid states. Image courtesy of the National Snow and Ice Data Center, University of Colorado, Boulder. https://nsidc.org/cryosphere/seaice/processes/albedo.html

Is there ever a time when the water warms up more than the sand because of these differences in reflectivity? If one calorie of energy from light from the Sun falls on one gram of water and all of that energy is absorbed by the water, its temperature will go up at most 1°C because its specific heat is 1.0 cal/(g°C).

What happens when one calorie of energy from light from the Sun falls on one gram of sand? If the sand absorbs all of the energy, we saw above that its temperature goes up 5ºC because its specific heat is only 0.2 cal/(gºC).

If the sand reflects 40% of the incoming energy, however, how much does one gram of sand's temperature go up if it receives 60% of the incoming energy? If one gram of sand only needs 0.2 calories to increase in temperature by one degree Celsius and it absorbs 0.2 cal + 0.2 cal + 0.2 cal = 0.6 cal, its temperature will go up 3°C.

Even in this worst case, with the water absorbing the most it can and the sand reflecting the most it can and absorbing the least it can, the sand will increase in temperature much more than the water. This confirms that the differences in reflectivity are not very important; what matters more is the difference in specific heats.

(g) Considering the relative importance of various properties. Thinking about what properties and processes might matter during an exploration is an important part of doing science. Figuring out which matter more than others is useful so that one can focus on the causes of major effects before investing a lot of time and effort in exploring less important effects.

V. Using Central Ideas to Explain Intriguing Phenomena Involving Local Weather at the Beach

Students in our area of the country can go to the beach on sunny days. The sand is warm; brrr, the water is cold! How can that be? Later in the day, however, the sky often clouds over and a breeze comes up from over the water. Why would that happen?

A. Considering the influence of the properties of materials on thermal effects

Question 3.8 Why is the sand warm and the water cool at the beach if the Sun has been shining on both in the same way for the same time?

- Use central ideas about the properties of sand and water, such as their thermal conductivities, specific heats, and reflectivities, to explain why the sand is hot and the water cool at the beach even though the Sun has been shining on them in the same way for the same time.

1. Example of student work explaining about hot sand and cool water at the beach

> *At a sunny day at the beach, the top of the sand is warm. The radiation from the Sun heats up the surface of the sand, but sand has a low thermal conductivity, so this energy stays at the surface of the sand. When you dig your feet into the sand it is cool below because the energy from the Sun was not transferred below the surface of the sand.*
>
> *Water has a higher thermal conductivity, meaning the energy from the Sun is quickly transferred throughout the water, a big area. This means the heat will be*

even throughout the water, taking a lot more energy than is supplied to finally heat up the entire ocean. The water also feels cool because water has a bigger specific heat than sand. Despite the water receiving the same amount of energy for the same amount of time as the sand, the water needs more energy to change one gram of the water one degree Celsius. It takes 1 calorie of energy from the Sun to change one gram of the water one degree Celsius, while sand only needs 0.2 calories of energy from the Sun to change the same amount. This means it will take longer for the water to increase in temperature because water needs more energy to do so.

Another factor contributing to water temperature is the angle of the Sun. If the Sun is shining on the water from an angle, some of the light is reflected. When the light is reflected the energy is not being absorbed, so the temperature is not increasing as much. When the Sun is high in the sky above the water, the energy will be absorbed because the light is not being reflected.

Physics student, Spring 2016

B. Considering the influence of light and thermal effects on weather at the beach

A wonderful sunny day at the beach can turn cloudy and somewhat chilly with a breeze coming off the water late in the afternoon. What causes this shift in the weather?

Question 3.9 Why do clouds and sea breezes often form in the afternoon after a sunny day at the beach?

- Draw a diagram that illustrates why sand is warm, water cool, clouds often form in the sky, and breezes blow in from the sea in the afternoon after a sunny day at the beach.
- Explain these aspects of local weather at the beach in terms of transfer of energy processes such as radiation from the Sun, reflection, absorption, conduction, evaporation, condensation, and convection.
- To explain a complex sequence of physical processes, start with radiation from the Sun and discuss each step with your group members. What is the influence of differences in thermal conductivity and specific heat between sand and water? What roles do conduction, evaporation, condensation, and convection play in setting up a circulation of air above the sand and water?
- Monitoring what one is doing can be helpful when developing complicated explanations. Every so often, step back and consider: What are we doing? Why are we doing this? How is doing this helping us?

Complete your explanations before looking at an example of student work. Next consider nuances about the influence of light and thermal phenomena on local weather at the beach. Then enjoy reading about how three young children learned to interpret a sea breeze diagram like the one below.

1. Example of student work explaining about cloudy skies and sea breezes forming in the afternoon after a sunny day at the beach

This student created a clear diagram of the convection cycle underlying sea breezes:

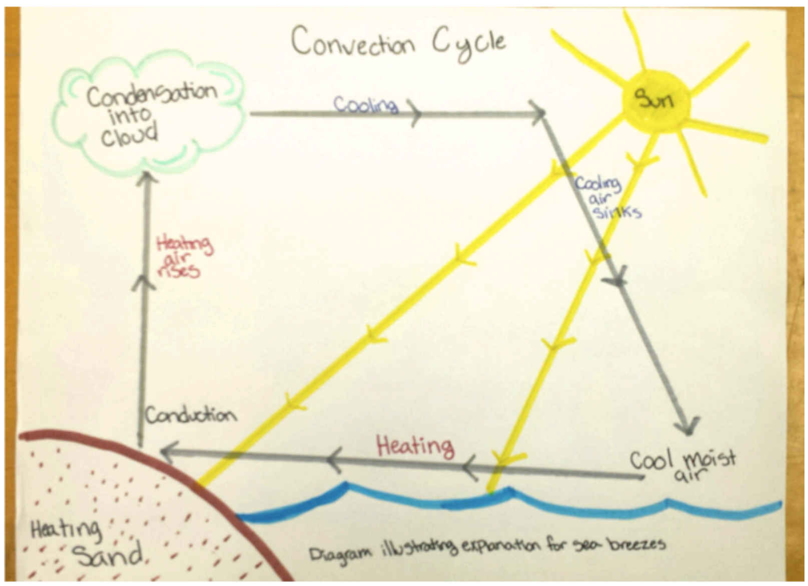


FIG. 3.22. Student's diagram explaining why clouds and sea breezes often appear in the afternoon after a sunny day at the beach.

The diagram is labeled *Convection Cycle* and as a *diagram illustrating explanation for sea breezes*. The student drew and labeled a *Sun* whose rays shine on both the land and sea, *heating* the *sand* and water. The warm sand warms the air above by *conduction*, and the *heating air rises*, represented by the gray upward arrow. Some water evaporates forming *cool moist air* above the water, which blows toward the shore forming a sea breeze, represented by the gray arrow toward land. A cloud forms in which *Condensation into cloud* occurs as moisture in the warm moist air condenses in the cooler upper atmosphere.

The *cooling air sinks*, represented by the gray arrows to become *cool moist air* over the water, which then blows toward shore, represented by the gray arrow toward the land.

The student interpreted the diagram as follows:

> *As we have learned in the past few weeks, light leaves a source such as the Sun and travels in all directions,* (including) *to the sand and to the water. Sand is a poor conductor of heat so when the Sun warms the sand, the heat is not distributed evenly, making the surface hot. Also the specific heat of sand is lower than that of water so when both are exposed to the same amount of light, the sand at the surface will have a higher change in temperature.*
>
> *Water is a good conductor of heat so the heat from the sunlight is evenly distributed throughout the water. Also water has a higher specific heat than sand so it will not warm as much when exposed to the same light.*
>
> *Over the water, some of the light energy is used to change the state of some water, evaporating it into a gas state. This makes the air over the water cooler moist air.*
>
> *The air above the sand continues to heat, because the sand heats at a higher rate than the water. As the air* (above the sand) *warms, it rises. The cool moist air above the water begins to move toward the sand,* (*forming the sea breeze*).
>
> *The hot sand heats the cool moist air in a process called conduction, causing the air to rise,* (cool), *and the gaseous water to form a cloud through condensation. As the air cools, it sinks back toward the water. As the warm and cool air moves, it is called "convection."*
>
> Physics Student Fall 2015

2. Nuances about explaining changes in the weather during a sunny day at the beach

There are many sea breeze diagrams available on the Internet. Some are quite detailed, such as http://www.yachtingmonthly.com/sailing-skills/understand-sea-breeze-49027). This is intended for people interested in sailing in coastal waters. Some diagrams show land breezes that occur at night as well as sea breezes that occur during the day, such as http://climate.ncsu.edu/edu/Breezes . This website refers to differences in air pressure that are related to changes in the density of air. As the land warms by energy radiated from the Sun, the air immediately above it also warms by *conduction*; as the warm air expands, it become less dense than the cool air above it and the warm air rises. This forms a low pressure region over the land. The cool moist air over the water is more dense. This forms a high-pressure region over the water. The cool moist air then flows toward the land, which forms the sea breeze. As this moist air warms over the warm land by conduction, it also expands and rises. This sets up a *convection* current of warm moist air rising and cool air flowing from the ocean over the land up into the upper atmosphere and back down to the water. The upper atmosphere is cool and as the rising warm moist air cools, the moisture *condenses* into tiny droplets of water, forming clouds. This complex cycle is an example of the interactions of several of Earth's systems, the geosphere (rock, soil, and sediments including sand), hydrosphere (water in the ocean and atmosphere), and atmosphere (air over both land and sea).

3. Example of learning and teaching about sea breezes with friends and/or family members

Question 3.10 What happens when teaching friends or family members about the physical phenomena underlying changes in the weather at the beach?

The student who drew the diagram in Fig. 3.22 chose to discuss sea breezes with three children for whom she baby sat: Lucie-7, Ava-4 and Ruby-4:

> *I did this project with some of the children I babysit, Lucie, Ava, and Ruby. I asked the girls if they had ever heard about sea breezes and what they think when they hear that phrase.*
>
> *Lucie, said: "um is that like breezes from off of the sea?" Ava and Ruby asked: "is that like when you can see the wind moving leaves and stuff?" I then showed the girls a diagram of sea breezes and asked them their initial thoughts.*
>
> *Mind you the girls are 4 and 7 so the answers I got are interesting.*
>
> *Me: Which do you think is warmer when you go to the beach, the water or the sand?*
>
> *R: "The sand!"*
>
> *A: "The water….. I mean the sand!"*
>
> *L: " the sand, cause sometimes the sand is super hot and burn-y and you have to dig down to where it isn't as hot."*
>
> *Me: Okay so do you think the air above the water is warmer or colder than the air above the sand?*

L: *"The air above the sand is probably warmer, cause it is being warmed up by the sand."*

Me: *Okay good. Does warm air sink or rise do you know?*

A:*" Um, I think warm air rises."*

Me: *Why?*

A: *" Well cause in our room during the summer it was always way hotter on my top bunk than it was on Ruby's bottom bunk. And it was way hotter at the top of the house than in the downstairs and dad said its cause hot air likes to go up."*

Me: *That's really good thinking Ava. So do you think that the warm air at the beach warms and rises too?*

A: *"Well yeah probably."*

Me: *Okay so say there is wind that comes and blows the air above the sea over to the sand, what would happen?*

L: *"well the air would get warmer, cause it would be with the warm sand. Then it would rise up like the hot air in the house does."*

Me: *Ruby can you show me on the diagram where you think this is happening?*

Ruby pointed to where the arrow points up on the diagram and goes towards the cloud.

R: *Right here is where it is happening. It goes up and into a cloud.*

Me: *Good job Ruby. Okay so when the hot air goes up something called condensation happens, which is like when you have a cold water bottle and the water drops collect on the outside of the bottle. This is because the water inside the bottle is colder than the water in the air outside the bottle. This is also how clouds form. The different air temperatures mix and the water drops form into a cloud because a cloud is actually a mist and a lot of water drops. Now on the diagram what looks like it happens to the cloud?*

L: *The cloud goes back out to the ocean.*

Me: *Okay and as the air goes back to the ocean it gets colder, what happens to colder air?*

R: *Colder air goes down!*

Me: *Good job Ruby, Ava can you point to where the colder air is going down?*

Ava pointed to the arrow of cold air descending back to the top of the water.

Me: *Okay now what do you think will happen to the air when it gets back above the water?*

L: *I think it will keep going in this circle like the diagram says. Cause it will get pushed by sea breezes; then it will get all hot again over the sand. And that will make* *it rise up into the air and be a cloud. Then it will get pushed back out to sea and sink again when it gets cold. And start again and again.*

One thing that I think Lucie in particular learned about was patterns, which described by the article are: "Patterns. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them." Lucie was able to say that she thought that the air would continue in a cycle and would follow the sea breeze cycle in a pattern that the cold air would always sink and the hot air would always rise.

I also think that the girls participated in engaging in argument from evidence. When Ava explained to me why she thought that the hot air would rise she used evidence she had from her own life to explain what she thought would be true. She was engaged in forming an argument, and backing it up with what she already knew.

Also the girls worked on asking question and on finding a good way to answer the questions that I proposed to them, to think about what the other girls had said, and to make a guess or to answer with that in mind.

I also learned that I am not completely comfortable explaining this phenomena, mostly because I am not sure that I fully understand how this cycle is taking place yet so I was not sure how to phrase questions. I also didn't do the best job of having the girls try and figure out the diagram on their own. This is something for me to work on in the future when I work with other students.

Physics student, Fall 2015

VI. Using Mathematical Representations to Estimate a Quantity of Interest

In our area, going to the beach involves being aware of and prepared for the possibility of a tsunami occurring. A tsunami is a large wall of water that may flood a beach and surrounding areas because of an earthquake. Geologists have used mathematics and knowledge of physical phenomena to build complex computer models for predicting earthquakes and tsunamis.

A. Exploring computer models designed to predict earthquakes and tsunamis

A major 9.0 earthquake may occur, for example, off the coast of northern California, Oregon, Washington and British Columbia. This region is called the Cascadia Subduction Zone (see http://www.oregon.gov/oem/hazardsprep/Pages/Cascadia-Subduction-Zone.aspx). This fault line is about 600 miles long and lies under the Pacific Ocean about 70 to 100 miles beyond the shoreline. If there is a major earthquake along this fault line, a tsunami wave that comes ashore is predicted to be up to 100 feet high.

Question 3.11 How do geologists predict earthquakes and tsunamis?

The Earth's surface is broken up into *tectonic plates*, (*https://www.geolsoc.org.uk/Plate-Tectonics/Chap2-What-is-a-Plate*). A *subduction* zone is a region in which one plate moves underneath another. The cause of multiple earthquakes in the Pacific Northwest region is attributed to movement of the Juan de Fuca oceanic plate under the North American plate as shown in Fig. 3.23.

FIG. 3.23 Model of Juan de Fuca Plate subsiding under the North American Plate. CC0 http://www.oregon.gov/oem/hazardsprep/Pages/Cascadia-Subduction-Zone.aspx

When one tectonic plate presses against another, pressure builds up until motion occurs; the earthquake releases energy that travels outward through the Earth as *seismic waves* (http://www.geo.mtu.edu/UPSeis/waves.html). The primary waves, known as p-waves, are compression waves that travel quickly through the Earth as shown in Fig. 3.24. P-waves move the earth back and forth in the direction of motion. Secondary waves, known as s-waves, are like water waves, they move the earth up and down, or side to side, as shown in Fig. 3.24. https://en.wikibooks.org/wiki/Historical_Geology/Seismic_waves

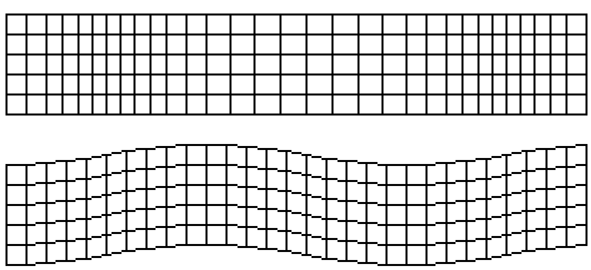


FIG 3.24. Top: p-waves; Bottom: s-waves. Actualist [CC BY-SA 3.0] https://en.wikibooks.org/wiki/Historical_Geology/Seismic_waves

- For each pair of students to model what happens during an earthquake: Use a Slinky® .
- To model p- waves, each pair holds the end of a Slinky® with the Slinky® stretched out along the floor. One gives the Slinky® a hard push toward the other.
- Next model s-waves. One person gives the Slinky® a quick jerk side to side. If the pair are standing up, jerk the Slinky® up and down.

If such an earthquake happens off the Pacific Northwest coast, a series of large ocean waves, up to 100 feet high, may quickly flood coastal areas in 15 to 20 minutes (see: http://www.oregongeology.org/tsuclearinghouse/). These huge waves are called tsunamis. Tsunamis might also originate in distant earthquakes occurring under the ocean elsewhere, with perhaps several hours warning. Signs in tsunami zones alert residents and visitors with a visual display of the danger as shown in Fig. 3.25.

FIG. 3.25 Tsunami danger alert sign. http://www.oregongeology.org/pubs/tsubrochures/NewportSouthEvacBrochure-12-12-12_onscreen.pdf

Residents of these areas and visitors to the beaches and coastal towns need to be aware of where high ground is and how to get there. For links to evacuation maps for many Oregon locations see, for example: http://www.oregongeology.org/tsuclearinghouse/pubs-evacbro.htm . Details are available at http://www.oregongeology.org/pubs/fs/TIM-maps-factsheet.pdf. Before leaving home, visitors should locate where they will be and review evacuation routes and what to do in case of a tsunami (see http://nvs.nanoos.org/TsunamiEvac and Fig. 3.26 and Fig. 3.27.)

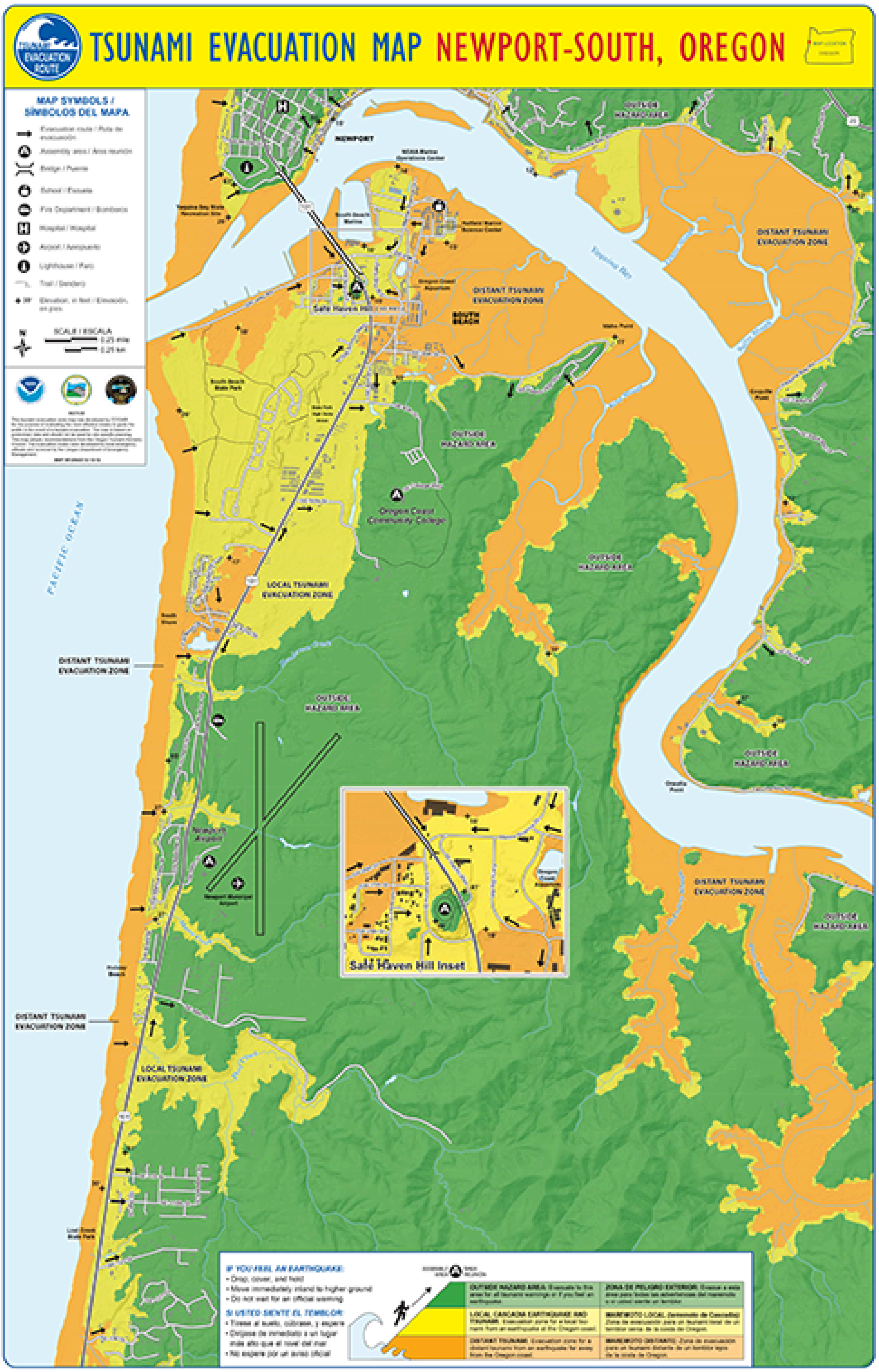


FIG. 3.26 *Tsunami evacuation map for South Newport, OR:* [*https://www.oregongeology.org/pubs/tsubrochures/NewportSouthEvacBrochure-12-12-12_onscreen.pdf*](https://www.oregongeology.org/pubs/tsubrochures/NewportSouthEvacBrochure-12-12-12_onscreen.pdf)

The instructions at the top of the map state:

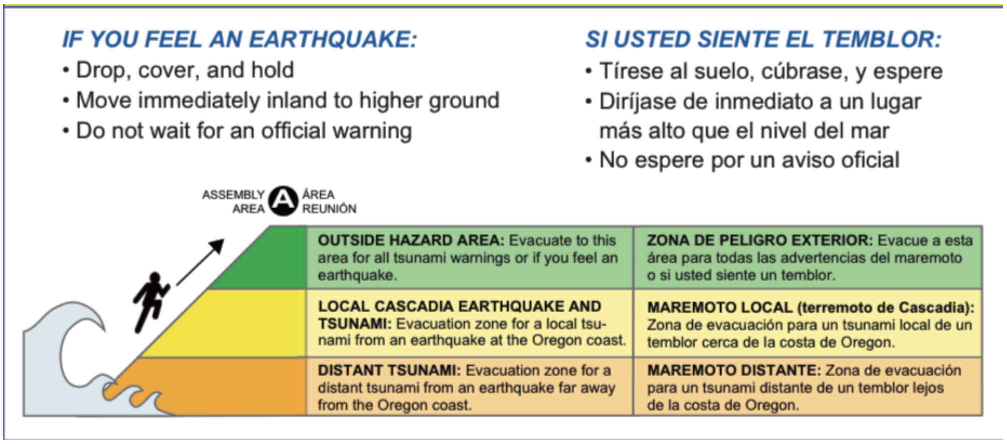


FIG. 3.27 *Instructions if you feel an earthquake. https://www.oregongeology.org/pubs/tsubrochures/NewportSouthEvacBrochure-12-12-12_onscreen.pdf*

The predicted safe areas are green, the areas likely to be inundated by a local tsunami are yellow, and those likely to be inundated not only by a local tsunami but also by a distant tsunami from an earthquake far away from the Oregon coast are orange. An A on the green area of the map indicates a designated assembly area in the event of an evacuation.

Steps to be prepared include making a disaster plan, preparing supplies in case of a disaster, protecting yourself during an earthquake, evacuating if necessary, and following your plan (see: http://www.oregongeology.org/tsuclearinghouse/steps-visitors.htm#prepare). Although an enticing very low shore may occur just before and after a large wave, it is important to head immediately away from the beach as more very large waves may follow.

Preparation includes assembling a 'Go-Bag' to keep in your car in case of a disaster (see: (https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em8864.pdf). Suggested items include water (1 gallon per person per day), 3-day supply of non-perishable food, first aid kit, non-prescription drugs, tools and supplies, sanitation items, entertainment (games, books), clothing and bedding, special requirements, and important family documents.

1. Examples of student reflections upon discussing earthquake and tsunami preparedness with a friend or family member

A guest, Douglas Lownsbery, facilitated a class session in which he provided information and set up four centers about earthquakes and tsunamis: a set of items for students to choose within 10 seconds which they would put in a "go bag," a large plastic container with sand, water, and toy people and houses with which to model a tsunami occurring, a long slinky® to model p- and s-waves, and a core sample that he had prepared with 5th graders at a local beach, that included evidence of a previous tsunami in our area. After the session, the students wrote about their experiences discussing earthquake and tsunami preparation with a friend or family member. A student provided the reference for an article and a reflection on a conversation with a roommate:

> *The New Yorker Magazine, How to Stay Safe When the Big One Comes* [*http://www.newyorker.com/tech/elements/how-to-stay-safe-when-the-big-one-comes .*](http://www.newyorker.com/tech/elements/how-to-stay-safe-when-the-big-one-comes)
>
> *My "learner" this week was one of my roommates. I had her read over the article that I had chosen from the New Yorker and we had quite a big discussion about it. We talked about how we and no one we know bolt things down in our homes for safety. We also do not have a kit to be prepared for a tsunami or an earthquake.*
>
> *After talking about the article, I started talking about how we should all have "go bags." Many of us do not think that this would affect us, but it could happen at any time we are near the coast and it is best to be prepared to help yourself and to help others. We were wondering what exactly we SHOULD put in our go bag because that was not extremely clear when we were learning about it in class. The city of Seaside Oregon has a "go bag" section on their website. They recommend that you pack:*

- *First Aid kit,*
- *prescriptions and non-prescription medication*
- *Water bottle and treatment supplies capable of providing 1 gallon per person per day*
- *Non-perishable food*
- *Cooking and eating utensils, can opener, cook stove.*
- *Waterproof matches, lighter or flint*
- *Shelter (tent, tarp or poncho)*
- *Emergency blanket*

- *Portable NOAA weather radio*
- *Flashlight or headlamp, and extra batteries*
- *Warm clothing*
- *Personal hygiene items (toilet paper, soap, toothbrush)*
- *Tools and supplies (pocket knife, shut-off wrench, duct tape, gloves, whistle, plastic bags)*
- *Cash*

> *This did not include things like rope or an emergency blanket, but a "go bag" can be different for everybody. The important part is that we always have one in our car.*
>
> *We talked a lot about cause and effect. When an earthquake hits-what do we do? What happens next? When can you tell a tsunami is about to hit? Where should you go when it is hitting? What happens to houses and people that are not in the safe zone? What does a town look like after a tsunami hits? How far away from the coast can a tsunami travel?*
>
> *The cause: the earthquake/tsunami*
>
> *The effect: how it effects people and towns*
>
> *In doing this we used the science and engineering practice of asking questions and defining problems. This was an easy one to cover because we do not know much about tsunamis and earthquakes because this area does not seem to be worried about them even though we should be.*

Another student talked with a family member who lives in a tsunami evacuation zone

> *I decided to engage my mom in learning about earthquakes and tsunamis. I chose to talk to her about this topic because she lives on the coast and will directly be impacted by the earthquake and tsunami that are due to occur anytime soon. I have noticed that many people are aware of the fact that Oregon is expecting a natural disaster in the near future but no one has done anything to prepare for this.*
>
> *I first began by asking my mom what she knew about earthquakes and what she has done so far to prepare for an earthquake and tsunami. She knew a lot of facts about earthquakes along with understanding the scientific reasoning for why tsunamis happen but unfortunately she has not done anything to prepare.*
>
> *I took this time to pull up the elevation map that was shown in class to show the best places to run to during a tsunami. While looking at this map we both realized that our house is in a zone that is expected to be under water in the event of a tsunami.*

"I am not even sure what I would put in a go bag if I needed to make one." stated my mother. I took this opportunity to talk to her about the activity we did in class where we had 10 seconds to pack 10 items in a bag. I told her about some of the items I put in the bag and why I put these things in. She asked what types of food would be best to start stocking up on.

I told my mom the story about the little girl named Tilly that saved not only her family but also other people while on vacation in Thailand. Since my mom is a fourth grade teacher I told her the importance of talking about this topic with her students. She understood and agreed with me and said she wants to start talking about earthquakes and tsunamis more in her classroom.

…We also talked about evacuation routes, plans, and communication. My mom made the decision to continue this investigation by researching different ways to educate her students on the importance of being prepared during this type of event. The crosscutting concept that we used during this discussion was cause and effect. We talked about earthquakes and tsunamis and the impact it would have on our family physically, mentally, and emotionally.

An emphasis on how to prepare helps to mitigate the fear that one may experience in realizing what might happen should a major earthquake occur.

B. Exploring computer models designed to predict the weather

Computers also can make weather predictions based on complex mathematical models. Many of these are developed by government agencies and are available for public use on the Internet.

Question 3.12 How do meteorologists predict the weather?

Meteorologists use mathematics to build complex computer models that they use to predict the weather. See an example provided by the National Oceanic and Atmospheric Administration's Weather Prediction Center at http://www.wpc.ncep.noaa.gov/ Also put in http://www.weather.gov and enter a zip code for a local prediction.

VII. Making Connections to Educational Policies

Many US states have adopted the *Next Generation Science Standards* (NGSS, Lead States, 2013). In addition to science and engineering practices and crosscutting concepts, this document recommends disciplinary core ideas that student should learn at various grade levels.

A. Learning about the US *Next Generation Science Standards: Disciplinary Core Ideas*

Question 3.13 What NGSS science and engineering practices, crosscutting concepts and disciplinary core ideas have you used in developing an explanation for the occurrence of hot sand, cool water, clouds, and sea breezes late in the afternoon after a sunny day at the beach?

The *Next Generation Science Standards* describes *disciplinary core ideas* in terms of *learning progressions* (NGSS, Lead States, 2013, Appendix E) (See: https://www.nextgenscience.org/resources/ngss-appendices.) These indicate what students should learn about a topic in Kindergarten-2nd grade, 3rd-5th grade, 6th-8th grade and 9th-12th grade.

Disciplinary core ideas in physical science, for example, include:

PS3.B *Conservation of energy and energy transfer*:

- During Kindergarten-2nd grade, students should learn that s*unlight warms Earth's surface.*
- During 3rd-5th grade, students should learn that e*nergy can be converted from one form to another form.*
- During 6th-8th grade, students should learn that t*he relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter.*

    - During 9th-12th grade, students should learn that t*he total energy within a system is conserved.*
- How are these disciplinary core ideas relevant to the development of an explanation for sea breezes?
- Provide an example of how the explanation of sea breezes incorporates one or more of the eight NGSS science and engineering practices: asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations and designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information.
- Provide an example of how the explanation of sea breezes incorporates one or more of the seven NGSS crosscutting concepts: patterns; cause and effect; scale, proportion, and quantity; systems and system models; energy and matter: flows, cycles, and conservation; structure and function; and stability and change.

The disciplinary core ideas, science and engineering practices, and crosscutting concepts are called *dimensions* of science learning and teaching. It is important to consider all three dimensions when designing learning experiences in science contexts.

B. Reflecting upon this development of a complex explanation

Explaining sea breezes is complicated. As the conversation with Ava above illustrates, however, even four-year-old children know that "hot air rises" and can support that claim with evidence "in our room during the summer it was always way hotter on my top bunk than it was on Ruby's bottom bunk. And it was way hotter at the top of the house than in the downstairs…" This four-year-old already has understood the essence of the nature of science, being able to make an argument based on evidence. Young children are capable of scientific reasoning in contexts with which they are familiar and have had relevant experiences upon which to draw in making sense of what they are learning.

What happens when energy radiated from the Sun shines on sand and water at a beach in the same way for the same time? A more complex version of Ava's scientific reasoning occurs in making an argument about what happens when different materials absorb incoming energy. One way to explore this question is to create a model of the situation in the laboratory. What happens when energy radiated from a lamp shines on equal masses of sand and water in the same way for the same time?

The graphs in Fig. 3.17 and 3.19, for example, demonstrate a major difference in that the temperature versus time line for the sand was clearly steeper than the line for the water. This replicates the effects seen at the beach, that equal input of energy results in very difference changes in temperature for sand and water. Using specific heat information from outside sources indicated that the s*pecific heat* of sand was about 0.2 calories of energy to change the temperature of one gram by one degree C whereas the specific heat of water was by 1.0 calories of energy to change the temperature of one gram by one degree C.. This difference in the property of specific heat, *in* how much energy is needed to change the temperature of one gram of a material by one degree Celsius, is the key to explaining why sand at the beach is hot and the water cool even though the sun has been shining on both in the same way for the same time.

Differences in other properties, such as *thermal conductivity* and *reflectivity*, also contribute to causing this effect. The temperature near the bottom of the cup of sand was lower than the temperature near the surface, whereas the temperature of the cup of water was the same throughout. This indicates that the sand had a low thermal conductivity. This means that the incoming energy absorbed by the sand stayed near the surface, warming the surface sand whereas the incoming energy absorbed by the water on the surface flowed throughout the cup of water. Using reflectivity data from outside sources also demonstrated that reflectivity effects were minor compared to the big difference in effect due to the property of specific heat.

Tracing the flow of energy in a system also is useful in understanding what is happening. As shown in Fig. 3.14, convection occurs when a circular current forms as warm fluid rises and cold fluid sinks. Similarly, as energy flows from the warm sand to the dry air above it by conduction, the less dense warm air rises; as energy flows from the warm air into the cooler upper atmosphere, the cooling air becomes more dense, and sinks back down toward the surface, setting up a convection current. Meanwhile some of the liquid water absorbs enough energy from the sun to evaporate into the cool air above the water's surface. As the warm air rises above the hot sand, the cool moist air above the surface of the water blows toward shore, forming a sea breeze. When the moist air warms, rises, and cools in the upper atmosphere, the moisture condenses back into liquid water droplets and forms clouds.

Developing this complex explanation of local weather that students have experienced at the beach seems to be motivating. Several have identified this session as a highlight of the course. The pleasure students seem to experience in this accomplishment may help them to appreciate the hard work of figuring something out as well as understanding the emotional satisfaction that scientists derive from their studies.

One goal of this course has been to build confidence in using the tools of science, particularly graphs and diagrams. Creating a graph of data and telling the 'story' that the graph displays can be a powerful skill to have, both professionally and personally. Also powerful is the ability to create and use diagrams that visually explain whatever needs explaining. In addition, the process of articulating what was done, found, and understood in this complex context can help students gain confidence as science writers, able to set forth their own ideas and reasoning in clear and coherent ways.

C. Making connections to NGSS understandings about the nature of science

This unit provides a good example of the NGSS science and engineering practice of *constructing explanations*as well as the crosscutting concept of *cause and effect* in focusing upon the difference in the property of specific heat for sand and water. The very low specific heat of sand compared to that of water causes large differences in increases in temperature when light from the Sun shines on sand and water in the same way for the same time. This is an example of aspects that students in grades 3-5 should learn to do, to *identify the evidence that supports particular points in an explanation.* They also should understand that *the transfer of energy can be tracked as energy flows through a designed or natural system* while they are learning disciplinary core ideas about the *conservation of energy* and energy transfer.

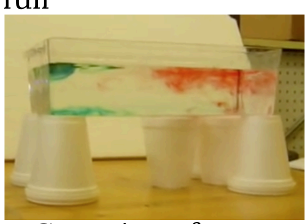
Unit 3 also has provided additional examples of the nature of science such as that *science knowledge assumes an order and consistency in natural systems* (NGSS Appendix H https://www.nextgenscience.org/resources/ngss-appendices . This unit assumes, for example, that what happens with small amounts of sand and water warmed by a lamp in the laboratory is consistent with what happens with large amounts of sand and water at a beach. Also assumed is that similar mechanisms cause the apparent paradox that the sand is very hot but the water is cool even though the Sun is shining on both in the same way. The students explored possible causes for these different effects by considering the role of differences in three properties of sand and water: their reflectivities, thermal conductivities, and specific heats. They observed differences in how much the temperatures changes on the surface when energy flowed from a lamp placed equal distances from cups of sand and water.

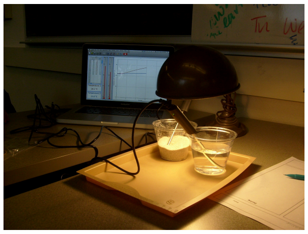
The process of explaining why the sand is hot but the water cool as well as why sea breezes and cloudy skies often appear in the afternoon after a sunny day at the beach was a culmination of the earlier explorations of the nature of light and thermal phenomena. Students may gain from this exploration some understandings about how scientific knowledge grows and connects in multiple ways across many contexts. The process of engaging friends and family members in learning about sea breezes at the beach also may help convey some of these understandings about the nature of science to others.

VIII. Physical Phenomena: Summary of Equipment and Supplies for Unit 3

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 3

***Exploring Physical Phenomena*: Summary of Equipment and Supplies for Unit 3**			
When used	For instructor and demonstrations	For each group of 3	For each student
Unit 3 **Week 5** Day 9 **Question 3.1 Connecting to initial knowledge about water and weather**		1 cup of water	
Question 3.2 Exploring changes in states of matter	Rice cooker or pot and hot plate Tray of ice cubes 2 digital thermometers to connect to laptop computer (or two regular thermometers with range below 0°C and above 100°C)		U3H2 Diagnostic Question about Changes in States of Matter

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 3			
Question 3.3 Exploring the water cycle	Evaporation: Tray, food coloring, water to make puddle, lamp, Transpiration: Plant, plastic bag to fit over it, Condensation: metal container, blue ice cubes, Precipitation: Large jar, cup that fits inside opening, ice for cup, about ½ jar of very hot water, Convection: Plastic bin (shoe box size) Red food coloring, Blue ice cubes, 4 paper cups to support bin, 1 ceramic or Styrofoam cup for very hot almost boiling water, **Room temperature** water to fill bin 2/3 full  Container for waste water if no sink in room	If feasible, provide equipment for convection demonstration for each small group U3H1 Exit Ticket	U3H3 Table.III.1 U3H4 Table.III.2 U3H5 Water cycle diagram

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 3			
Unit 3 **Week 5** Day 10 **Question 3.7 Explaining hot sand, cool water, clouds, and sea breezes in the afternoon after a sunny day at the beach** **Question 3.13 Reflecting upon the NGSS Crosscutting Concepts Experienced in Unit2 and 3**		2 digital temperature probes connected to laptop (or regular thermometers) 2 clear plastic cups Sand (about 1/3 cup) **Room temperature** water (about ½ cup) Lamp with bendable stem 1 tray  U3H1 Exit Ticket	U3H6 Table.III.3 & graph U3H7 Sea breeze diagram) U3H8 NGSS Crosscutting concepts U3H9 Anonymous questionnaire U3H10 NGSS practices review Units 1-3 U3H11 NGSS crosscutting concepts review, Units 1-3

UNIT 4: CONSIDERING THE INFLUENCE OF LIGHT AND THERMAL PHENOMENA ON GLOBAL CLIMATE

Exploring Physical Phenomena: What happens when light from the Sun shines on the Earth?

Unit 4 Table of Contents

Figures

Tables

I. Introduction

The theme for this course is: *What happens when light from the Sun shines on the Earth*? In this unit, you will be exploring the effect of light from the Sun on the Earth's atmosphere, land, and oceans. In particular, you will be developing additional central ideas about light and thermal phenomena as well as considering ways that energy from the Sun enters and leaves the Earth. While exploring these phenomena, you will be:

- ***identifying resources*** such as what you already know about aspects relevant to global climate change
- ***developing additional central ideas based on evidence*** about models of light and thermal phenomena
- ***explaining intriguing phenomena*** such as the greenhouse effect and rising sea levels
- ***developing mathematical representations*** of changing quantities such as the rate of change in the mass of melting glaciers
- ***using mathematical representations to estimate a quantity of interest*** such as predictions about the likelihood of flooding at particular locations and
- ***making connections to educational policy***, such as the *Next Generation Science Standards* (NGSS Lead States, 2013), the science standards adopted by many US departments of education.

This unit continues your exploration of learning processes as well as of physical phenomena. The main sections present questions with suggestions for exploring topics and for writing reflections about your findings. Text in gray font indicates that these are suggestions; you may think of other ways to explore the topic. Asking your own questions as well as those posed here will enhance learning both about physics and about learning. Check with your instructor if you choose to devise an alternative approach.

Small groups will be exploring various phenomena in class. Keeping track of what one is doing and thinking is important. In this course, use a template for a physics notebook page on which to record your notes during class. The physics notebook page can help you remember your thoughts *before*, *during*, and *after* an exploration. An experienced elementary teacher, Adam Devittt, designed this notebook page to mirror the structure of *before*, *during*, and *after* reading strategies:

Before starting your exploration, think about and discuss with your group members what you know already about this topic, how you plan to conduct the exploration, and what you think you might find out.

During your exploration, record what is happening, what you are observing, and what you are thinking about what you are observing. Include sketches of equipment and observations. Note any words that are new and their definitions.

After your exploration, record any central ideas that have emerged from your observations and discussions. Also note the evidence on which you have based these ideas. State explicitly how the evidence is relevant and supports the claims you are making in stating these ideas. Also explain why this result is important. Then write a reflection about whatever you want to remember about this experience. In addition, briefly state what you are still wondering in this context.

In summarizing and reflecting upon your explorations, you also will be integrating science and literacy learning. This includes learning to speak clearly, listen closely, write coherently, read with comprehension, and create and critique media.

After writing your own summary of your findings, read some examples of student work. The student authors first wrote drafts, received feedback for ways to enhance content and clarity, and submitted these final versions. Also read about some nuances to consider when explaining the phenomena explored. You should read both of these sections of the text to be sure you have understood both the physics and the learning processes involved.

Also available are students' reflections about teaching a friend or family member about what they have just learned in class. Some additional sections present historical information about ways knowledge about the topic developed. In addition, some reflect upon relevant aspects of the nature of science in the context of the topic explored. Read these sections to broaden your understanding of science and of science learning and teaching.

II. Identifying Student Resources

In this section you will consider a local example of the influence of light and thermal phenomena on a closed system. You also will be documenting some what you already know about aspects of global climate change.

A. Connecting to relevant everyday experiences

A phenomenon that you may have experienced occurs when light from Sun shines into an enclosed area.

Question 4.1 What happens when a closed car is parked in the Sun on a sunny day?

- Discuss with your group members experiences you may have had in getting into cars that have been parked with the windows up on a sunny day. Why do you think that happens?

This is an example of a system in which more energy enters than leaves the system. Although the mechanisms differ, the result, an increase in temperature inside the car, is similar to what seems to be happening to the global climate here on Earth.

B. Documenting initial knowledge about aspects of global climate.

Question 4.2 What do you already know about the influence of light and thermal phenomena on global climate?

Document your initial knowledge about the influence of light and thermal phenomena on global climate by responding to the following *diagnostic questions*. These diagnostic questions focus upon two aspects of changes in global climate: the greenhouse effect and rising sea levels. Your responses will not be graded. You will answer the same questions again near the end of the unit, compare initial and current responses, and write a reflection about changes in understandings and ways these occurred.

Name____________________________ Date____________

Diagnostic Questions

about Aspects of the Influence of Light and Thermal Phenomena on Global Climate

1. How aware are you of the greenhouse effect?

1	2	3	4	5
Have not heard of it	Have heard of it	Have talked about it	Have read about it	Have studied it in a course

2. What is the greenhouse effect?

3. What can cause an increase or decrease in sea levels?

4. In what grades/courses, if any, have you learned about global climate change? In what ways?

Elementary school:

Middle school:

High school:
College:

5. What question(s) do you have about global climate change?

III. Developing Central Ideas Based on Evidence

When light from the Sun shines on a person, the person feels warmer; when light from the Sun shines on a closed car, the seats, dashboard, steeling wheel, and air inside the car get warmer; when light from the Sun shines on a greenhouse in a garden, the plants, soil, and air inside the greenhouse get warmer.

What happens when light from the Sun shines on the atmosphere, land, and oceans of the Earth? Discussions about a warming Earth often refer to the *greenhouse effect*. To understand what is happening in the greenhouse effect on the entire Earth, we first need to review some of the central ideas developed in earlier units and to develop some additional central ideas about light and thermal phenomena.

A. Developing additional central ideas about light phenomena

Unit 1 developed the central idea that light can be envisioned as rays traveling in straight lines. As shown in Fig. 4.1, this was useful in drawing ray diagrams to explain the upside-down projection in a pinhole camera. Such ray diagrams also were useful to explain the apparent rise of a dot on the inside of a cup when the cup is filled with water as well as the appearance of rainbows in the sky.

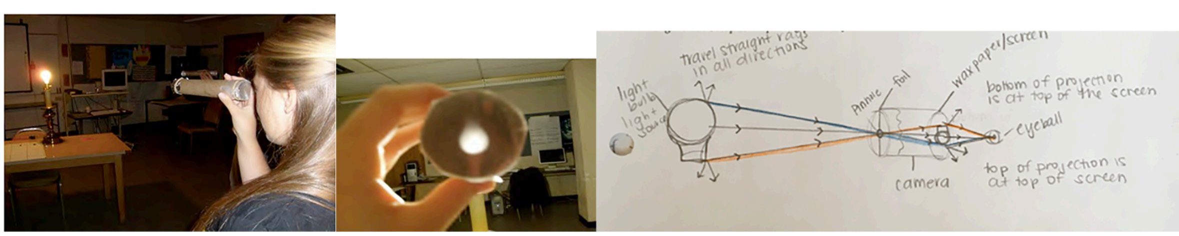


Fig. 4.1 Using light rays to explain why a pinhole projection is upside down. (Repeated from Unit 1, Figs. 1.12 and 1.15)

Sometimes sunlight shining through clouds looks like rays of light, often informally called sunbeams and known as *crepuscular rays* (http://www.atoptics.co.uk/atoptics/ray1.htm). Children typically draw pictures of a sun with bright rays shining out in all directions. However, can you actually *see* rays of light traveling from various objects straight to your eyes?

Question 4.3 Are rays of light visible or invisible?

- Discuss with your group members in what sense you think light rays are visible or not.

When a driver sees a traffic light turn bright green, light must be traveling from the bulb to the driver's eyes but the light rays' journeys are not visible. Are there other experiences in which you can detect something even though its journey is not visible? When standing near an oven, for example, you can see the oven but how do you know whether the oven is "on" or not?

Question 4.4 What is "invisible light"?

If you are standing near an oven that is cooking dinner, you likely are aware the oven is on because you can feel its warmth. How is that energy getting to you? The oven is radiating energy even though you cannot see that energy is leaving the oven and traveling to your body. This process is called energy transfer by *thermal radiation.* You too are warm and radiating energy!

Equipment: If you have access to a thermal camera or to a computer with a "thermal camera" effect:

- What do think you will see? Which areas of your face, for example, might appear to be brighter than other areas when viewed through a thermal camera?

All objects radiate energy. Thermal cameras detect thermal radiation and represent it on the camera screen with varying levels of brightness that indicate varying levels of temperature as shown in Fig. 4.2.

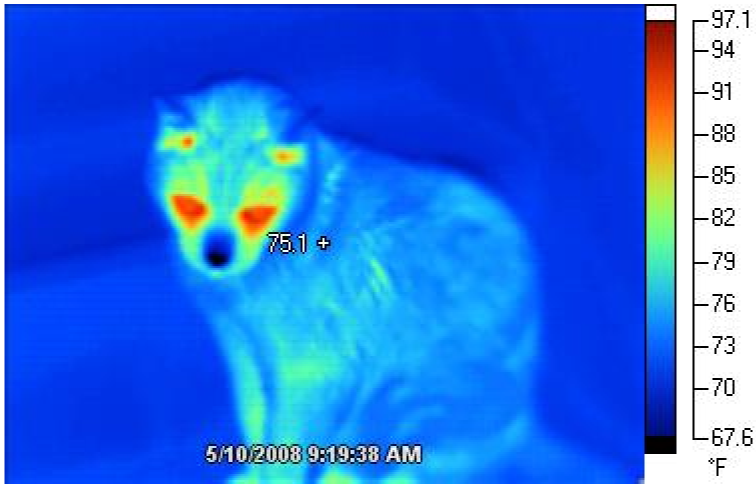


Fig. 4.2 Infrared image of a cat. CC by-NC 2.0
https://www.flickr.com/photos/cd_1940/2481838891

Sometimes called *night-vision cameras*, thermal cameras are helpful for "seeing" warm bodies in the dark or in smoky settings such as houses on fire. Thermal cameras have many uses in safety, law enforcement, healthcare, electronics, and maintenance. For information about various ways to use such cameras, search the Internet for "uses of thermal cameras" and view a website such as https://reductionrevolution.com.au/blogs/news-reviews/69333381-over-60-unexpected-uses-of-infrared-thermal-imaging-camera-images .

Thermal radiation also is known as *infrared radiation*. Some telescopes can "see" infrared radiation emitted by astronomical phenomena. Visible light images and infrared images look very different, as shown in Fig. 4.3. Both of these images are of the constellation known as Orion, the Hunter (https://in-the-sky.org/data/constellation.php?id=61). This constellation is visible in both northern and southern hemisphere skies.

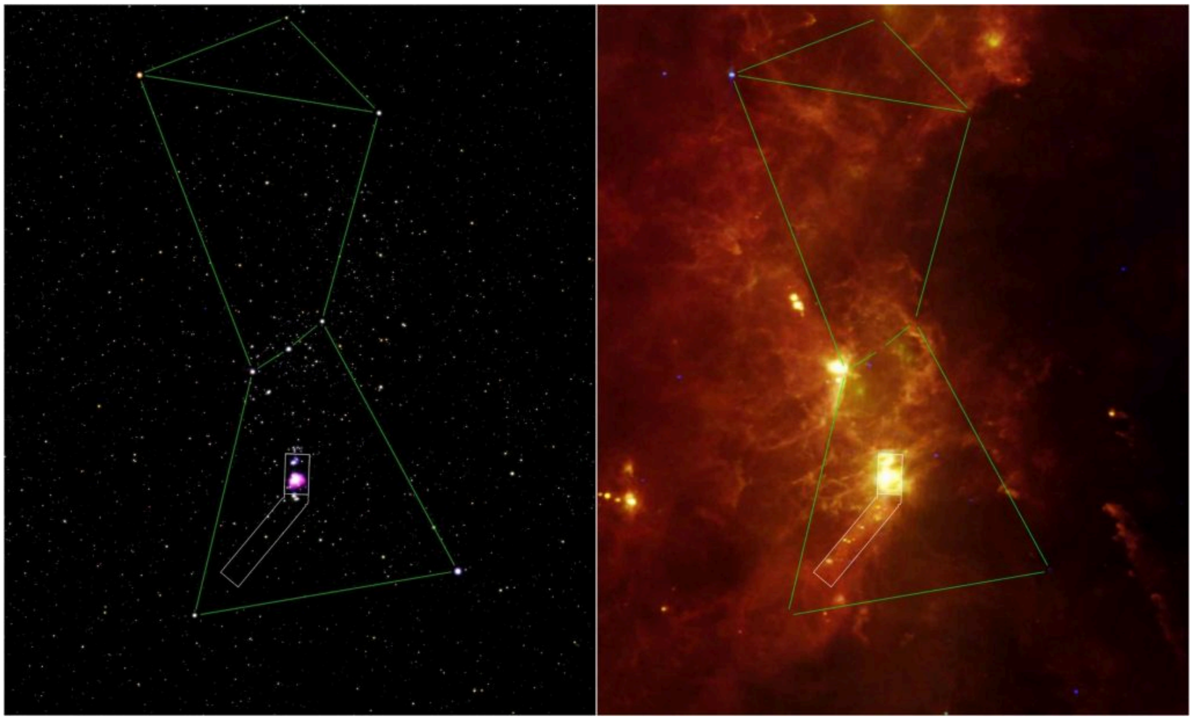


Fig. 4.3 Visible light image (left) and infrared image (right) of the constellation known as Orion, the Hunter. Credit: NASA/JPL-Caltech/IRAS /H. McCallon (*https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA08656*)

On the left image, the light green lines connect the stars outlining the envisioned hunter's shoulders, belt, and knees; a sword seems to hang below the belt. Within the blade of the hockey-stick figure is a giant cloud of dust, gas, and young stars known as the Orion nebula. This region of active star formation may be faintly visible on a clear dark night away from city lights. (See: https://www.nasa.gov/feature/goddard/2017/messier-42-the-orion-nebula). The constellation's dusty clouds are vividly visible, however, in the infrared image on the right.

Infrared radiation is part of the *electromagnetic spectrum*. Your eyes cannot see infrared radiation but your skin can detect it as warmth. Light that you can see when light shines onto the retinas of your eyes is called *visible light* and consists of white light and its component colors. As shown in Fig. 4.4, however, visible light is only a small part of the electromagnetic spectrum.

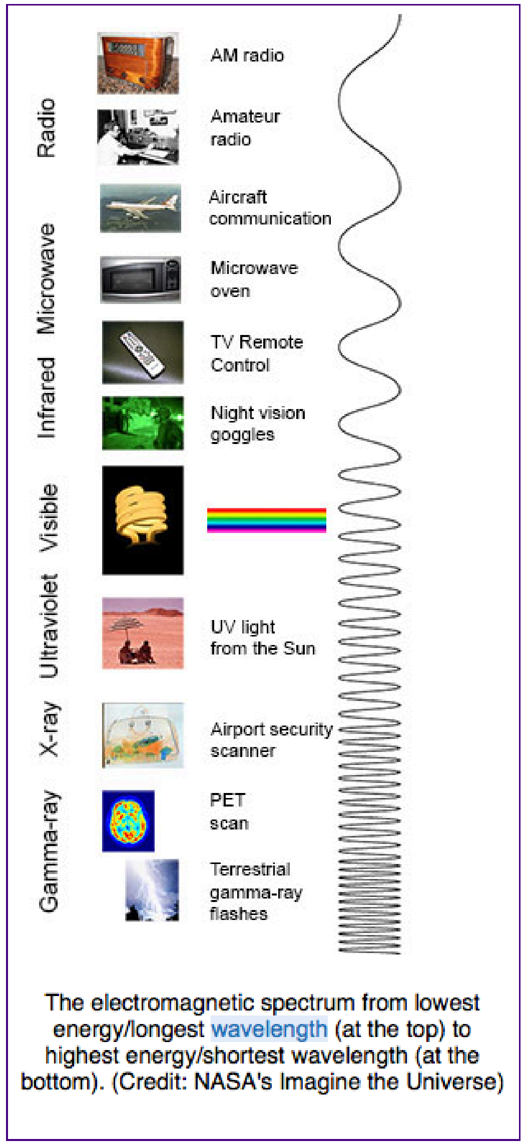


FIG. 4.4 Electromagnetic spectrum. [*https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html*](https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html)

Although the names used in the electromagnetic spectrum refer both to rays (infrared radiation, ultra violet radiation, x-rays, gamma rays) and to waves (microwaves, radio waves), all of these forms of light can be described as waves, with varying wavelengths, as shown in Fig. 4.4. They also have varying frequencies, the number of waves that pass a point each second.

Fig. 4.5 illustrates the meaning of *wavelength*, the distance from one crest to the next, from one midpoint to the next, or from one trough to the next of a wave. The Greek letter lambda, λ, is typically used as the symbol to represent wavelength.

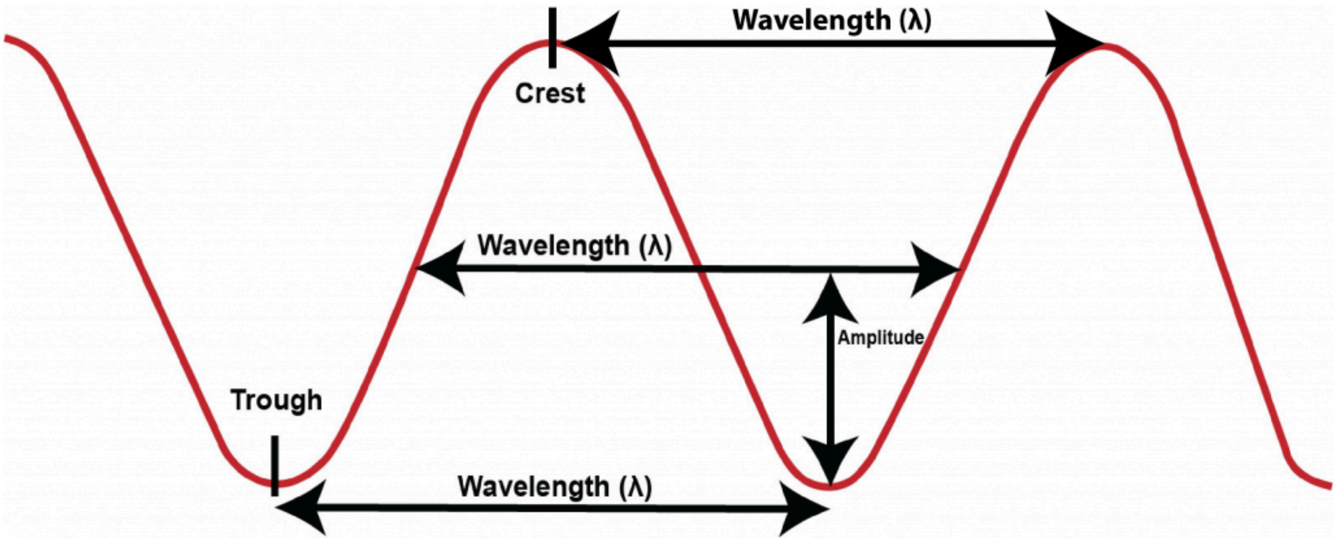


FIG. 4.5 Wave diagram showing wave length, λ, and amplitude. Modified from Phil Stoffer *http://geologycafe.com/images/wavelength.jpg*

Forms of light with larger wavelengths than visible light are known as *infrared radiation*, *microwaves*, and *radio waves*. Forms of light with smaller wavelengths than visible light are known as *ultra violet radiation*, *x-rays*, and *gamma rays*. Radio waves have the largest wavelengths but the lowest frequencies and lowest energies. Gamma rays have the smallest wavelengths but the highest frequencies and energies.

Exploring the wave model of light

Equipment: Use a Slinky® for each pair of students

- Each pair holds an end of a Slinky® with the Slinky® stretched out along the floor. What happens when one person gives the Slinky® a quick jerk side to side? These waves are similar to the s-waves that travel through the earth during an earthquake (see Fig. 3.24 in Unit 3).
- For more information about the electromagnetic spectrum, search on the Internet and read one of the many relevant websites, such as http://earthsky.org/space/

what-is-the-electromagnetic-spectrum and http://hubble.stsci.edu/reference_desk/faq/answer.php.id=70&cat=light

- To learn more about infrared radiation, watch *Infrared: More Than Your Eyes Can See* (6:45 min), with astrophysicist Dr. Michelle Thaller, from NASA's Spitzer Space Telescope, at https://www.youtube.com/watch?v=2-0q0XlQJ0. Watch carefully what happens when Dr. Thaller demonstrates differences in the way that different materials transmit white light and infrared radiation:
    - What happens when she puts her hands inside a black plastic bag when viewed with a regular camera? With an infrared camera?
    - What happens when she brings a clear pane of glass near her face when viewed with a regular camera? With an infrared camera?

The clear glass pane and black plastic bag differ in the property of *transmissivity*, how they transmit different forms of light. The black plastic bag transmits infrared but not visible light. This clear pane of glass transmits visible light but not infrared.

Two related properties are *absorptivity*, how well a material absorbs light, and *emissivity*, how well the material emits light. Materials that absorb energy from visible light, emit infrared radiation as they warm up. Another property of materials is known as *reflectivity*, how well a material reflects light. This property was explored in Unit 1, VII.A.Question 1.20. All of these properties of materials affect what happens when light from the Sun shines on the Earth. Also relevant is the composition of light from the Sun: about 44.7% of solar energy is in the visible range, about 48.7% is in the near-infrared, and about 6.6% is ultraviolet (See: https://coolcalifornia.arb.ca.gov/science-of-cool-roofs)
Additional information about infrared radiation is available at many websites such as https://science.nasa.gov/ems/07_infraredwaves . For information about what astronomers observe in the infrared region of the spectrum, see https://herschel.jpl.nasa.gov/farIRandSubmm.shtml. The Herschel Space Observatory is named after William Herschel, who was the first to notice this invisible form of light.

- Complete entries in Table IV.1. Then write a summary of what you have learned before reading an example of student work about visible light and infrared radiation.

TABLE IV.1 Central ideas about influence of light and thermal phenomena on global climate

TABLE IV.1 Central ideas about influence of light and thermal phenomena on global climate

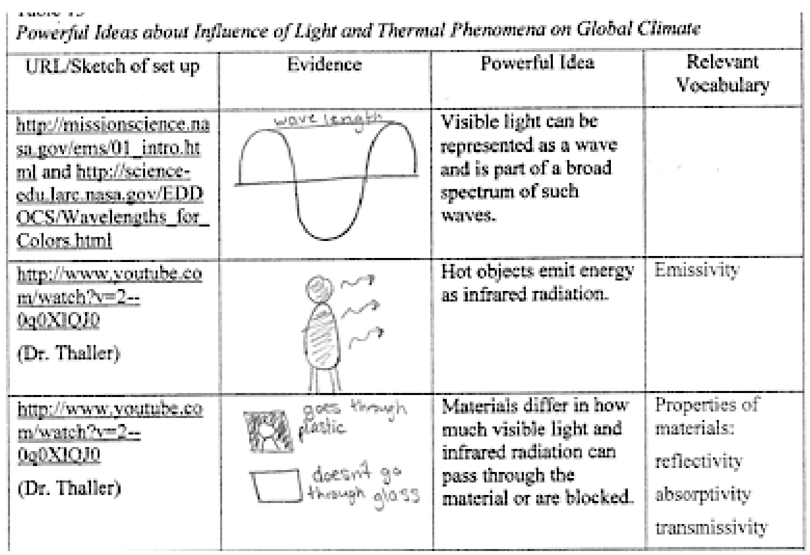
URL/Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
http://hubble.stsci.edu/reference_desk/faq/answer.php.id=70&cat=light		Visible light and infrared radiation can be represented as waves and are part of a broad spectrum of such waves.	Electromagnetic spectrum Infrared radiation
http://www.youtube.com/watch?v=2-0q0XlQJ0 (Dr. Thaller)		Hot objects emit energy as infrared radiation.	Emissivity

http://www.youtube.com/watch?v=2-0q0XlQJ0 (Dr. Thaller)		Materials differ in how much visible light and infrared radiation can pass through the material or are blocked.	Properties of materials: transmissivity reflectivity absorptivity

1. *Example of student work about visible light and infrared radiation.*

Many of us have experienced the heat of the sun, as light shines on Earth and heats up the surface. We have noticed that sidewalks are hot on a sunny day, and that a car with the windows rolled up is hotter than a car with the windows rolled down.

Table (IV.1) features ideas explored in this lab about the influence of light and thermal phenomena on global climate.



Powerful Ideas about Influence of Light and Thermal Phenomena on Global Climate

URL/Sketch of set up	Evidence	Powerful Idea	Relevant Vocabulary
http://missionscience.nasa.gov/ems/01_intro.html and http://science-edu.larc.nasa.gov/EDDOCS/Wavelengths_for_Colors.html	wave length	Visible light can be represented as a wave and is part of a broad spectrum of such waves.	
http://www.youtube.com/watch?v=2--0q0XlQJ0 (Dr. Thaller)		Hot objects emit energy as infrared radiation.	Emissivity
http://www.youtube.com/watch?v=2--0q0XlQJ0 (Dr. Thaller)	goes through plastic; doesn't go through glass	Materials differ in how much visible light and infrared radiation can pass through the material or are blocked.	Properties of materials: reflectivity absorptivity transmissivity

FIG. 4.6 A *student's entries for Table IV.1.*

In row 1, the student drew a picture of a wave and a half wave and identified a wave length as extending from one crest to the next.

In row 2, the student drew a person with arrows representing infrared radiation emitted from the person's body.

In row 3, the student drew a black plastic bag and wrote *goes through plastic*; the student also drew a glass pane and wrote *doesn't go through glass.*

The student wrote the following rationales for the ideas claimed in the third column of the table:

> ***Visible light can be represented as a wave and is part of a broad spectrum of such waves.*** *In this lab we stretched our perception of light, envisioning it as moving in waves. The wave still travels in a straight line, which is the midpoint of the wave. The distance between each crest is the wavelength. The height of a wave is called amplitude, and frequency is how often the wave crest passes a point each second. Light waves emitted by the sun come in various wavelengths, which create the electromagnetic spectrum. Waves are classified by their wavelengths. The shortest waves are gamma rays, then x-rays, then UV rays. The visible light is what the human eye can see. The next largest wavelength is microwaves, and then radio waves have the largest wavelength on the spectrum.*
>
> ***Hot objects emit energy as infrared radiation.*** *Dr. Michelle Thaller, http://www.youtube.com/watch?v=2-0q0XlQJ0, introduces the idea that, "Everything in the universe emits some kind of light." Infrared radiation is a kind of light wave that is not visible to the human eye. Dr. Thaller provides many examples of infrared cameras, which measure the energy being emitted by an object, or temperature. Warmer objects look bright in infrared, because they are giving off more infrared radiation. Colder objects look dark because they are giving off less infrared radiation.*
>
> ***Materials differ in whether visible light and infrared radiation can pass through the material or are blocked.*** *Dr. Michelle Thaller introduces the idea that visible light and infrared light pass through and are blocked by different materials. Infrared radiation can often pass through things that visual light cannot, such as a black plastic bag. Infrared also gets stopped by something visible light gets through, such as clear glass.*
>
> Physics student, Spring 2016

The history of the development of knowledge about various forms of "invisible light" is an example of the way that science develops, with participation and different points of view expressed and explored by a variety of individuals in many countries over several centuries (1600 to present day). To broaden your understanding, read about the discovery of infrared radiation as well as discoveries of the other forms of invisible light in the electromagnetic spectrum. The following two sections (III.A.2 and 3) provide a glimpse of this journey if the reader has time and interest. Otherwise proceed to Section III.B below.

2. Discovery of infrared radiation

In 1672, in England, Sir Isaac Newton published in the *Philosophical Transactions of the Royal Society of London* a paper about his new theory about light and colors. He explained in detail his many experiments with white light and its component colors in a book, *Opticks*, published in 1704. About a century later, an astronomer in England, Sir William Herschel (1800 a, b, c, d) reported his discovery of the *invisible rays of the Sun* in a series of papers he also published in the *Philosophical Transactions of the Royal Society of London.*

What did Herschel mean by the “invisible rays of the Sun”? He was interested in the Sun as well as in the stars. To study the Sun during the day, he used different colored filters on his telescope to reduce the sunlight’s intensity. Some colored filters seemed to warm his eye more than others and he became curious about this uncomfortable effect.

To explore how the different colors in the spectrum warmed a material, Herschel placed a prism in a window and oriented it to make a spectrum of red, orange, yellow, green, blue, and violet light shine on a table. As Newton had observed about 100 years earlier, the red light rays were bent the least by the prism and violet the most (see Unit 1, IX). Herschel, however, was asking a different question, about how light of different colors warmed materials.

As shown in Fig. 4.7, Herschel used three thermometers: thermometer #1 measured changes in temperature when its bulb was placed within a band of color in the spectrum on the table; thermometers #2 and #3 served as controls when placed nearby but outside the spectrum.

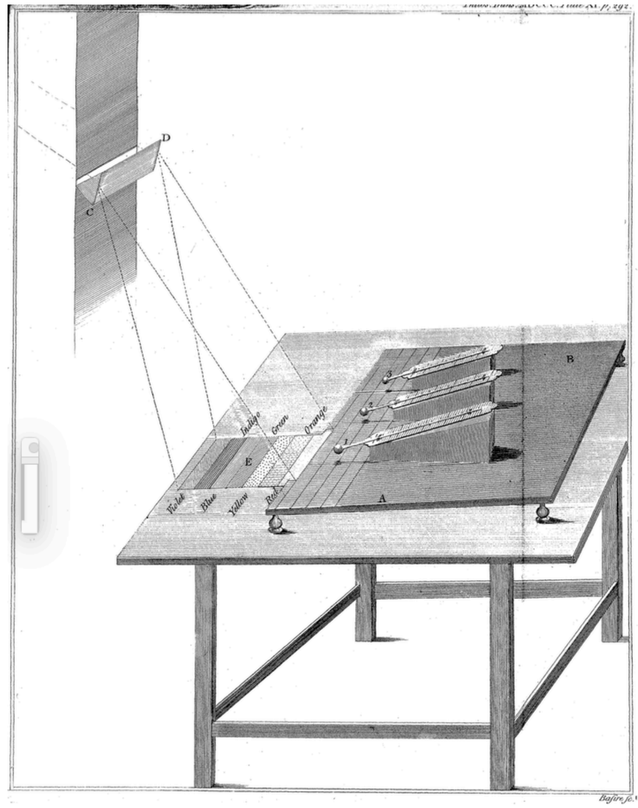


FIG. 4.7 Herschel's drawing showing a thermometer placed beyond the red band in the spectrum from a prism placed in his window. *http://rstl.royalsocietypublishing.org/content/90/284.full.pdf+html, p. 292.*

Herschel was surprised that thermometer (#1) warmed up when he placed it just beyond the red band of the visible spectrum. It warmed even though no light appeared to be shining on it! Like Newton, Herschel referred to the refraction of light rays by the prism as *refrangibility*. After reporting details of his experimental setup and data collected, Herschel concluded:

> *The first four experiments prove that there are rays coming from the sun, which are less refrangible than any of those that affect the sight. They are invested with a high power of heating bodies, but with none of illuminating objects; and this explains the reason why they have hitherto escaped unnoticed.*
>
> Herschel, 1800b, p. 290

These were *invisible rays of the Sun* because they could heat an object without appearing to shine on the object, illuminating it. These invisible rays were bent by the prism less than any of the colored rays, landing on the apparatus just beyond the red band of the visible spectrum.

Herschel also demonstrated that these invisible rays exhibited the same laws of reflection and refraction that were well known for white and colored light. He also studied similar effects for *terrestrial rays* such as from fires whose embers were no longer red hot but still warmed thermometers placed nearby.

This was the discovery of what is known as *infrared radiation*, energy that warms materials but does not make them visible to human eyes. This is an example of an unexpected finding during an exploration motivated by a practical need: Herschel wanted to understand why filters of different colors warmed his eye differently when he was looking at the Sun through his telescope. He was surprised when he noticed the increased temperature of the thermometer placed beyond the red band of the spectrum.

Herschel also had placed a thermometer beyond the violet band of the spectrum. Seeing little if any temperature change, however, he had concluded, "I was now sufficiently persuaded that no rays which might fall beyond the violet, could have any perceptible power, either of illuminating or heating" (Herschel, 1800b, p. 288).

- One way to explore infrared radiation is to replicate Herschel's experiment. See, for example, http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/herschel_example.html. This experiment uses a glass prism, several identical thermometers, a way to hold the prism still, a white sheet of paper, a box, and a sunny day.
- See https://www.youtube.com/watch?v=zmiU5tJRJd4 for an introduction to infrared radiation and a demonstration of this experiment.
- Neil deGrasse Tyson, an astrophysicist who is director of the Hayden Planetarium, has described "the brilliant way that infrared light was discovered" at https://www.youtube.com/watch?v=Pr4qEhcGPq8.

Herschel and his sister Caroline became world famous for their surveys of the skies with telescopes made and used in their home. Among Caroline Herschel's achievements were the discovery of three nebulae and eight comets as well as development of an extensive catalogue of stars and nebulae (https://www.skyandtelescope.com/observing/in-caroline-herschels-footsteps; https://www.noao.edu/image_gallery/html/im1017.html). In 1828, she was the first woman to be awarded a Gold Medal of the Royal Astronomical Society (https://www.esa.int/Science_Exploration/Space_Science/Herschel/Caroline_and_William_Herschel_Revealing_the_invisible).

Herschel's papers and Newton's 1672 paper in the *Philosophical Transactions of the Royal Society of London* are available online as is Newton's *Opticks*:

Herschel, W. (1800a). Investigation of the powers of the prismatic colours to heat and illuminate objects; with remarks, that prove the different refrangibility of radiant heat. To which is added, an inquiry into the method of viewing the sun advantageously, with telescopes of large apertures and high magnifying powers. *Philosophical Transactions of the Royal Society of London* 90, 255-283. http://rstl.royalsocietypublishing.org/content/90/255.full.pdf+html

Herschel, W. (1800b). Experiments on the refrangibility of the invisible rays of the sun. *Philosophical Transactions of the Royal Society of London* 90, 284-292. http://rstl.royalsocietypublishing.org/content/90/284.full.pdf+html

Herschel, W. (1800c). Experiments on the solar, and the terrestrial rays that occasion heat; with a comparative view of the laws to which light and heat, or rather the rays which occasion them, are subject, in order to determine whether they are the same, or different. Part I. *Philosophical Transactions of the Royal Society of London* 90, 293-326. http://rstl.royalsocietypublishing.org/content/90/293.full.pdf+html

Herschel, W. (1880d). Experiments on the solar, and the terrestrial rays that occasion heat; with a comparative view of the laws to which light and heat, or rather the rays which occasion them, are subject, in order to determine whether they are the same, or different. Part II. *Philosophical Transactions of the Royal Society of London* 90, 437-538. http://rstl.royalsocietypublishing.org/content/90/437.full.pdf+html

Newton, I. (1672). A letter of Mr. Isaac Newton, Professor of the Mathematics in the University of Cambridge; Containing his new theory about light and colors: Sent by the author to the publisher from Cambridge, Febr. 1671/72; in order to be communicated to the R. Society. *Philosophical Transactions of the Royal Society of London*, 6, (60-80) 3075-3087. https://royalsocietypublishing.org/doi/pdf/10.1098/rstl.1671.0072

Newton, I. (1704). *Opticks: Or a treatise of the reflections, refractions, inflections and colours of light*. London: Printed for Sam. Smith and Benj. Walford. Printers to the Royal Society. http://www.gutenberg.org/files/33504/33504-h/33504-h.htm

3. Discoveries of the other invisible portions of the electromagnetic spectrum

Discovery of the rest of the invisible portion of the electromagnetic spectrum occurred during the next hundred years, 1800-1900. A German scientist, Johann Wilhelm Ritter, was aware of Herschel's discovery of invisible rays beyond the red band in the spectrum of visible light and decided to check for himself whether there were invisible rays beyond the violet band.

Ritter had been experimenting with a chemical, silver chloride, that darkened when placed in sunlight. In 1801 he found that this chemical reacted very little when placed in the red band of the spectrum, darkened when placed in the blue band, and reacted intensely when placed beyond the violet band in the spectrum, demonstrating the presence of an invisible form of light there also. He attributed this effect to *chemical rays*, which later were called *ultraviolet radiation* (see: https://astronomy.swin.edu.au/cosmos/U/Ultraviolet .)

A hundred years earlier, Newton and Huygens had disagreed about whether light should be envisioned as rays, made up of particles traveling in straight lines, or as waves, traveling in spreading circles. This discussion continued with Herschel writing in terms of rays and a contemporary, Thomas Young, writing in terms of waves.

Herschel described his findings in terms of *invisible rays* of the Sun that were reflected and refracted in the same way as white light and the colors of the visible spectrum. Young, however, envisioned light as *undulations* that spread out from a source in expanding waves, like sound waves and water waves when a pebble is dropped in a puddle. In an article published in 1802 in the *Philosophical Transactions of the Royal Society of London*, Young used a wave model of light to explain findings from a double-slit experiment, in which light passing through two slits created interference patterns on a screen (see: http://micro.magnet.fsu.edu/primer/java/interference/doubleslit/.)

Young, T. (1802). The Bakerian Lecture: On the Theory of Light and Colours. *Philosophical Transactions of the Royal Society of London*, **92**, 12-48. http://rstl.royalsocietypublishing.org/content/92/12.full.pdf+html

More than sixty years passed before a Scottish scientist, James Clerk Maxwell predicted the existence of other forms of electromagnetic waves in his theoretical article, *A dynamical theory of the electromagnetic field*, published in 1865 in the *Philosophical Transactions of the Royal Society of London* (see: https://science.hq.nasa.gov/kids/imagers/ems/consider.html).

Maxwell, J. C. (1865). A dynamical theory of the electromagnetic field. *Philosophical Transactions of the Royal Society of London*, **155**, 459-512. http://rstl.royalsocietypublishing.org/content/155/459.full.pdf+html

In 1888, a German scientist, Heinrich Hertz, designed ways to produce and study radio waves and microwaves experimentally (http://www.sparkmuseum.com/BOOK_HERTZ.HTM). [Percy Spencer, an American scientist, invented the microwave oven in 1946 after noticing that something had melted in his pocket one day as he was working on improving radar technology (http://www.popularmechanics.com/technology/gadgets/a19567/how-the-microwave-was-invented-by-accident/ .]

A German scientist, William Roentgen, received the first Noble Prize in Physics, in 1901, for discovering X-rays in 1895. He named these new puzzling rays after the "x" representing unknowns in mathematics (https://www.nobelprize.org/nobel_prizes/physics/laureates/1901/rontgen-bio.html)

A French scientist, Paul Villard, discovered gamma rays in 1900. Gamma rays are generated by radioactive atoms (https://link.springer.com/article/10.1007/s000160050028). He was using a radioactive sample he had been given by a Paris colleague, Marie Curie. She won the Nobel Prize twice, in 1903 and 1911, for her studies of radioactivity https://www.nobelprize.org/nobel_prizes/physics/laureates/1903/marie-curie-facts.html)

The issue of *what IS light* continued to be discussed during the 20th century: is light a series of spreading waves or is light a stream of particles moving in straight lines? In 1905, Albert Einstein wrote:

> *Indeed, it seems to be that…the production or conversion of light can be understood better if one assumes that the energy of light is discontinuously distributed in space. According to the assumption to be contemplated here, when a light ray is spreading from a point, the energy is not distributed continuously over ever-increasing spaces, but consists of a finite number of energy quanta that are localized in points in space, move without dividing, and can be absorbed or generated only as a whole.*

Einstein, A. (1905). On a heuristic point of view concerning the production and transformation of light. *Annelen der Physik* 17: 132-148. (translated from the German by Dr. Anna Beck and Professor Peter Havas in *The Collected Papers of Albert Einstein Volume 2: The Swiss Years: Writings*, 1900-1909, p. 87 (http://einsteinpapers.press.princeton.edu/vol2-trans/101) Princeton University Press.

Einstein received the Nobel Prize in 1922 for this paper, in which he explained the photoelectric effect in terms of particles of light, now known as photons. A series of Nobel Prizes were awarded during the 20th century for theorists and experimentalists exploring the wave and particle natures of both light and matter as inferred in the context of quantum mechanics. See https://www.nobelprize.org/nobel_prizes/themes/physics/ekspong/ for the story of evolving understandings about the wave-particle duality of light and matter.

See https://ocw.mit.edu/courses/chemistry/5-111sc-principles-of-chemical-science-fall-2014/unit-i-the-atom/lecture-3/ for a recent lecture about the Wave-Particle Duality of Light in an open source course at the Massachusetts Institute of Technology by Professor Catherine Drennen. Her lecture on the Wave-Particle Duality of Matter and the Schrodinger Equation is available at https://ocw.mit.edu/courses/chemistry/5-111sc-principles-of-chemical-science-fall-2014/unit-i-the-atom/lecture-4/.

Professor Lisa Randall (https://www.physics.harvard.edu/people/facpages/randall), a theoretical physicist at Harvard University, has written about the wave-particle duality in terms of the level at which one is looking, whether one is using one's eyes looking at everyday things or "looking" at an atomic level where quantum mechanical effects occur. The phrase *classical* refers to physics understandings in the everyday world. The phrase *quantum mechanical* refers to physics understandings at the level of and within atoms and molecules.

> *…none of us (with the possible exception of superheroes) sees individual photons, so quantum mechanical effects cannot be easily detected. Ordinary light doesn't look as if it's made up of quanta. We see bunches of photons that constitute visible light. The large number of photons together act as a classical wave.*
>
> *You need a very weak source of photons, or a very carefully prepared system, to observe the quantized nature of light. When there are too many photons, you can't distinguish the effect of any single one. Adding one more photon to classical light, which contains many photons, just doesn't make a big enough difference. If your lightbulb, which behaves classically, emitted one additional photon, you would never notice. You can observe detailed quantum phenomena only in carefully prepared systems.*
>
> Randall, L. (2005). *Warped passages: Unraveling the mysteries of the universe's hidden dimensions.* New York: Harper Collins, p. 136-137.

B. Reviewing central ideas about thermal phenomena developed in earlier units

Units 2 and 3 developed some central ideas about how energy flows from one place to another. These ideas are relevant in exploring what happens when light from the Sun shines on the Earth.

Question 4.5 How does energy flow from one place to another?

Energy transfer processes include transmission, reflection, absorption, emission, conduction, convection, melting, freezing, sublimation, transpiration, evaporation, and condensation. Properties of materials such as specific heat, thermal conductivity, and reflectivity also affect what happens when energy flows from one place to another such as on a sunny day at the beach when the sand is hot, the water cool, and a cloudy sky as well as sea breezes often occur in the afternoon (Unit 3, V. Questions 3.8 and 3.9). Tracing the flow of energy in this scenario involved interpreting a diagram as shown in Fig. 3.9 and repeated as Fig. 4.8 below.

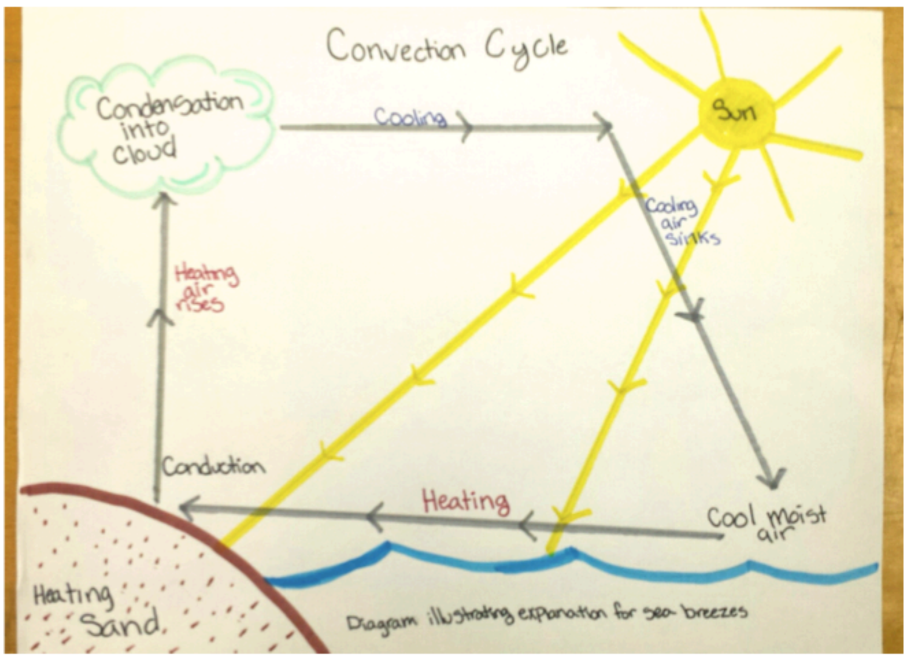


FIG. 4.8 Student diagram for explaining sea breezes.

The explanation of sea breezes included the following story about how energy flows from the Sun and circulates around the sand, water, and atmospheric system during a sunny day at the beach:

The Sun *radiates* energy to the Earth.
Some of the energy is *reflected* by the sand and the water
Some of the energy is *absorbed* by the sand and the water.

Sand and water differ in the property of *specific heat*. One gram of water needs about five times as much energy as one gram of sand to change temperature by one degree C.

This means that if equal masses of sand and water absorb the same amount of energy, the sand's temperature will increase about 5 times as much as the water's temperature increases.

Sand and water also differ in the property of *thermal conductivity*. Sand's thermal conductivity is low; this means that energy absorbed by the sand stays near the surface of the sand; sand below the surface remains cool. Water's thermal conductivity is high; this means that energy absorbed by the water at the surface spreads throughout the water; water below the surface warms along with the water at the surface.

Because energy absorbed stays near the surface of the sand and less energy is needed to increase the sand's temperature, sand gets hot. Because energy absorbed spreads throughout the water and more energy is needed to increase the water's temperature, the water stays cool even though the sun has been shining on both sand and water in the same way for the same time.

Sand and water also differ in the property of reflectivity. Sand reflects up to 40% of incoming sunlight depending upon its composition whereas liquid water reflects only about 6% unless the Sun is close to the horizon. However, this difference is masked by the large difference in specific heats. Even if a gram of water absorbed an entire calorie of energy from the sun and a gram of sand reflected 40% of a calorie of energy from the sun, the sand would still warm up three times as much as the water.

Also some of the water evaporates into the air above the surface of the water. Evaporation uses energy to change water from a liquid to a gaseous form, so the energy from some of the light from the Sun shining on the water goes into this process rather than into warming the water.

Energy flows from hot objects to cold objects. When the objects are touching this process is called *energy transfer by conduction*. The hot sand warms the cool air above it by conduction.

Fluids expand when warmed. The warmed air, becoming less dense, rises into the cooler upper atmosphere; the warmed air cools as its energy flows into the cooler surrounding air; cool more dense air sinks back toward the surface. This process is called *energy transfer by convection*.

As the warm air rises, moist cool air over the water forms a sea breeze by flowing toward the land. The hot sand warms the moist air; the warmed moist air becomes less dense and rises into the cooler upper atmosphere; the warmed moist air cools as its energy flows into the cooler surrounding air; as the moist air cools, the moisture condenses into water droplets, forming clouds; this releases some energy into the upper atmosphere as the water changes back from a gaseous to liquid form; this energy may get dissipated during storms as wind, thunder, and lighting; the cool more dense air sinks back toward the surface.

This complex process of tracing the energy from the Sun as it flows from one place to another is useful preparation for thinking about happens when the Sun shines not only on the sand and water at a beach but on the entire Earth.

Question 4.6 What is the role of systems thinking in understanding the Earth's energy budget?

In Unit 2, Question 2.10, it was important to think about the *system* involved when comparing the ratio of masses of hot and cold water to the ratio of their changes in temperature when mixed together. Was all the energy lost by the hot water flowing into the cold water or was some energy flowing into the containers or nearby air? To completely account for all of the energy lost by the hot water, one needed to think what was happening to the energy in the entire system, not only in the cups of hot and cold water but also in their surroundings.

In this unit, the system of interest includes the entire Earth. What is happening to the energy that the Sun is radiating to the Earth? Is the amount of energy radiated to Earth from the Sun also the same as the amount of energy flowing away from the Earth into space? The balance between energy flowing in and out is referred to as the Earth's *energy budget* in analogy to a financial budget that monitors the balance between income and expenses.

For a system to be in thermal equilibrium, the amount of energy leaving the system must equal the amount of energy entering the system. This central idea underlies the influence of light and thermal phenomena on global climate and in particular, the phenomenon known as the greenhouse effect.

- Complete entries in the continuation of Table IV.1

TABLE IV.1 Central ideas about influence of light and thermal phenomena on global climate (continued)

TABLE IV.1 Central ideas about influence of light and thermal phenomena on global climate (continued)			
URL/Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
		Energy transfer occurs through a variety of processes.	Radiation Reflection Absorption Emission of infrared radiation Transmission Conduction Convection Changes in State
http://earthobservatory.nasa.gov/Features/EnergyBalance/page4.php		The Earth's energy budget is the flow of incoming and outgoing energy.	System

Complete documenting your exploration and writing a summary before looking at an example of student work about energy transfer processes and the Earth's energy budget.

1. Example of student work about energy transfer processes and the Earth's energy budget.

Powerful Ideas about Influence of Light and Thermal Phenomena on Global Climate

URL/Sketch of set up	Evidence	Powerful Idea	Relevant Vocabulary
From our touch: From another source:	Energy transfer occurs through touch, and through emission	Energy transfer occurs through a variety of processes.	Radiation Reflection Absorption Emission of infrared radiation Transmission Conduction Convection Changes in State
http://earthobservatory.nasa.gov/Features/EnergyBalance/page4.php	Sun in out Earth	The Earth's energy budget is the flow of incoming and outgoing energy.	

FIG. 4.9 A *student's entries to Table IV.1 (continued)*

In the first row, the student drew a picture of a hand touching a block (from Unit 2,III,A,Question 2.2) and wrote *From our touch*: The student also drew a picture of a light bulb and wrote *From another source*. The student also wrote, *Energy transfer occurs through touch, and through emission.*

In the second row, the student drew a half circle representing *Earth* and an arrow pointing *in* from the *Sun*, represented with a small circle, as well as an arrow pointing *out* from the large half circle representing Earth.

The student wrote the following rationales for the central ideas claimed in the third column of the table:

> ***Energy transfer occurs through a variety of processes.*** *Energy from the Sun is transferred through radiation – light rays traveling to an object – like sand, and transferring the energy, heating the sand. Reflection can block some energy from being transferred, such as the ocean reflecting radiation when the Sun is at an angle. The sand on the beach absorbs the Sun's energy all along the top layer of the sand, heating it. Infrared radiation is emitted from warm objects, such as a person's hand. An infrared camera can detect and display warm and cold regions based on the emission of infrared radiation. Conduction transfers energy through direct contact, such as a warm hand on a piece of metal. Convection is the energy transfer that can occur in fluids, when a heat source heats an area of water… The warm water rises and travels towards the cooler area, and the cool water sinks and travels towards the*

warmer area…An example of a change in state of water due to energy is evaporation. Sometimes sunlight provides enough energy for some of the liquid water in bodies of water to evaporate.

The Earth's energy budget is the flow of incoming and outgoing energy. *Through the processes of radiation, reflection, and absorption, energy enters and exits Earth's atmosphere. For a stable environment, Earth's incoming energy should be equal to Earth's outgoing energy. If the budget is not balanced, the temperature within Earth's atmosphere, oceans and land forms will change. If the incoming energy is greater than the outgoing energy, then the temperature will rise. If the outgoing energy is greater than the incoming energy, then the temperature will decrease. For stabile temperatures on Earth, the incoming and outgoing energy should be equal.*

Physics student, Spring 2016

These central ideas about energy transfer processes and the concept of the Earth's energy budget are key for understanding the greenhouse effect within the Earth's climate system.

IV. Using Central Ideas about Light and Thermal Phenomena to Explain the Greenhouse Effect

The greenhouse effect is often mentioned in discussions about global climate. The name of this effect refers to an analogy between what happens when the Sun shines on the entire Earth and what happens when the Sun shines on a greenhouse in a garden here on Earth.

A. Considering what happens during the greenhouse effect in a garden greenhouse

A student noted that sometimes people have no idea what is happening in a greenhouse here on Earth:

> *I asked my sister if she knew anything about the greenhouse effect and she said nothing. So I asked if she ever heard of it before and she said no. Then I reminded her that greenhouses are used for gardens. She went 'Oh, right' but didn't know what they did for the gardens…*
>
> Physics 111 Student, Spring 2016

Therefore it can be helpful to start this discussion with a focus on greenhouses in gardens here on Earth

Question 4.7 What is the greenhouse effect that occurs within a greenhouse in a garden?

- Figure 4.10 shows a photograph of a greenhouse. What do you know about greenhouses: How are they made? What is their purpose? Why do they work?

FIG. 4.10 A greenhouse in a garden by [Steve Daniels](#) [CC BY-SA 2.0](#) Source: https://www.geograph.org.uk/of/4182114

To explore the *greenhouse effect* in a greenhouse in a garden, you will need:

- 2 identical clear glass or plastic containers,
- 2 thermometers that agree on the same number for room temperature or 2 digital temperature probes connected to a computer and calibrated so that they read the same temperature
- 2 rulers,
- 2 moist paper towels
- 2 identical lamps with identical bulbs or one lamp that can shine equally on both containers or access to a place to put the containers in the Sun)
- clear plastic wrap or glass cover for one of the containers.

- How could you use this equipment to explore what happens when an energy source (the Sun or a lamp) shines on an open versus a closed container?
- To model the greenhouse effect that occurs in garden greenhouses, prepare two clear glass or plastic containers in the same way:

- put two paper towels moistened in the same way in the bottom of each container
- check that two thermometers or two temperature probes connected to a computer give the same reading for room temperature
- place a ruler diagonally in each container with one end on the bottom and the other end resting on an edge of the container
- lay a thermometer on the ruler in each container so that the bulb of the thermometer is not resting on the bottom of the container but is supported at about a third of the height of the container, with the scale facing up so that the thermometer reading is visible (or place a digital thermometer on the ruler in each container)
- record the initial temperatures of the air in the containers; these should be the same

- At the top of your physics notebook page, record the *Topic* of this exploration. Under *Before*, draw a picture of the set up. What do you predict will happen to the temperatures of the containers after one container is covered and both are placed in the Sun or under identical lamps placed the same distance away from the containers? Why do you predict this will happen?
- Continue preparing to model the greenhouse effect:
    - cover one of the containers with a clear glass plate or plastic wrap
    - place the containers in the sun or place two identical lamps with identical bulbs so that they shine on the containers in the same way from the same distance away or place one lamp so it shines equally on the two containers
    - monitor the temperatures every few minutes or so
- Under the *During* section of your physics notebook page, make a table recording the temperatures of the containers or draw or take a picture of the graph drawn by the computer connected to the temperature probes.
- Note any vocabulary that is new to you.
- Discuss your findings and formulate a relevant central idea. In the *After* section of the physics notebook page, report this central idea and the evidence on which it is based.
- Write a rationale that explains how the evidence supports this idea and why this is important
- Also reflect upon this exploration such as what connections can you make to other experiences? How might you use what you learned in your own classroom?
- What have you learned and what are you still wondering?

Write a summary of what you have learned about the greenhouse effect in a garden and explain why a greenhouse in a garden gets warm when light from the Sun shines upon it.

Complete documenting your exploration on your physics notebook page and writing a summary before looking at an example of student work about exploring the greenhouse effect in garden greenhouses.

1. Example of student work about exploring the greenhouse effect in garden greenhouses

Greenhouse effect. (Figure 4.11) is a sketch of the experiment done in class.

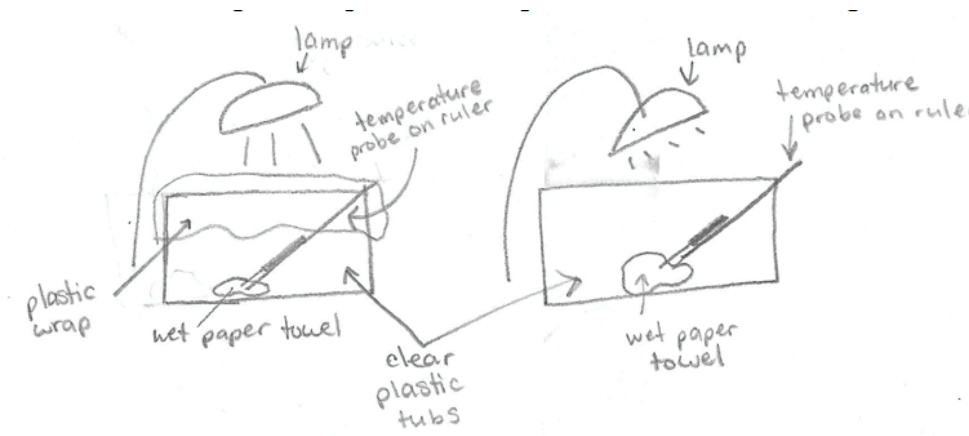


FIG 4.11 Student drawing of model of the greenhouse effect in a garden greenhouse.

The student labeled two *lamps* shining on two *clear plastic tubs*. Both tubs had *wet paper towels* in the bottom and *temperature probes on rulers* leaning on one edge of the tub, with the ruler resting on the bottom. One tub had *plastic wrap* covering the top of the tub.

> *Two plastic tubs were set up under lamps with a wet paper towel in each. Both tubs also had a temperature probe attached to a ruler so we could track any changes in temperature that may have occurred. One tub had plastic wrap covering the opening, and the other had no covering. We predicted what would happen, and many of us thought that the one with plastic would be warmer, since heat could not escape as easily as the tub without plastic wrap. At the beginning of this experiment both temperatures were about 22°C. Later in the lab we returned to these tubs to*

see that the tub with plastic wrap had condensation on the plastic, and was much warmer than the other tub. At the end of this experiment, the tub without plastic was 27.9° and the tub with the plastic wrap was 35.7°C. Both tubs had an increase in temperature as a result of heat from the lamp. However, with the plastic wrap blocking heat (energy) from leaving the tub, it was much hotter than the tub without a blocked exit. Like this model, if greenhouse gasses block energy from leaving the Earth, then Earth's temperature will drastically increase.

Physics student, Spring 2016

The greenhouse effect in this model of greenhouses in gardens involves an enclosed container getting warmer when more energy from the light source enters than leaves the container. The warmed air in the open container can circulate outside the container so the open container does not warm as much as the covered container.

Enclosed greenhouses in gardens prevent warmed air from circulating with cooler air outside. In addition, the garden greenhouse may be made out of glass that transmits visible light but not infrared light. Although the plants use some of the energy they absorb to grow, they also emit infrared radiation as they warm, as do the other contents of the greenhouse such as the soil, tables, and tools. If the infrared radiation cannot travel out through the glass and remains within the greenhouse, the temperature of the contents and the air increases. This mechanism differs from what happens when light from the Sun shines on the entire Earth, but the overall effect, an increase in temperature because of energy that does not leave the system, is the same.

If more energy enters than leaves, a system warms up. Within a garden greenhouse, the owner can use vents to modulate the energy flow in and out if the greenhouse gets too hot (see, for example, https://www.advancingalternatives.com/blog/getting-started-greenhouse-ventilation-systems/. With a greenhouse effect operating within the entire Earth, however, what can the Earth's "owners" do if the Earth gets too hot? That is the issue that concerns scientists and others convinced on the basis of evidence that the Earth is warming up now much more rapidly than in the past.

B. Considering what happens during the greenhouse effect on a global scale

Question 4.8 What is the greenhouse effect in the context of the entire Earth?

> To consider the *greenhouse effect* in the context of the entire Earth, each group will need: a large white board as well as a white board marker and eraser for each student.

- With your group members, talk about the greenhouse effect on a global scale.
- On a large white board, draw a diagram to represent your group's initial ideas about what is happening to the energy that enters the Earth's system when light from the Sun shines on the Earth:
    - Where does this energy go?
    - What changes does it undergo while on Earth?
    - How does it leave the Earth?

- Plan and practice briefly what each group member will say when presenting your group's diagram to the whole group.
- Share your ideas and their representation on a whiteboard with the whole group:
    - What patterns do you notice in these presentations?
    - How are the groups' ideas similar? How are they different?
    - How do they help you think about the greenhouse effect on the Earth?

1. *Examples of students' initial diagrams about the greenhouse effect*

As shown in Fig. 4.12, Group 3's diagram portrays the basic idea of the greenhouse effect, that *thermal energy* travels in rays from the Sun to the surface of the Earth and some of this *thermal energy* travels back out from the surface through the *atmosphere* to space. Some *energy* travels from the surface into the *atmosphere* but is *trapped* and returns back to the surface. The *atmosphere* includes two gases, *water vapor* and *carbon dioxide* that are relevant to this process.

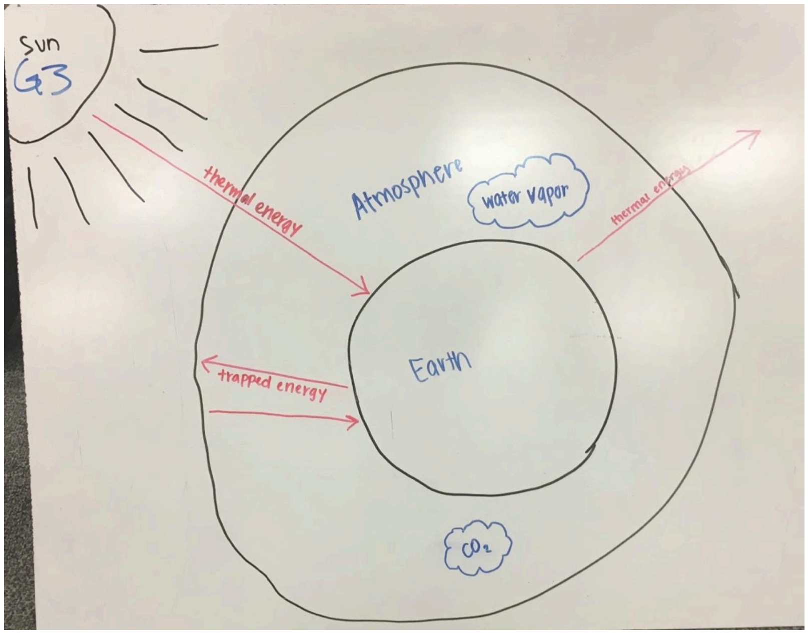


FIG. 4.12 Group 3's initial diagram for the greenhouse effect on Earth.

As shown in Fig. 4.13, Group 5's diagram portrays the basic idea of the greenhouse effect with some details. These include that rays from the *Sun heat up* the surface of the *Earth*; that some rays cannot penetrate the atmosphere due to water vapor; that some rays bounce back and forth between the Earth's surface and clouds in the *atmosphere* (*It's a TRAP!*), and some rays escape out to space, which raises an interesting question, does *light disappear*?? in space because *Space is dark*. A red star draws attention to the statement *light can only penetrate the atmosphere if it is not blocked by clouds!*

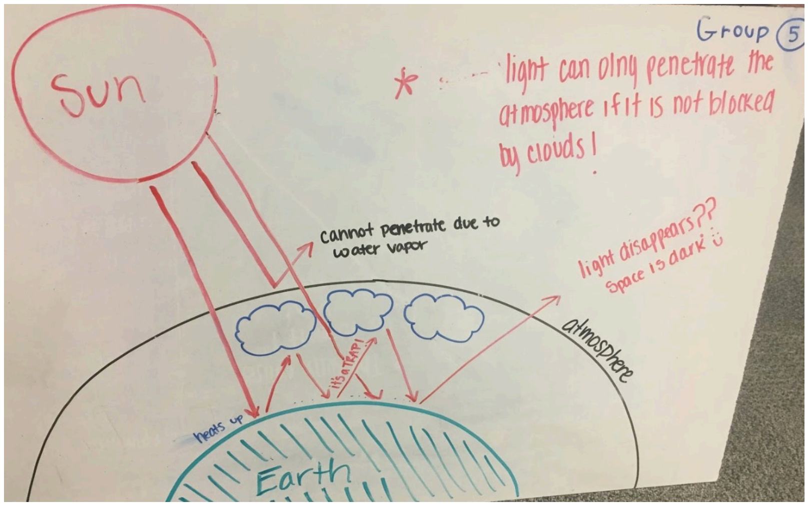


FIG. 4.13 Group 5's initial diagram for the greenhouse effect on Earth.

As shown in Fig. 4.14, Group 2's diagram portrays the basic idea of the greenhouse effect with some additional details. The *Sun* sends rays in many directions, including toward *Earth*. Implied is that some of these rays get through the *atmosphere* and interact with the surface, which *keeps the earth warm – also heats it up*! The surface includes our classroom, Room 328, within a building within our country. Three clouds represent what happens in the *atmosphere*: a *cloud*, *this is also a cloud…and so is this. Just so you know . The water vapor heats up – doesn't allow the light to go through.* The *atmosphere contains* : *gases…oxygen* and *nitrogen.* These students recognized that the Sun affects *other planets* and they suggest *use your imagination* to consider the Sun's effect there.

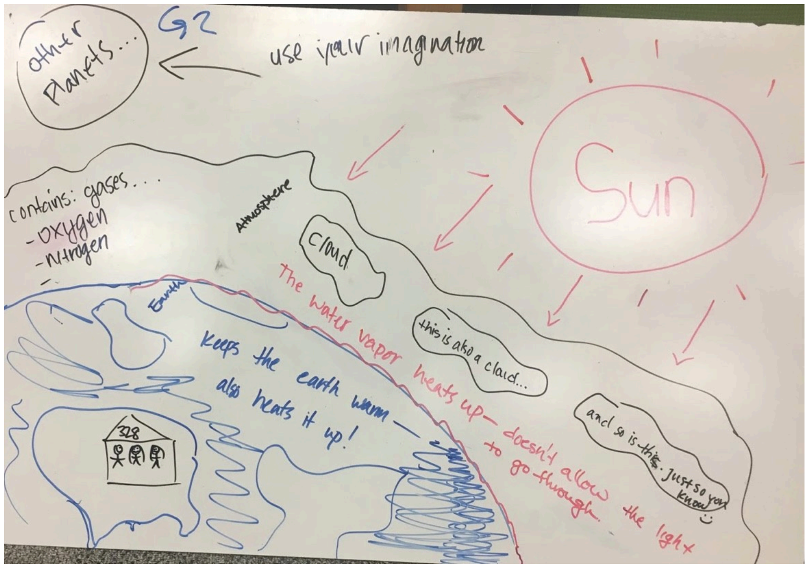


FIG. 4.14 Group 2's initial diagram for the greenhouse effect on Earth.

The students moved their chairs to form a circle and each group presented their whiteboard to the others. These examples demonstrate that the students already had useful knowledge about the importance of the Sun and the atmosphere, about some of the relevant processes, and about their effects. Many of the details needed elaboration and/or refinement but the small groups were able to make reasonable first attempts at creating these complex diagrams. The actions of talking with one another in the small groups, creating their group's initial greenhouse effect diagrams, and sharing these ideas and diagrams through the *circle conversation* set the context for studying a controversial and complex topic in a respectful way.

2. *Greenhouse effect diagram provided by the Intergovernmental Panel on Climate Change*

The Intergovernmental Panel on Climate Change (IPCC, www.ipcc.ch) is an organization with 195 member countries through which scientists work together to collect and analyze information about climate change from studies all over the world. Figure 4.15 presents a diagram prepared by this organization to represent what happens to the energy that radiates to the Earth from the Sun.

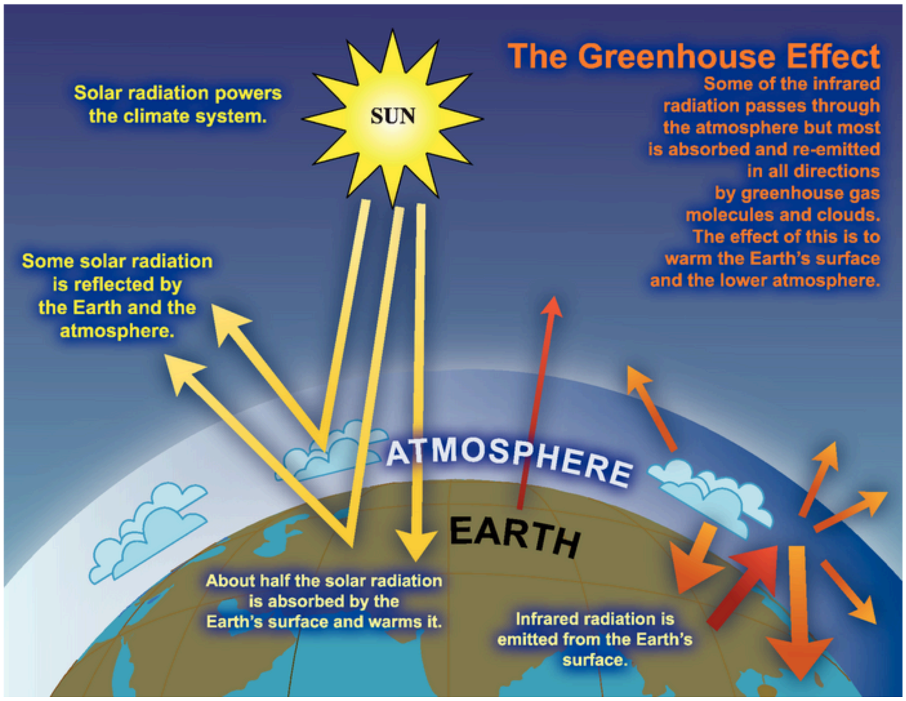


FIG. 4.15 An idealized model of the natural greenhouse effect. Intergovernmental Panel on Climate Change, Assessment Report 4, Question 1.3, Figure 1, What is the Greenhouse Effect? [*https://www.ipcc.ch/report/ar4/wg1/historical-overview-of-climate-change-science/*](https://www.ipcc.ch/report/ar4/wg1/historical-overview-of-climate-change-science/)

- To interpret this diagram, tell the story of what happens to the energy radiated from the Sun as it moves through the Earth's climate system:
  - What do each of the three yellow rays represent?
  - What does the narrow reddish ray represent?
  - What does the thick reddish ray represent?
  - What does each of the orange rays represent?

- Put "greenhouse effect diagram" in your computer browser and view the many versions available for representing the greenhouse effect. Select one or make your own and write your own interpretation of a diagram presenting the greenhouse effect.

3. Example of student's written work about the greenhouse effect on the entire Earth

I went to the Internet to learn more about the process and the flow of energy surrounding the greenhouse effect. I came upon this diagram:

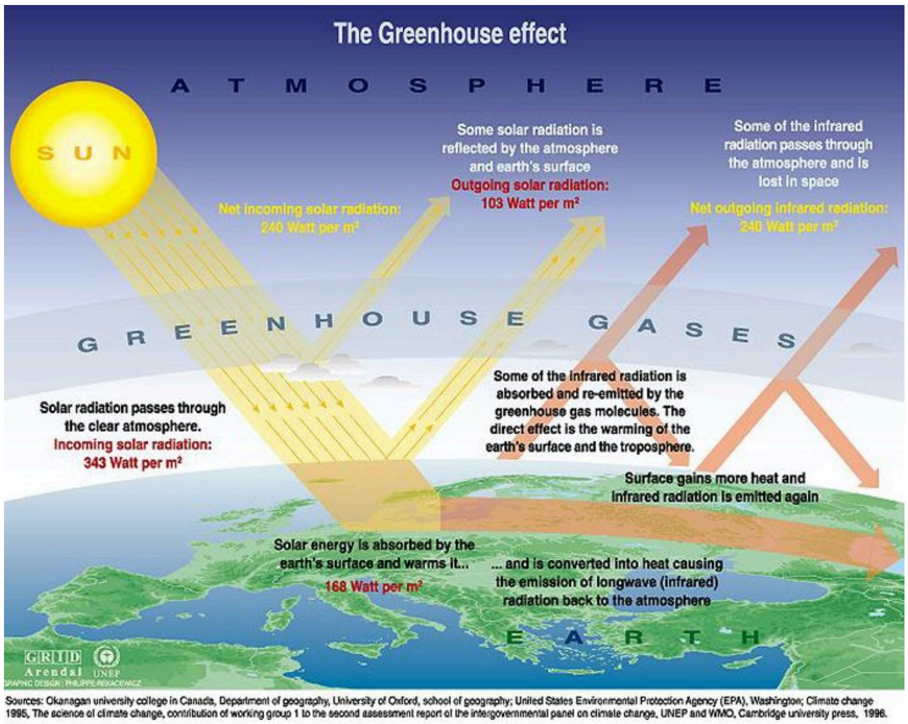


FIG. 4.16 "The Greenhouse effect." Greenhouse Effect. Delaware Department of Natural Resources and Environmental Control, n.d. Philippe Rekacewicz, Emmanuelle Bournay, UNEP/GRID-Arendal See http://www.dnrec.delaware.gov/climatechange/pages/greenhouse%20effect.aspx and http://www.grida.no/resources/6888

I used this diagram to help create my own diagram, because I learn best though my own creations. I decided to make a diagram that had steps to show how the radiation from the sun goes through a course to heat up the earth:

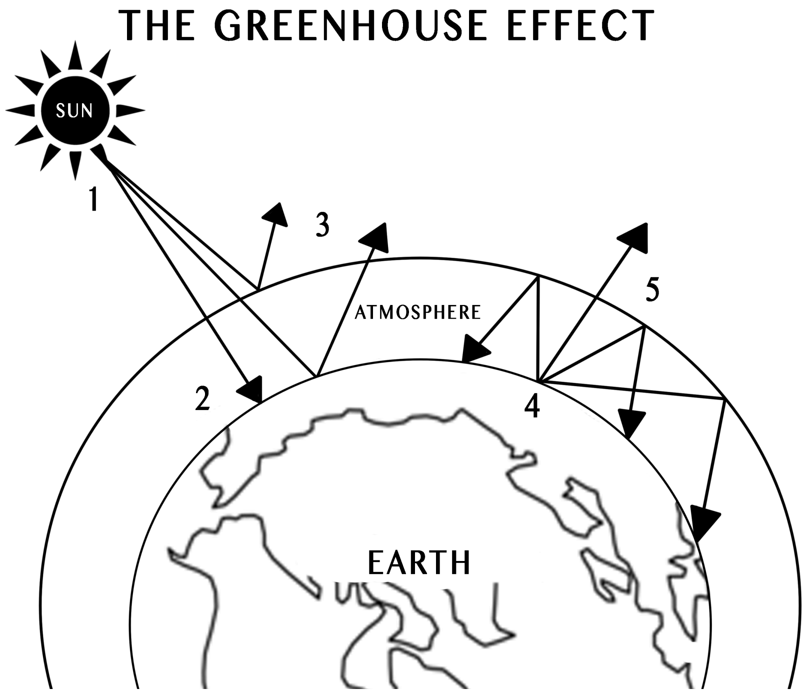


FIG. 4.17 *Student drawn computer diagram of the greenhouse effect.*

1. *Solar radiation is emitted from the sun, headed toward Earth.*
2. *Most of the sun's radiation is absorbed by the earth's surface, thus warming the earth.*
3. *Some of the solar radiation is reflected back out to space by the earth surface and atmosphere.*
4. *As the solar radiation heats up the earth's surface and lower atmosphere, the radiation is converted into thermal energy called infrared radiation.*
5. *Some of the infrared radiation escapes Earth's atmosphere, but most of it is absorbed and re-emitted to the earth by the greenhouse gasses in the atmosphere, warming the surface even more.*

The earth should be able to keep a proper balance of energy in and energy out in order to keep the surface temperature stable for our current ecosystems; however this is no longer true. The earth's "energy budget" has been disrupted by the presence of more than the natural amount of greenhouse gases in our atmosphere. Deforestation, excessive use of fossil fuels, and massive beef consumption all are factors that contribute to excess greenhouse gasses such as carbon dioxide and methane. Infrared rays have a hard time passing though these gases in the *atmosphere, trapping more from escaping. This means that the earth is receiving the same amount of energy from the sun as it always had, but it is unable to release a balanced amount back out to space, throwing off the energy budget. Unfortunately, while there are things we as humans can do to aid in this issue, many people are not willing to make the necessary changes in order to save the planet.*

Physics Student, Fall 2016

4. Nuances about the greenhouse effect and the Earth's energy budget

Some students are curious about what it means for the infrared radiation to be "trapped" by the green house gases. Some have questions about the details involved in what happens to the energy entering and leaving the Earth's system. This section provides additional information for those interested.

(a) Mechanism that underlies the statement that energy is "trapped" by greenhouse gases. Discussions of the greenhouse effect often refer to energy being "trapped" by greenhouse gases in the atmosphere. What are greenhouse gases and what does being "trapped" mean in this context?

The Earth's atmosphere is composed of a mixture of gaseous molecules (see, for example, http://climate.ncsu.edu/edu/Atmosphere). Most of the atmosphere consists of nitrogen molecules (N_2) and oxygen molecules (O_2). These molecules transmit the sunlight shining through them. Greenhouse gases, however, are molecules that interact with infrared radiation from the Sun as well as with infrared radiation emitted from the surface of the Earth. The major greenhouse gases are:

- water vapor, formed by two atoms of hydrogen bonded to one atom of oxygen, H_2O
- carbon dioxide, formed by one atom of carbon and two atoms of oxygen, CO_2
- methane, formed by one atom of carbon and four atoms of hydrogen, CH_4.

The greenhouse gas molecules in the atmosphere "trap" energy by absorbing infrared radiation and then emitting infrared radiation in all directions, including back toward the surface of the Earth. These gases absorb and emit infrared radiation by vibrating in complex ways. See, http://energyeducation.ca/encyclopedia/Infrared_radiation, for example, and https://www.youtube.com/watch?v=AauIOanNaWk for forms of vibration in carbon dioxide molecules. A diagram of such vibrations is shown in Fig. 4.18.

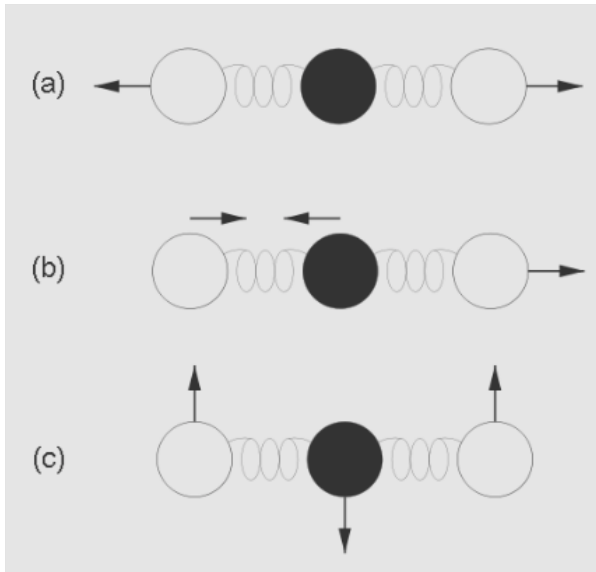


FIG. 4.18 Three modes of vibration for a molecule of carbon dioxide.
Credit: Martin C. Doege, Windows to the Universe®, © 2007 National Earth Science Teachers Association, https://www.windows2universe.org/earth/climate/greenhouse_effect_gases.html CC 3.0

The black dot represents a carbon atom, the two clear dots represent the oxygen atoms and the coils of springs represent the chemical bonds holding these atoms together as one molecule. The vibrations may involve (a) the two oxygen atoms both moving away from the carbon atom, (b) one oxygen atom and the carbon atom moving toward each other while the other oxygen atom moves away, or (c) the carbon atom moving one way perpendicular to the bonds while the two oxygen atoms move in the opposite direction.

This mechanism of the greenhouse gas molecules absorbing energy by vibration differs from the mechanism creating the greenhouse effect in greenhouses on earth. Green houses made out of glass panes that do not transmit infrared radiation warm up when incoming visible light is transmitted through the glass panes, absorbed by the contents of a greenhouse, emitted as infrared radiation, but not transmitted back out through the glass panes. Also, the greenhouse effect can occur simply by enclosing a container as in the exploration described in Question 4.7. However, the effects are the same in that the temperature of a system increases if more energy enters a system than leaves it.

(b) Details about what happens to energy entering and leaving the Earth's system. Figure 4.19 presents a more detailed analysis of what would happen to the energy radiated from the Sun to the Earth during the greenhouse effect process if the Earth's energy budget were balanced. To be in balance:

i. the incoming energy at the edge of the atmosphere should equal the outgoing energy at the edge of the atmosphere;
ii. the incoming energy within the atmosphere should equal the outgoing energy within the atmosphere and
iii. the incoming energy absorbed by the surface of the Earth should equal the outgoing energy at the surface.

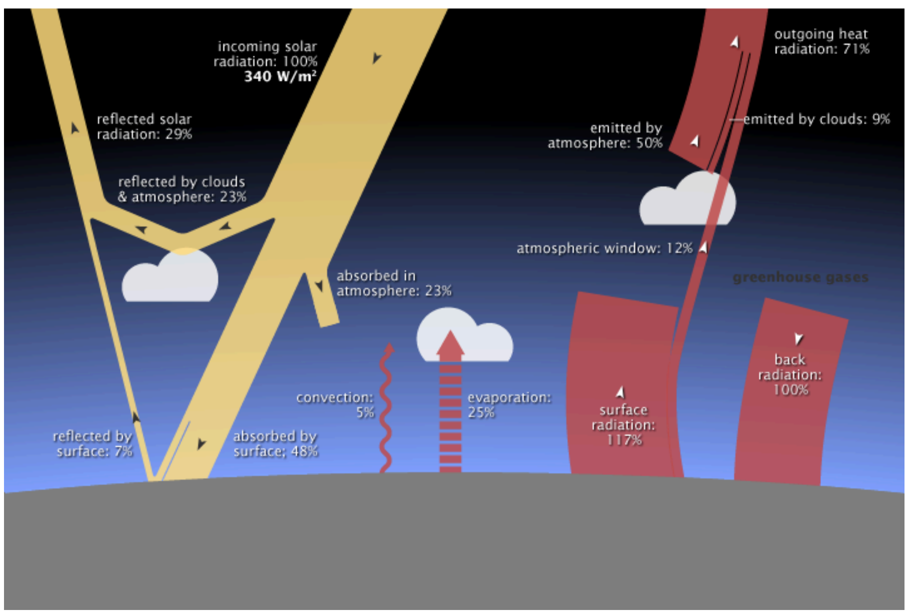


FIG. 4.19 *An analysis of incoming and outgoing energy of the Earth's system in balance. NASA illustration by Robert Simmon, adapted from Trenberth et al. 2009, using CERES flux estimates provided by Norman Loeb.*
[*https://earthobservatory.nasa.gov/Features/EnergyBalance/page6.php*](https://earthobservatory.nasa.gov/Features/EnergyBalance/page6.php)

i. What happens at the edge of the atmosphere if the Earth's system is in balance? The thick yellow ray represents the incoming energy from the Sun

(100%). The thinner yellow ray at the upper left corner of the diagram represents that 29% of that energy would be reflected back out into space from clouds, the atmosphere, and the surface. The somewhat thick red ray near the top right of the diagram represents that 71% of that energy would pass back out of the Earth's atmosphere into space. If the Earth's energy budget were in balance, the total incoming radiation would be balanced by the total outgoing radiation after reflection by the clouds, atmosphere and surface as well as after various absorption and emission processes within the atmosphere.

ii. What happens within the atmosphere if the Earth's system is in balance? The thin yellow branch of the incoming ray that points into the atmosphere represents the 23% of the incoming energy absorbed by the atmosphere. Also entering the atmosphere are three sources from the surface: convection as in the sunny day at the beach (5%), evaporation (25%), and surface radiation (117%) for a total of 170%. Leaving the atmosphere is energy emitted by the atmosphere (50%), emitted by clouds (9%), and energy from the surface that gets through the "atmospheric window" directly out to space (12%) for a total of 71% and also energy emitted from greenhouse gases back in the direction of the surface (100%) for a total of 171%, which is balanced (the extra 1% probably due to rounding).

iii. What happens at the surface of the Earth if the Earth's system is in balance? Incoming energy absorbed by the surface would be transferred to the atmosphere by several processes: The thin waving red ray, pointing upward, represents transfer of the incoming energy through convection (5%) in ways similar to those described in explaining sea breezes in Unit 3. Air warmed by the surface by conduction, expands, rises into the cool upper atmosphere, and cools as energy flows from the warm air into the cooler surrounding atmosphere. The red ray made out of horizontal segments, pointing upward, represents transfer of energy from the surface to the atmosphere through evaporation (25%) such as from puddles, streams, oceans and through transpiration by plants. When moist air is warmed, rises, and cools, the gaseous water releases energy as it condenses into droplets, forming clouds. The thick red ray with the arrow pointing upward represents the transfer of energy from the surface to the atmosphere when the surface emits infrared radiation (117%) at a rate determined by its temperature. The total energy from the surface to the atmosphere would be 148%. Some gases such as water vapor, carbon dioxide, and methane absorb most of the infrared radiation and re-emit it in all directions, including back down toward the surface of the Earth (100%), represented by the red ray with the arrow pointing downward. There would be a net sum of the energy emitted from the surface that would equal the incoming energy that is absorbed by the surface. Also some of the energy from the sun shines directly on the surface (48%) represented by the yellow ray pointed toward the surface. The energy reaching the surface (148%) would balance the energy leaving the surface (148%).

As the amount of water vapor, carbon dioxide, and methane gases in the atmosphere increases, however, more infrared radiation will be absorbed, emitted in all directions, including back toward the surface, with more and more energy staying in the Earth's system, increasing the global temperature of the Earth. For more information about the Earth's energy budget, search on the Internet for "Earth's energy budget" and view, for example, a series of pages (4-7) at https://earthobservatory.nasa.gov/Features/EnergyBalance/page4.php

To deepen understanding about the influence of light and thermal phenomena on global climate read some students' reflections about engaging a friend in learning about the greenhouse effect.

5. Examples of student work reflecting upon engaging a friend or family member in learning about the greenhouse effect

The students explored websites that discuss the greenhouse effect and selected one or more to use in engaging a friend or family member in learning about the greenhouse effect. One student wrote:

> *I chose to explore the greenhouse effect with my two friends. Prior to exploring the website, they told me that they knew that the greenhouse effect was related to "gases getting trapped in the atmosphere and heating it up." The website, https://energyeducation.ca/encyclopedia/Greenhouse_effect is provided by Energy Education Canada. Both of them said that is was very helpful to observe a diagram depicting the greenhouse effect, which aided their understanding of the readings provided by the website. One of my friends said that the thing that hindered*

his understanding was that the arrow accompanying the text that reads, "Infrared radiation is emitted by the Earth's surface," emerges from water, rather than from land or a combination of land and water, which led him to believe that the diagram was indicating that only water emits infrared radiation.

Both of them asked me what infrared radiation is, and I explained to them that infrared emits energy in the form of heat, as well as that the color of an object when observed through night vision goggles indicates how much infrared radiation it emits, with objects that appear red emitting a lot of infrared radiation, and objects that appear blue emitting much less infrared radiation. Neither of them had prior knowledge of infrared radiation, and they stated that this was the most interesting thing they learned from the website. Additionally, neither of them had ever heard the term "enhanced greenhouse effect," which is what is referred to in discussions of the greenhouse effect and climate change.

When I asked them how they felt about the potential consequences of climate change, including rising sea levels, they both wondered if climate change will drastically affect them personally in their lifetime. Additionally, they wondered how much of the greenhouse effect is due to livestock, which sparked an interesting discussion about how many cows and chickens are on the earth, as well as how the raising and consuming of animal products contributes to climate change. This experience taught me that sometimes a conversation may not go the way you expect it to, but it can still lead to beneficial discussion and learning. I was not expecting to discuss livestock with them, but they were very interested in the various layers of climate change, and I felt that they gained a lot from the website and grew in their curiosity throughout our discussion.

Both of my friends engaged in the NGSS Science practice of obtaining, evaluating, and communicating information during this exploration. Not only did they obtain information from the website that I showed them, but when our discussion shifted toward the effect of livestock farming on climate change, they both began to research articles on the topic, obtained knowledge from them, and shared that knowledge to enhance our discussion. They also engaged in the NGSS crosscutting concept of systems and system models, as the diagram from the website helped them to envision the system of the greenhouse effect and see how it works.

Physics student, Winter 2018

Another student chose to talk about the greenhouse effect with her father:

So I did this assignment with my father. I had a feeling it would not go well but I wanted to show him evidence of climate change. I first started by asking him what *he knew about the greenhouse effect. He said "It causes global warming, climate change, and has something to do with too many cows giving off ethanol into the air." I then decided to show him the NASA website* https://climate.nasa.gov/causes/ *because it was my favorite. We looked over the website. It was easy to navigate the website and the pictures were really helpful. The pictures helped the most and the website even had before and after photos of bad events around the world. We talked about the future effects of global warming but he did not ask any questions. After we finished exploring the website I explained the model diagram of the greenhouse effect again and explained that humans are the real cause of this. I then asked what my father thought about global warming. He said "the planet has always been changing and it always will." So after showing all this proof to my father he then says "it's propaganda." My father just nodded while looking at the website.*

I think my father did not have any questions because he is closed off and does not want to hear that humans are causing the Earth to heat up and it could harm/ is harming the environment. I went into more detail about the greenhouse gasses being the real cause and that human activity is the cause but he just wasn't interested. Through this experience I think I have learned that it is hard to teach topics that people already think they know or feel strongly one way about. No matter how much evidence is shown. It is discouraging to think about how many people are out there, unable to face the facts that global warming is real. The older I get, the more I realize a lot of people do not listen to science and just believe what they want to. For example, learning about vaccines. It does not matter how much we show the scientific evidence of the safety and success of vaccines, people still believe they cause autism and make people sick.

The crosscutting concept of cause and effect is strongly shown in the topic of greenhouse gasses because we are showing that human activity is causing an effect on the Earth, causing it to warm up. One NGSS practice used was modeling. We used the model given on the website to help explain the greenhouse effect.

Physics student, Winter 2018

These students had very different experiences, with a welcome sharing of thoughts and additional learning for all concerned in the first and with a reluctant listener not yet open to alternative points of view in the second. Afterward, the second student raised in class the question of what to do. This is a difficult question to which there are no easy answers. To what extent is one willing to risk personal relationships in discussing controversial topics? How can one convey information based on evidence effectively?

How can one keep one's own spirits up in the face of such discouraging encounters? Our hope is that the small group activities and whole group discussions in class will at least make possible more positive experiences as well as increase information getting to the reluctant listeners whose friends or relatives choose to risk the conversation.

V. Considering the Evidence for Global Climate Change

Science is a way of knowing that involves noticing that something is happening, being curious about why it is happening, and asking questions and seeking answers based on evidence, particularly if what is happening seems threatening in some way. If the Earth is warming more quickly than in the past, what evidence is there that this is happening?

A. Viewing evidence for global climate change

Scientists from all over the world have collected and analyzed data that confirm that the Earth's climate is warming more rapidly than in the past. In order for citizens to learn about and understand what is happening, this evidence needs to be communicated in readily understood ways.

Question 4.9 How is the evidence for global climate change being communicated?

A variety of approaches are available. A visually compelling display may be more persuasive than a more detailed presentation. The Internet provides many resources suitable for different audiences such as children, teachers, and the general public. Scientists have formed an international community to collaborate by assembling evidence from multiple studies and to interpret these findings for policy makers.

1. Examples of efforts to create visually compelling displays

Tables of data are hard to interpret. Long paragraphs reporting findings are hard to grasp. Therefore, many presentations about climate change include visually compelling displays of data.

What, for example, is the evidence that the mean global temperature is rising? As shown in Fig. 4.20, the National Aeronautics and Space Administration (NASA) provides a 33 second video graphic showing an image of the globe on which changing temperatures are represented as the colors shift from cooler (gray blue) toward warm (yellow) and then warmer (red) as time shifts from 1880 to 2018.

- Click on the URL in the caption for Fig. 4.20.
- What is this display demonstrating?

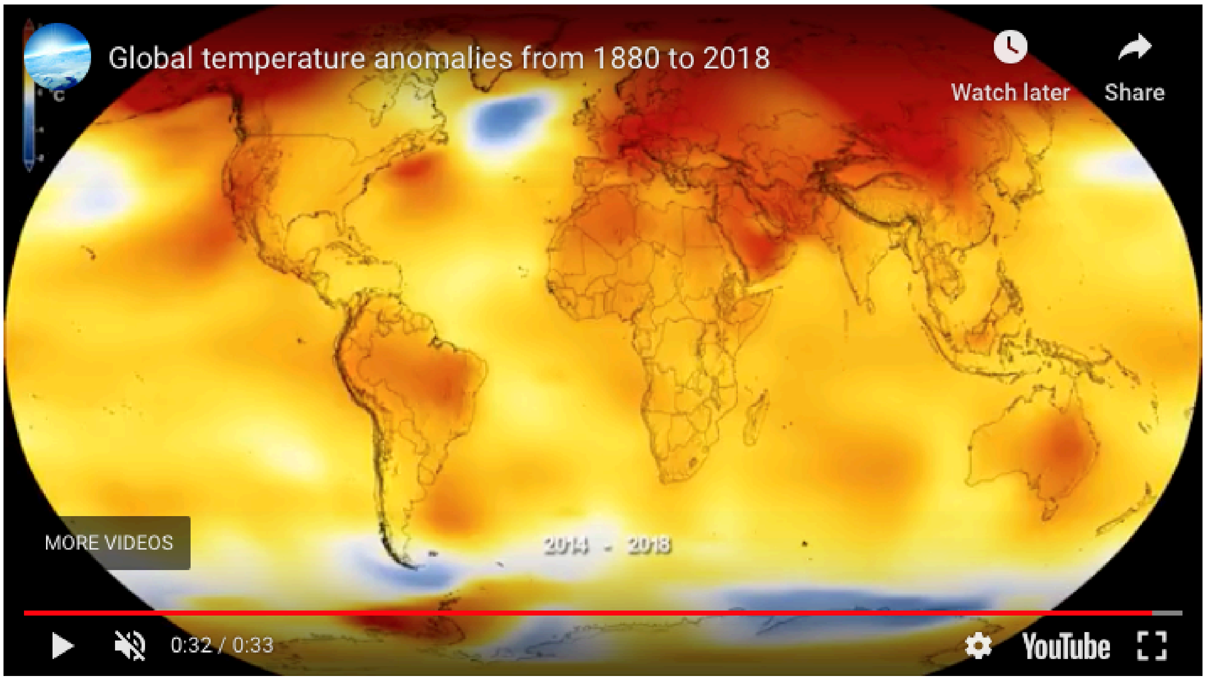


FIG 4.20 Global temperature anomalies from 1880 to 2018. NASA's Scientific Visualization Studio. Data provided by Robert B. Schmunk (NASA/GSFC GISS) https://climate.nasa.gov/climate_resources/139/graphic-global-warming-from-1880-to-2018/

Such video displays vividly illustrate differences across the globe in the ways that annual mean temperatures are changing; higher mean temperatures than normal are happening particularly in northern regions, for example, more than elsewhere.

This display represents changes in mean temperatures in an interesting way. Rather than the actual mean temperature for an area, this represents the *temperature anomaly*, how much the mean temperature for a given area differs for a specific year from normal for that area. The *normal* is defined as the mean temperature over a span of years, in this case the mean temperature for the span of thirty years from 1951 to 1980.

The reason scientists use anomalies rather than actual temperatures is explained at https://www.ncdc.noaa.gov/monitoring-references/dyk/anomalies-vs-temperature . The basic idea is that the mean temperature for a year at a monitoring station in a valley is likely to be different from the mean temperature for the year at a monitoring station on a nearby mountain. The *changes* in the mean temperature for both monitoring stations in this overall area, however, are likely to be similar if the mean temperature for the overall area is changing.

The data analyzed for 2018, for example, indicate that global mean temperatures were 0.83° Celsius (1.5° Fahrenheit) warmer than the 1951 to 1980 global mean temperature. See https://svs.gsfc.nasa.gov/4626 for information about how worldwide temperature data are collected and interpreted.

Another visually compelling way to present such data is to provide a line graph. Fig. 4.21, for example, shows a line graph of global temperature anomaly versus time for 1880 to 2018.

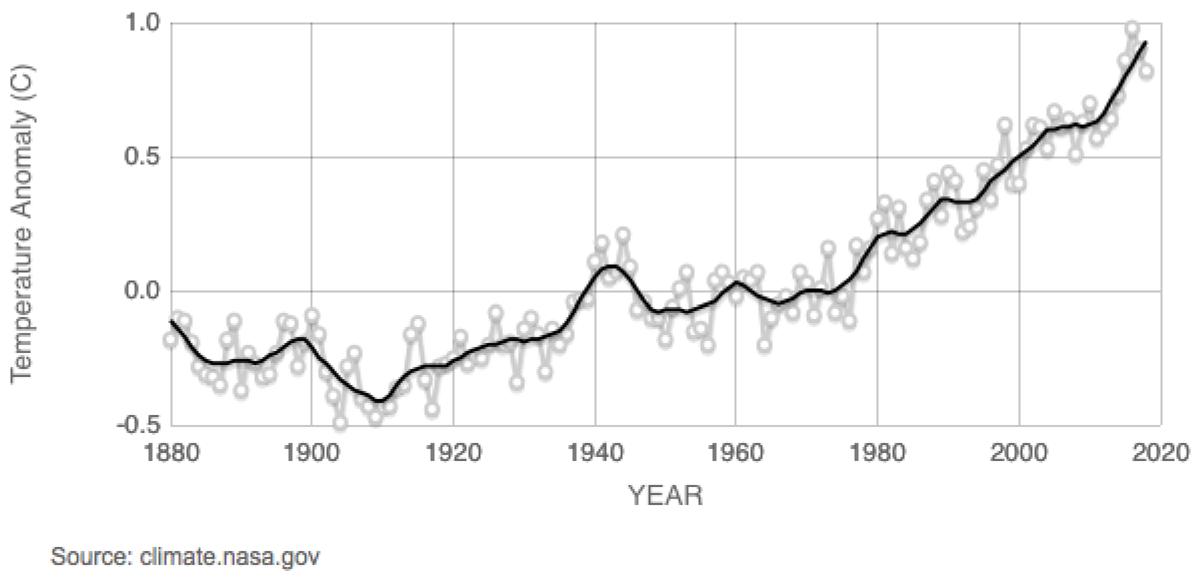


Fig. 4.21 Line graph of global temperature anomaly versus time for 1880-2018.
Data source: NASA's Goddard Institute for Space Studies (GISS).
NASA/GISS *https://climate.nasa.gov/vital-signs/global-temperature/*

The key to interpreting line graphs is to ask oneself:

- What does the horizontal axis on the graph represent?
- What does the vertical axis represent?
- What does the line represent?

- What does the shape of the line imply?

The horizontal axis for Fig. 4.21, for example, represents time from years 1880 to 2020.

The vertical axis represents the temperature anomaly in degrees Celsius, that is, how much the global mean temperature for a specific year differed from normal (defined here as the global mean temperature over the thirty-year span from 1951 to 1980).

A gray dot represents the mean temperature anomaly for a specific year.

The jagged gray line represents how the mean temperature anomaly changed year by year from 1880 to 2018.

The black line represents a mathematically "smoothed" plot of these mean temperature anomalies from 1880 to 2018.

Years with negative mean temperature anomalies were cooler than normal (the mean temperature during 1951 to 1980). These occurred primarily before 1960.

Years with positive mean temperature anomalies were warmer than normal (the mean temperature over the years during 1951-1980). These occurred primarily after 1960.

A general interpretation of the line graph shown in Fig. 4.21 is that globally mean temperature anomalies have been increasing in recent years, indicating an on-going increase in the mean global temperature beyond the normal for the years during 1951 to 1980.

Evidence presented via vivid line graphs can support arguments not only about whether global temperatures are rising but also about probable causes. A perspective sometimes stated, for example, is that the Earth's climate has always been changing and therefore no action is possible or needed. A company providing news to the business and financial communities, www.Bloomberg.com, presents an animated graphic, *What's Really Warming the World?* that directly confronts this perception. Go to https://www.bloomberg.com/graphics/2015-whats-warming-the-world/ to appreciate this effort by Eric Roston and Blacki Migliozzi to create a visually simple yet compelling display. They based a series of line graphs on findings from NASA's Goddard Institute for Space Studies. The scientists described their methodology for distinguishing contributions of various possible causes of global warming in detail in a paper published in the *Journal of Advances in Modeling Earth Systems* (Miller et al, 2014) (https://pubs.giss.nasa.gov/abs/mi08910y.html).

Interpret the first graph in this series:

- What does the horizontal axis represent?
- What does the vertical axis represent?

- What does the black line represent?
- What does the shape of the line imply?

Scroll down to see the subsequent graphs.

- What do the colored lines on these graphs represent?
- What factors do the graphs compare?
- Which factor seems to have had the most influence on the average global temperature?
- What aspects of this series of graphs make them visually compelling?

Scroll down and skim the notes about methodology. Note that the designers of this animated graphic used the thirty years from 1880 to 1910 to calculate a *normal* to which to compare what happened each year. They also used the term "average" when referring to the "mean" temperature; both terms refer to the same number, the result of adding up a series of numbers and dividing by the number of numbers. The black line for the observed data ends at 2012. The designers of the graphic present results from a study of climate modeling that ended in 2005 so the colored lines for various possible causes end at 2005.

The graph of the combined effects tracks the line representing the rising global temperature, with the greenhouse gases providing the biggest contribution. By separating the graphs of the possible effects and then combining them, this presentation demonstrated the correlation of the increase in greenhouse gases with the increase in average global temperature.

2. Examples of Internet resources available to the public

Many agencies have been developing and providing resources on the Internet for learning about global climate change. A wide variety of websites discuss, for example, the evidence that change is already underway. These websites typically target particular audiences such as children, teachers, the general public, and policy makers as shown in Figs.4.22-4.30.

Intended Audience: Children ***How do we know the climate is changing***?

The National Aeronautics and Space Administration (NASA) has developed an extensive website for children: Climate Kids. The website considers: Big Questions, Weather and Climate, Atmosphere, Water, Energy, and Plants and Animals

(See: https://climatekids.nasa.gov/climate-change-evidence/) Fig. 4.22 shows an example question from the Weather and Climate webpage.

Fig. 4.22 Example from NASA ClimateKids website. (*https://climatekids.nasa.gov/menu/weather-and-climate/*)

Many children's books about climate change are available for use at home and school (See: https://www.yaleclimateconnections.org/2018/08/childrens-books-about-climate-change/).

Intended Audience: Teachers ***How can teachers engage students in talking and writing about climate change?***

The National Oceanic and Atmospheric Administration (NOAA) has developed resources for teachers to use in engaging students in learning about climate change. See, for example, a 5th grade teacher's reflection about her students' climate change essays (https://oceanservice.noaa.gov/education/planet-stewards/talking-about.html). As shown in Fig. 4.23, the U.S. Global Change Research Program provides regional resources for teachers about the National Climate Assessment (NCA).

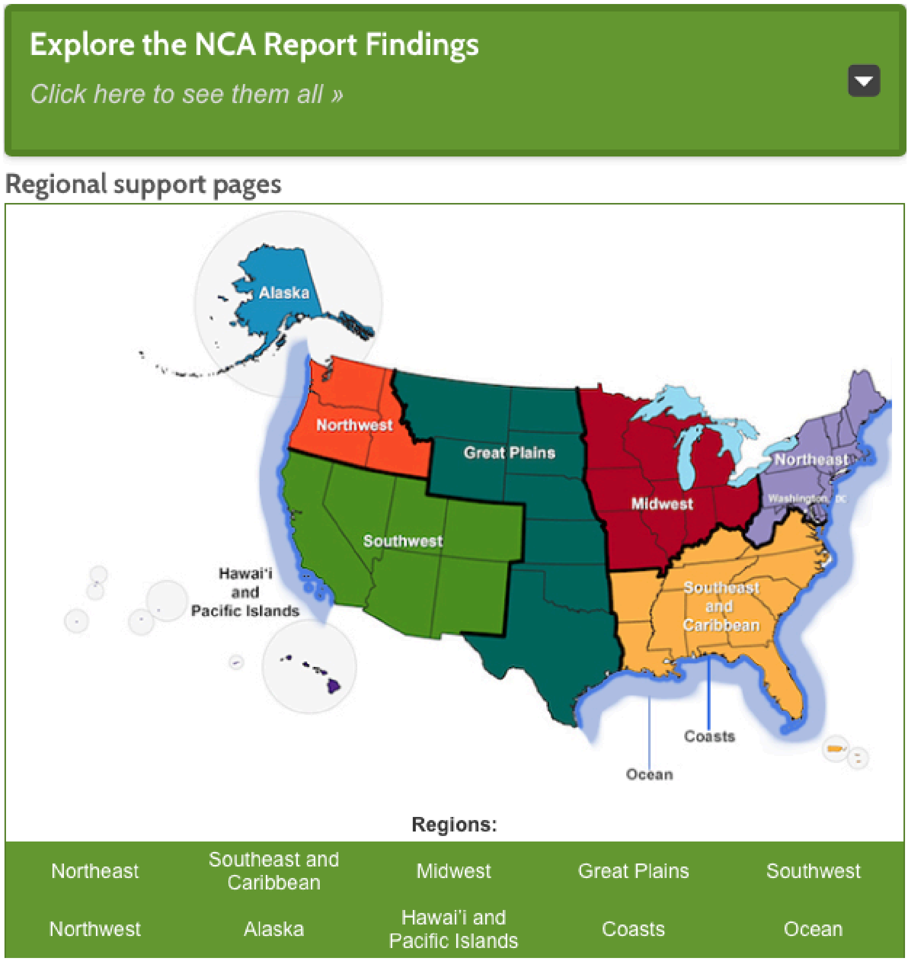


Fig. 4.23 Example of educational resources for teachers by region. National Climate Assessment (NCA) Teaching Resources (https://www.climate.gov/teaching/national-climate-assessment-resources-educators/2014-national-climate-assessment-resources)

By clicking on the region in which they live, teachers can access resources directly relevant to how global climate change may be impacting their students' lives. A summary for the Northwest, for example, states:

> *Changes in the timing of streamflow reduce water supplies for competing demands. Sea level rise, erosion, inundation, risks to infrastructure, and increasing ocean acidity pose major threats. Increasing wildfire, insect outbreaks, and tree diseases are causing widespread tree die-off.*

https://nca2014.globalchange.gov/report/regions/northwest

Intended Audience: General public ***What are some indicators of climate change?***

The U.S. Environmental Protection Agency (EPA) has assembled an extensive website providing information about various climate change indicators such as changes in the oceans (see: https://www.epa.gov/climate-indicators/oceans). One issue, for example, is the extent to which land has been converted to open water as sea levels rise. As shown in Fig. 4.24, this is now occurring regularly along the US Atlantic coast.

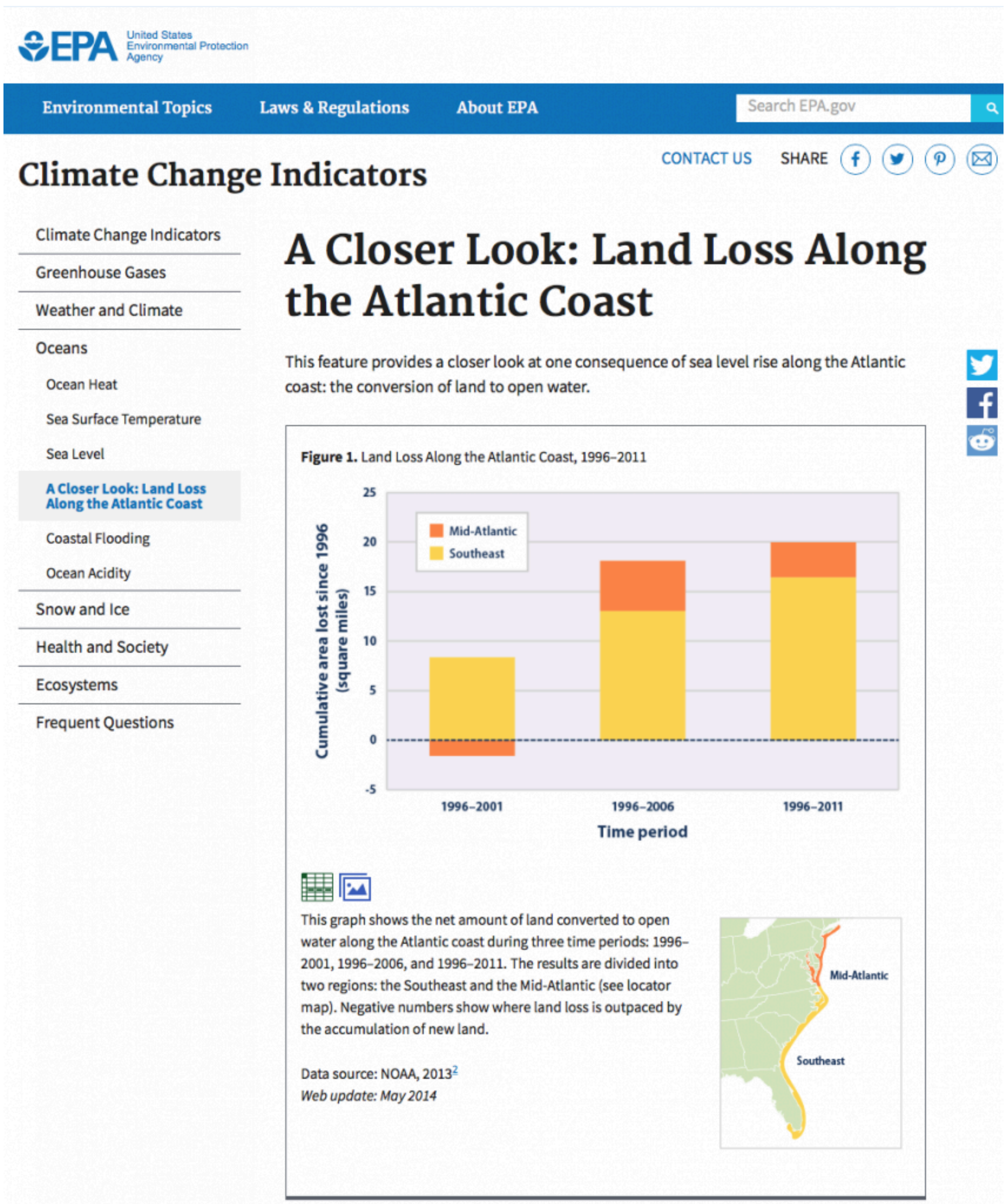


Fig. 4.24 Evidence of rising sea levels on the eastern US coast. (https://www.epa.gov/climate-indicators/atlantic-coast)

NASA also provides an extensive website documenting evidence that the climate is changing (see: https://climate.nasa.gov/evidence/).

Intended Audience: Policy makers: *What should policy makers know about observed global climate changes and their causes?*

The Intergovernmental Panel on Climate Change (https://www.ipcc.ch/about) provides policy makers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. The *IPCC 5th Assessment Report*, for example, included a *Synthesis Report* (see: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf (pp. 1-5).

This summary for policy makers was based on detailed analyses developed by scientists from around the world. *The Physical Science Basis*, for example, included 1409 pages prepared by Working Group 1 (*https://www.ipcc.ch/report/ar5/wg1/*). This group included a team of 209 coordinating-lead authors and lead authors, 50 review editors, and more than 600 contributing authors from all over the world. Their work was reviewed by 1089 expert reviewers and 38 governments. The result was a detailed presentation of the consensus about evidence that underlies claims made about climate change by scientists from around the world.

Based on the consensus supported by these analyses, the *Synthesis Report* included a Summary for Policy Makers Statement (SPM):

SPM 1.1 Observed changes in the climate system

> *Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.* (p. 2)

https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

The next section provides additional information about this effort to communicate to policy makers the consensus based on extensive evidence collected and analyzed in detail by scientists throughout the world.

Exploration of Internet resources. To explore Internet resources for communicating information about global climate change, use for each group: a large white board as well as a white board marker and eraser for each student.

- Work with your group members to access the suggested URL(s) above or identify alternative relevant URLs yourselves.
- Browse the website to see what is there. Select one aspect or link of interest.
- On a large white board, write a few statements that present the most useful or interesting information provided. Also include the source and URL.
- Plan and briefly practice what each of you will say during your group's presentation.
- Present your white board to the class, with each member of your group contributing something about what you learned from exploring this issue.
- At home, briefly review and critique these websites:
    - What do you find of interest?
    - What seems likely to help or to hinder learning by the intended audience?
    - What have you learned from this exploration of Internet resources about evidence that climate change is occurring?

3. Examples of the international community of scientists presenting findings to policy makers

This section considers the efforts of scientists from 195 countries to collaborate in collecting and assessing evidence about the state of the Earth's climate system. This is the issue that the Intergovernmental Panel on Climate Change (IPCC) was set up to address more than thirty years ago, in 1988, by the World Meteorological Organization and the United Nations.

Leading scientists from throughout the world prepare these assessments, based on evidence published in scientific studies that have been peer-reviewed. The reports for the fifth assessment are publically available (see: https://www.ipcc.ch/report/ar5/). The sixth assessment is expected in 2022.

The IPCC *Fifth Assessment Report* has four parts:

Climate Change 2013: The Physical Science Basis https://www.ipcc.ch/report/ar5/wg1/

Climate Change 2014: Impacts, Adaptation, and Vulnerability https://www.ipcc.ch/report/ar5/wg2/

Climate Change 2014: Mitigation of Climate Change https://www.ipcc.ch/report/ar5/wg3/

Climate Change 2014: Synthesis Report https://www.ipcc.ch/report/ar5/syr/

As indicated in Fig. 4.25, the part that focuses upon the *Physical Science Basis* presents the evidence for the claims being made that the global climate is changing, with average global temperatures increasing.

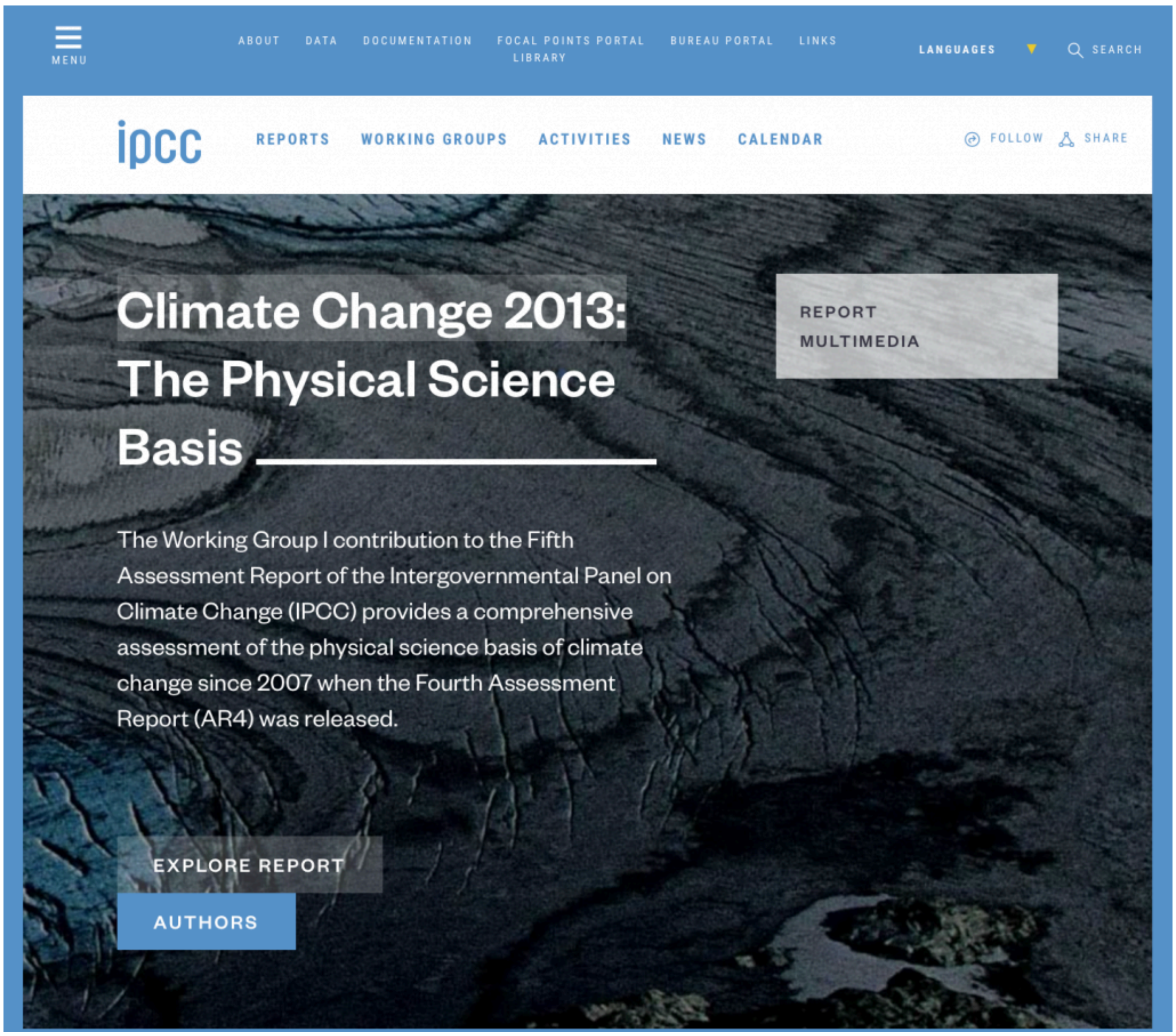


Fig. 4.25 IPCC Fifth Assessment Report: The Physical Science Basis. (https://www.ipcc.ch/report/ar5/wg1/)

Chapters include:

- Observations: Atmosphere and Surface
- Observations: Ocean
- Observations: Cryosphere (wherever frozen water is found on Earth)
- Information from Paleoclimate Archives
- Carbon and other Biogeochemical Cycles
- Clouds and Aerosols,
- Anthropogenic and Natural Radiative Forcing
- Evaluation of Climate Models
- Detection and Attribution of Climate Change: from Global to Regional
- Near-term Climate Change: Projections and Predictability
- Long-term Climate Change: Projections, Commitments and Irreversibility
- Sea Level Change,
- Climate Phenomena and Their Relevance for Future Regional Climate Change

As indicated in Fig. 4.26, the part that focuses on *Impacts, Adaptation, and Vulnerability* discusses how patterns of risks and potential benefits are shifting due to climate change.

Fig. 4.26 IPCC Fifth Assessment Report: Impacts, Adaptation, and Vulnerability. (https://www.ipcc.ch/report/ar5/wg2/)

Chapters of this part include:

Part A: Global and Sectoral Aspects

- Natural and Managed Resources and Systems, and Their Uses
- Human Settlements, Industry, and Infrastructure
- Human Health, Well-Being, and Security
- Adaptation
- Multi-Sector Impacts, Risks, Vulnerabilities, and Opportunities

Part B: Regional Aspects

- Africa
- Europe
- Asia
- Australasia
- North America
- Central and South America
- Polar Regions
- Small Islands
- The Ocean

As indicated in Fig. 4.27, the part that focuses upon *Mitigation of Climate Change* assesses literature on the scientific, technological, environmental, economic and social aspects of mitigation of climate changes.

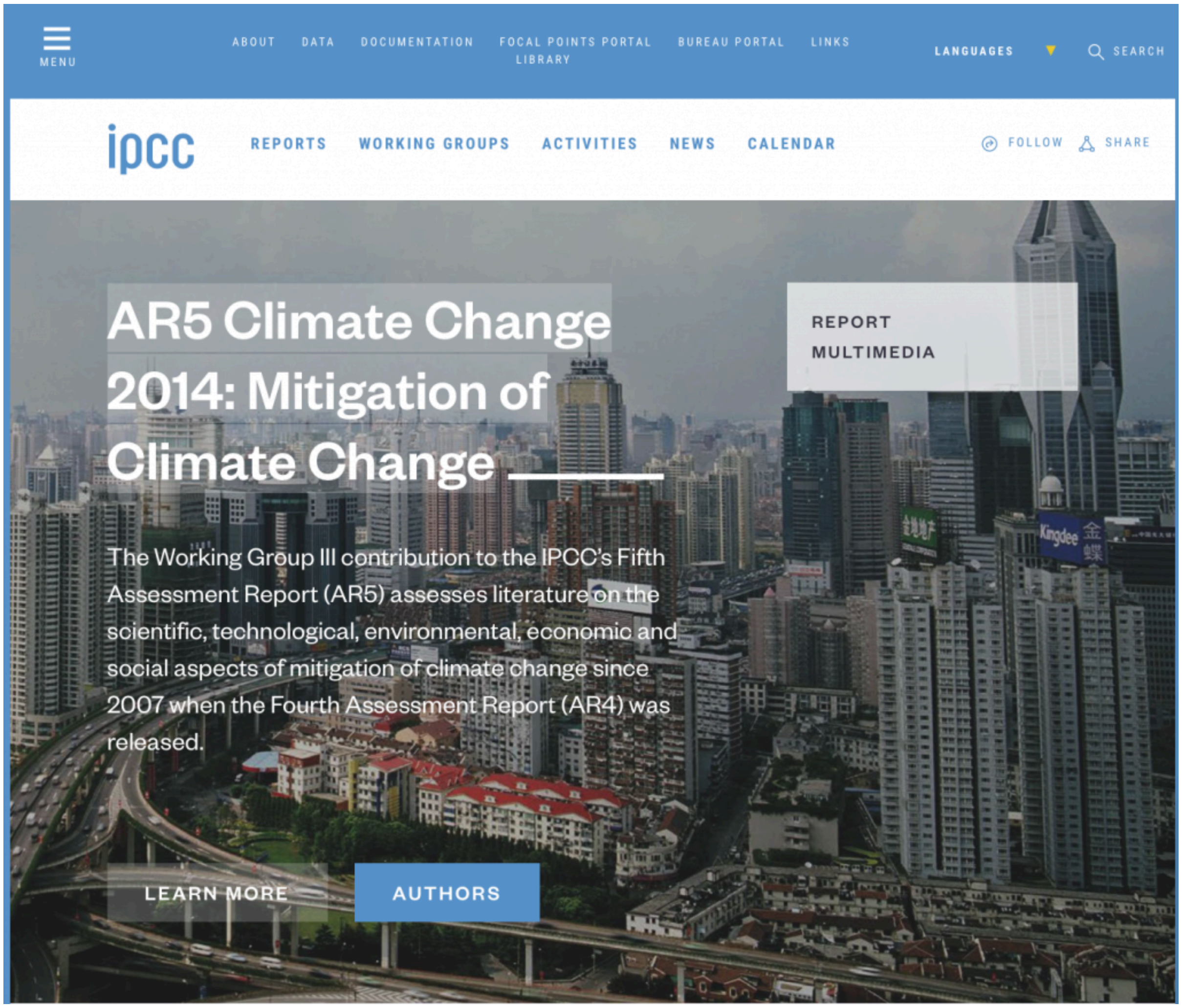


Fig. 4.27 IPCC Fifth Assessment Report: Mitigation of Climate Change (https://www.ipcc.ch/report/ar5/wg3/)

Chapters of this part include:

- Integrated Risk and Uncertainty Assessment of Climate Change Response Policies
- Social, Economic, and Ethical Concepts and Methods
- Sustainable Development and Equity
- Drivers, Trends and Mitigation
- Assessing Transformation Pathways
- Energy Systems
- Transport
- Buildings
- Industry

- Agriculture, Forestry and Other Land Use
- Human Settlements, Infrastructure and Spatial Planning
- International Cooperation: Agreements and Instruments
- Regional Development and Cooperation
- National and Sub-National Policies and Institutions
- Cross-Cutting Investment and Finance Issues

The *Synthesis Report* for the entire assessment includes a summary for policy makers (see: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf , (pp. 1-5). For an overview see a video at https://www.youtube.com/watch?v=6yiTZm0y1YA .
The *Synthesis Report* provides a series of Summary for Policy Makers (SPM) statements. The first set of summary statements focuses upon the evidence of changes and their causes. (Some of these statements use the term *anthropogenic*, which refers to something that is resulting from human activity.)

SPM 1. Observed Changes and their Causes

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse bases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. (p. 2)

SPM 1.1 Observed changes in the climate system

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen. (p. 2)

SPM 1.2 Causes of climate change

Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and now are higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are ***extremely likely*** *to have been the dominant cause of the observed warming since the mid-20th century. (emphasis in the original)* (p. 4)

SPM 1.3 Impacts of climate change

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. (p. 6)

SPM 1.4 Extreme events

Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions. (p. 7)

Two additional sets of statements look to the future:

SPM 2. **Future Climate Changes, Risks and Impacts** (p. 8)
SPM 3. **Future Pathways for Adaptation, Mitigation and Sustainable Development** (p. 17)

Each *Summary for Policy Makers* statement is supported by a summary of relevant evidence. Fig. 4.28-Fig. 4.30, for example, support SPM 1.1 *Observed changes in the climate system* by providing graphs representing observations of global changes in temperature, sea level, and greenhouse gas concentrations in the atmosphere. Fig. 4.31 supports SPM 1.2, causes related to carbon dioxide emissions from 1850 to 2012.

- In small groups, discuss one of the following graphs in detail. How do you interpret the information provided by the various features of the graph?

The graph in Fig. 4.28 represents the globally averaged combined land and ocean surface temperature *anomaly* from 1850 to 2012. The span of twenty years from 1986 to 2005 was used to calculate an average global temperature (represented by 0 on the graph) with which to compare the average temperature for each year (represented by the anomaly from -1.0°C to 0.4°C).

- What does the horizontal axis on the graph represent?
- What does the vertical axis represent?
- What do the lines represent?
- What does the shape of the lines imply about combined land and ocean surface temperatures between 1850 and 2012?

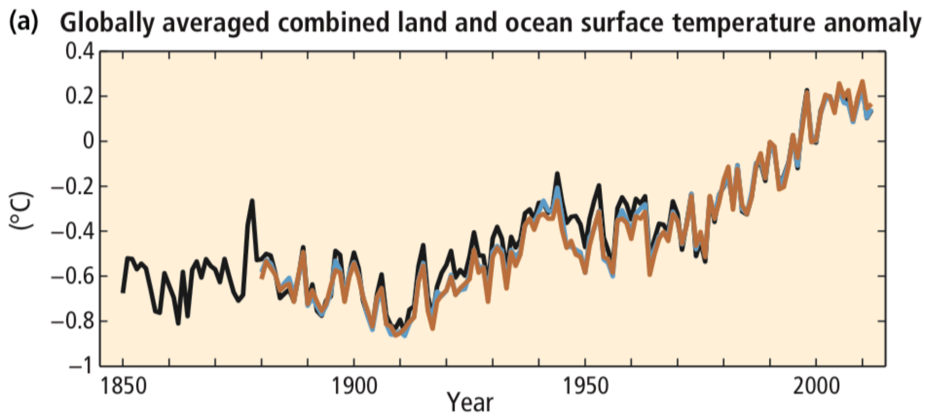


FIG. 4.28. Observations: Annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005. Colours indicate different data sets. Source: IPCC Climate Change 2014 Synthesis Report Summary for Policy Makers, Figure SPM.1, p. 3. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

The graph in Fig. 4.29 represents the globally averaged sea level change compared to the average sea level change for 1850 to 2012. The span of twenty years from 1986-2005 was used to calculate an average global sea level (represented by 0 on the graph) by which to compare the average global sea level for a specific year (represented by an anomaly from -0.2 meters to +0.1 meter) for several different data sets represented by the different colors.

- What does the horizontal axis on the graph represent?
- What does the vertical axis represent?
- What do the lines represent?
- What does the shape of the lines imply about globally averaged sea level change?

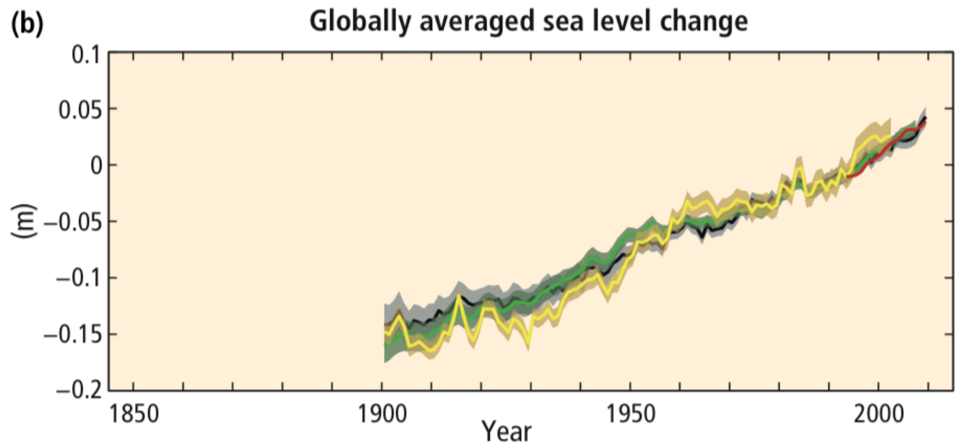


FIG. 4.29. Observations: Annually and globally averaged sea level change relative to the average over the period 1986 to 2005 in the longest-running dataset. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry data (red). Where assessed, uncertainties are indicated by coloured shading. Source: IPCC Climate Change 2014 Synthesis Report Summary for Policy Makers, Figure SPM.1, p. 3.
https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

The graph in Fig. 4.30 represents the globally averaged greenhouse gas concentrations from 1850 for carbon dioxide (green), methane (orange) and nitrous oxide (red).

- What does the horizontal axis on the graph represent?
- What does the vertical axis represent?
- What do the lines represent?
- What does the shape of the lines imply about globally averaged greenhouse gas concentrations?

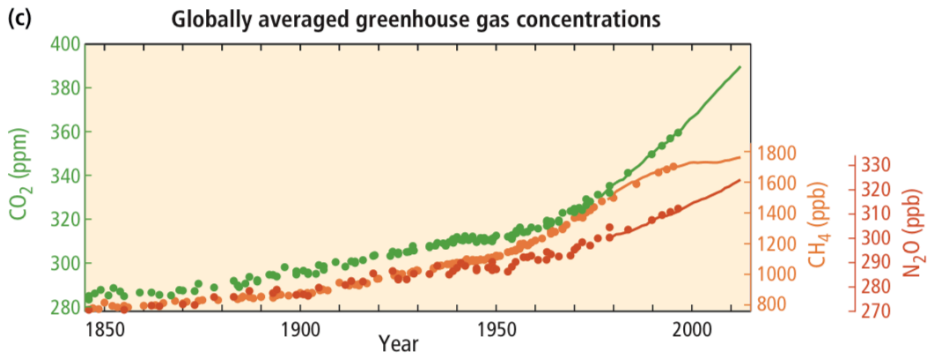


FIG. 4.30. Observations: Atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2, green), methane (CH_4, orange), and nitrous oxide (N_2O, red) determined from ice core data (dots) and from direct atmospheric measurements (lines). Source: IPCC Climate Change 2014 Synthesis Report Summary for Policy Makers, Figure SPM.1, p.3. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

The graph in Fig 4.31 represents the weight in gigatonnes per year of global emissions of carbon dioxide due to human activity, particularly from the use of fossil fuels, cement, and flaring (burning off gas at oil and gas fields), indicated by the gray portion of the graph and from forestry and other land use, indicated by the brown portion of the graph.

- What does the horizontal axis on the graph represent?
- What does the vertical axis represent?
- What do the lines represent?
- What does the shape of the lines imply?

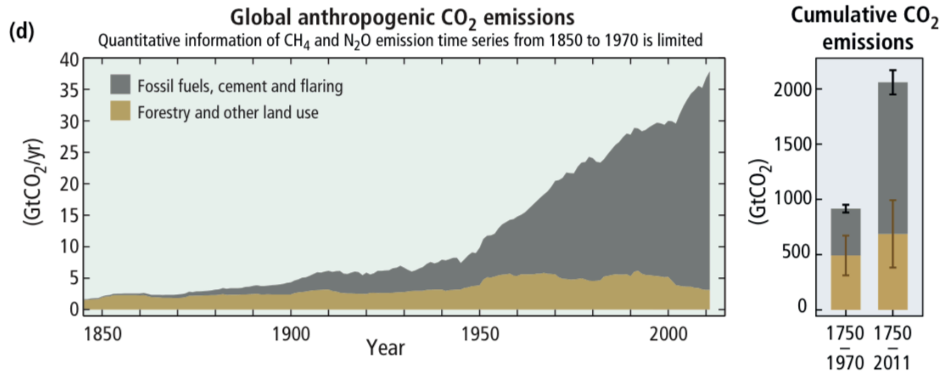


FIG. 4.31. Indicators: Global anthropogenic CO_2 emissions from forestry and other land use as well as from burning fossil fuel, cement production and flaring. Cumulative emissions of CO_2 from these sources and their uncertainties are shown as bars and whiskers, respectively, on the right hand side. The global effects of the accumulation of CH_4 and N_2O emissions are shown in panel c. Greenhouse gas emission data from 1970 to 2010 are shown in Figure SPM2. Source: IPCC Climate Change 2014 Synthesis Report Summary for Policy Makers, Figure SPM.1, p. 3. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

The details in these graphs can be perplexing. A general impression from viewing these graphs, however, is that there has been a steady increase recently in observations of the average global temperature, sea level, and greenhouse gas concentration in the atmosphere as well as of emissions of carbon dioxide and other greenhouse gases due to human activity. The International Panel on Climate Change's *Fifth Assessment Report* and *Summary for Policy Makers* are complex documents prepared by scientists for scientists and for others with a need for technical information.

There are, however, many other sources of information prepared by agencies and individuals attempting to communicate the central ideas to the public. See, for example, https://climate.nasa.gov/evidence.

- Complete Table IV.2 and write a brief summary about the evidence for an increasing average global temperature.

TABLE IV.2 Central ideas about evidence that the Earth's average global temperatures is increasing

TABLE IV.2 Central ideas about evidence that the Earth's average global temperatures is increasing			
Sketch of set up or URL	Evidence	Central Ideas	Relevant Vocabulary
https://climate.nasa.gov/climate_resources/139/graphic-global-warming-from-1880-to-2018/ https://climate.nasa.gov/vital-signs/global-temperature/		Visual displays can be compelling ways to communicate complex information	Temperature anomaly Line graph
https://climatekids.nasa.gov/climate-change-evidence/ https://oceanservice.noaa.gov/education/planet-stewards/talking-about.html https://www.epa.gov/climate-indicators/oceans https://www.bloomberg.com/graphics/2015-whats-warming-the-world/		Many agencies are developing websites to help children, teachers, and the general public learn about the evidence that the Earth's climate is changing	
www.ipcc.ch		In 1988, scientists formed a worldwide organization to collect, analyze, and communicate scientific findings about climate change	Intergovernmental Panel on Climate Change (IPCC)
https://www.ipcc.ch/report/ar5/wg1 https://www.ipcc.ch/report/ar5/wg2/ https://www.ipcc.ch/report/ar5/wg3/ https://www.ipcc.ch/report/ar5/syr/		IPCC provides detailed reports about : I: The Physical Science Basis;II: Impacts, Adaptation, and Vulnerability; III: Mitigation of Climate Change;and a Synthesis	

		These reports include information for scientists and policy makers about both natural and human causes of climate change	anthropogenic
https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf (page 3)		Some graphs show differences between a particular measurement and the average of a collection of similar data	anomaly
https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf (page 3)		There has been an increase in the global average temperature.	
https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf (page 3)		There has been an increase in the global average sea level.	
https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf (page 3)		There has been an increase in the average atmospheric concentration of greenhouse gases (carbon dioxide, methane, and nitrous oxide)	
https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf (page 3)		There has been an increase in emissions of carbon dioxide from various human activities since 1850	

VI. Using Central Ideas Based on Evidence to Consider the Impact of Global Climate Change

Evidence from multiple sources indicates that one impact of rising global temperatures is that sea levels are increasing at a more rapid rate than in the past. Although this is a global issue, there are many ways that individuals can reduce their own impact on global climate change.

A. Exploring the impact of global climate change on sea levels

What is the evidence that sea levels are rising? Why is this happening? In particular, what happens when light from the Sun shines on snow and ice on land versus in open water? What happens when light from the Sun shines on the oceans?

Question 4.10 What evidence indicates that sea levels are rising?

The IPCC Fifth Assessment report on *The Physical Science Basis* devoted Chapter 13 to the topic of sea level change (pp.1137-1216). Figure 4.32 presents a line graph from this report. This graph represents past, recent, and predicted global average sea levels.

- What does the horizontal axis represent?
- What does the vertical axis represent?
- What do the lines represent?
- What does the shape of the lines imply about global average sea level?

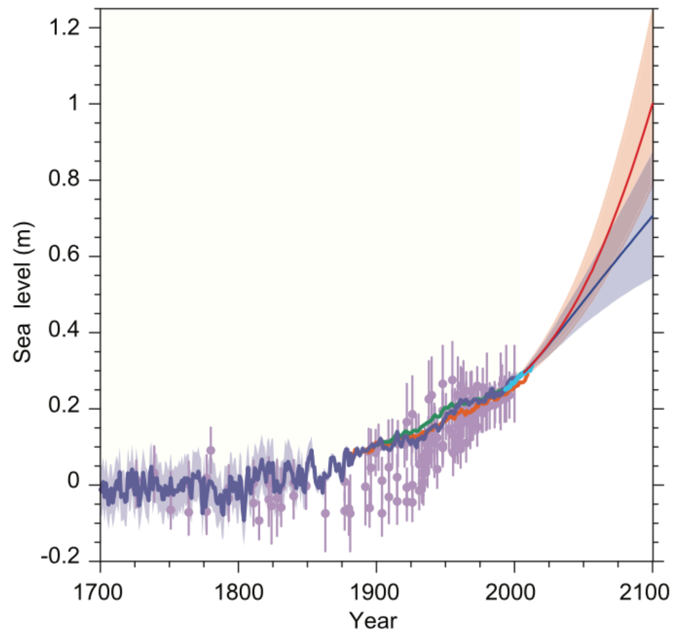


FIG. 4.32 Compilation of paleo sea level data, tide gauge data, altimeter data (from Figure 13.3), and central estimates and likely ranges for projections of global mean sea level rise for RCP2.6 (blue) and RCP8.5 (red) scenarios (Section 13.5.1), all relative to pre-industrial values. Source: IPCC Fifth Assessment, Working Group 1, Chapter 13, Figure. 13.27, page 1204. https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter13_FINAL.pdf

The global mean sea level appears to have been relatively stable from about 1700 to about 1800 according to interpretations of layers evident in vertical cores removed from peat in salt marches. The global mean sea level at about 1700 is taken to be the zero level to which later global mean sea levels are compared.

The global mean sea level appears to have begun rising slightly from about 1800 to about 1900 and continued rising at an increased rate from about 1900 to about 2000. The latter yearly mean sea levels were based on several different tide gauge studies, represented by different color lines, as well as from layers in cores of peat in salt marshes.

In 1993, satellite altimeter radar measurements began. (https://www.star.nesdis.noaa.gov/sod/lsa/SeaLevelRise/). Such highly accurate data can provide detailed information about the relative contributions by thermal expansion of the oceans and by melting ice in Greenland, Antarctica, and mountain glaciers elsewhere (https://sealevel.jpl.nasa.gov/science/ostscienceteam/scientistlinks/scientificinvestigations2013/cazenave/. Dr. Anny Cazenave was a lead author in such satellite altimeter radar studies (https://sealevel.jpl.nasa.gov/newsroom/spotlights/index.cfm?FuseAction=ShowNews&NewsID=349).

The lines projecting mean sea level rise during the 21st century are based on two computer models that differ in the predicted concentration of carbon dioxide and depend upon actions taken, or not taken, to curb greenhouse gas emissions. These models are called Representative Concentration Pathways (RCPs). RCP2.6 (blue) models a scenario that assumed reduced emissions with an increase in average global temperature of less than 2°C. RCP8.5 (red) models a scenario that assumed very high greenhouse gas emissions.

Question 4.11 What happens when light from the Sun shines on glacial ice and snow on land or on icebergs in the ocean?

When light from the Sun shines on the Earth, some of the light shines on snow and ice. The light supplies energy needed to warm the Earth and to change these solid forms of water into liquid water by melting. What impact does this have if the melting happens to glaciers on land compared to if the melting happens to icebergs already floating in the oceans?

How can you model and compare what happens when ice melts on land with what happens when ice melts in water? One way to explore this issue uses the following equipment for each group:

- 2 trays or one large tray such as a cookie sheet
- 2 low containers such as identical frozen dinner trays
- 1 flat rock in one low container
- As many ice cubes as possible to put on the rock and an equal number in the other low container
- Enough water to fill the low containers to the brim

- At the top of your physics notebook page, record the *Topic* of this exploration. Under

Before, draw a picture of your set up and describe your plan for this exploration. What do you predict will happen? Why do you predict this will happen?

- Place a container on a tray. Place an identical container on another identical tray or place both on a large tray like a cookie sheet.
- Place a flat rock in one container; place some ice cubes on the rock;
- Place the same number of ice cubes in the other container without rock;
- Fill both containers up to the lip with water. Be sure the water level is all the way to lip.
- Predict what will happen when the ice melts. Careful! DON'T JIGGLE THE TABLE!
- Observe the trays of melting ice every few minutes. What happens in each tray?
- Under the *During* section of your physics notebook page, record your observations and interpret these results.
- Discuss your findings and formulate relevant central ideas.
- In the *After* section of the physics notebook page, report these central ideas and the evidence on which they are based.
- Write a rationale that explains how the evidence supports the central ideas and why these are important.
- Also reflect upon this exploration such as what connections can you make to other experiences? How might you use what you learned in your own classroom?
- What are you still wondering?

Question 4.12 What happens when light from the Sun shines on the oceans?

To model what happens when light from the Sun shines on the oceans, provide for each student (or group), one regular thermometer with red liquid in a tube and bulb at the bottom .

- How can you model what happens when light from the Sun shines on the oceans? One way uses a thermometer, the kind that has a narrow tube with a red liquid (alcohol) inside a bulb at the bottom of the thermometer.
- At the top of your physics notebook page, record the *Topic* of this exploration. Under *Before*, draw a picture of your set up and describe your plan for this exploration. What do you predict will happen? Why do you predict this will happen?

- Record the room temperature reading for a thermometer that has been sitting in a room for a long time.
- Hold the bulb of the thermometer in your hand for a few minutes
- Record the temperature reading of the thermometer now.
- What do you observe? How do you interpret this observation?
- Under the *During* section of your physics notebook page, record your observations and interpret these results.
- Discuss your findings and formulate a relevant central idea.
- In the *After* section of the physics notebook page, report this central idea and the evidence on which is based.
- Reflect upon what you have learned and what you are still wondering.

Finish documenting these explorations on your physics notebook pages and writing summaries before looking at examples of student work about modeling what happens when light shines on the snow, ice, and the oceans.

1. Example of student work about modeling and comparing the impact of light from the Sun shining on ice on land and ice in the sea

Modeling rising sea levels due to melting ice on land:

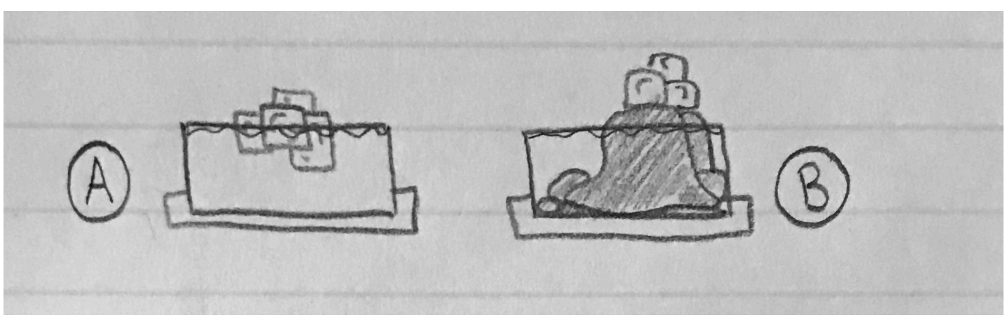


FIG. 4.33 *Student drawing of ice cubes melting on rock and in liquid water.*

In class we modeled the rising sea levels due to melting ice on land. We started off with two bowls, each with a clean tray under it. One bowl was empty and one had several rocks in it to act as land on Earth. We placed the same amount of ice cubes *in each bowl. In the empty bowl, we placed the ice cubes on the bottom. In tray B we placed the ice on top of the rocks. We then filled each tray to the brim with room temperature water, then waited. My table predicted that the tray without the rocks in it would not overflow because the ice already displaced the water with enough room for it when it melted. We also predicted that the bowl with the ice on the rocks would overflow because the ice was not already in the water and wasn't able to displace enough room for it when it melted. After an ample amount of time for the ice to melt, we came over and made our final observations. As we predicted, the bowl containing rocks had overflowed, whereas the tray without rocks did not. If you had a glass of ice water, when the ice melts, the glass doesn't overflow, but if you add ice to an already full glass of water, it will overflow. This is the same for the melting land ice flowing into the ocean vs. the sea ice already floating in the ocean. This means that the melting sea ice does not contribute to the rising sea levels, whereas the melting land ice does.*

National Geographic states some grim possible outcomes to rising sea levels. If we continue down the same path we are on, we could see the sea levels rise as much as 6.5 feet by the year 2100. It could be made even worse if we experience the complete melting of the Greenland ice sheet. This could push sea levels to rise to 23 feet, which is, horrifyingly, enough to submerge London: [*http://ocean.nationalgeographic.com/ocean/critical-issues-sea-level-rise/*](http://ocean.nationalgeographic.com/ocean/critical-issues-sea-level-rise/)

Physics student, Fall 2016

FIG. 4.34 *Tray on left overflowed when ice cubes on rock melted but tray on right did not overflow when ice cubes in liquid water melted.*

Figure 4.34 shows the equipment used in this exploration. An improvement would be to use food coloring in the water so that the overflow in the tray with the ice cubes on a rock would be more visible.

Students have periodically responded to a series of questions designed to elicit their thoughts about what is working well and what might improve their learning experiences in this course. A student wrote:

> *I thought that the activity that had the most powerful impact on my learning experience of global climate change was the activity about how melting ice on land is affecting rising sea levels. I thought it was a very simple, and straightforward way to model what is happening on our earth.*
>
> *I also enjoyed talking with my friend about the material that we went over. She is getting her degree in environmental studies with a focus on atmospheric science so it was interesting to hear her thoughts on what we were learning. She also found the way we were going about understanding the material as a way to help adults understand it as well. Many people don't have basic knowledge of what global climate change is so she saw the activities and lecture material that we went over as a good way to help the general population who is unaware of current environmental issues become educated.*
>
> Physics student, Spring 2015

In a conversation about the course, this student emphasized the importance of the use of simple equipment with which people are familiar and are likely to have at home that makes it easy to engage a friend or family member in thinking together about highly politicized issues like climate change.

2. Example of student work about modeling the impact of light from the Sun shining on the oceans

> ***Modeling rising sea levels due to thermal expansion of oceans.*** *In class we held thermometers in our hands to warm them and model the thermal expansion of oceans. The thermometers all began at room temperature, and then we heated them up by placing them in our hands. As our body temperature heated up the liquid inside, it caused the liquid to expand and rise up though the thermometer. This taught us that not only are oceans rising due to melting land ice, but also as the infrared radiation heats the ocean up more and more, it is beginning to expand. As the water in the oceans expands it rises, contributing to the rising sea level issue. BitsofScience.org discusses more scientific findings about the expansion of oceans in contribution to the rising sea levels. They also mention how the expansion of the*

water is easier to observe and predicate as it has less uncertainty than the melting ice caps: http://www.bitsofscience.org/sea-level-rise-thermal-expansion-7256/

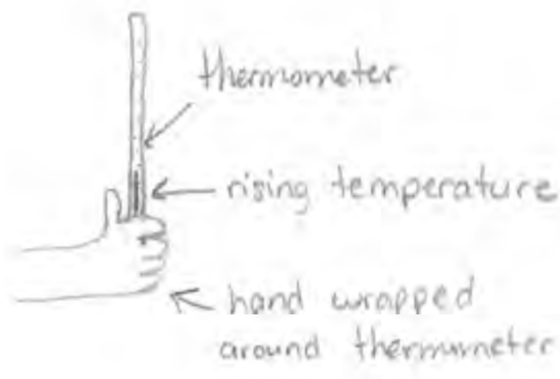


FIG. 4.35 Student drawing of modeling the expansion of water in warming oceans.

Scientists are developing computer models to predict rising sea levels and other aspects of climate change. Such websites as http://sealevel.climatecentral.org/ offer a "Risk Zone Map" that allow the public to see potential risks of their coastal areas. Some areas are less affected by the rising sea levels, whereas some cities will be lost to the ocean if the current rate of increasing global temperatures continues.

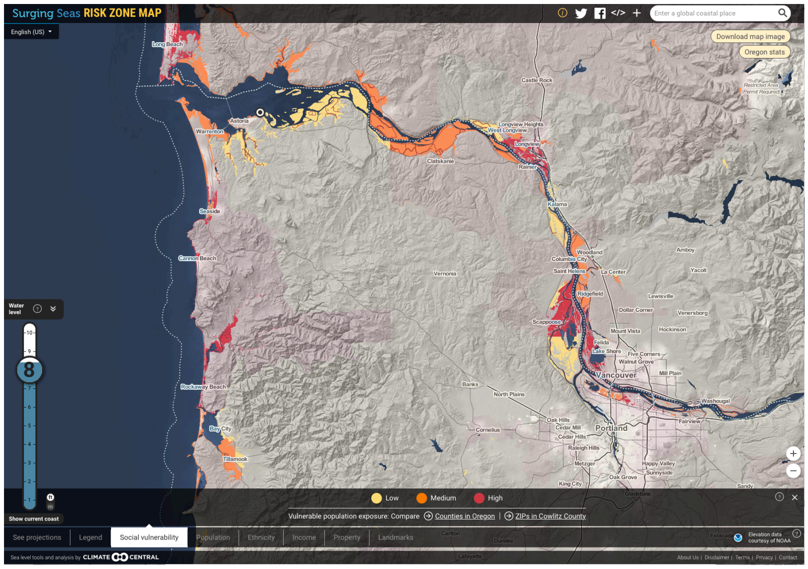


FIG. 4.36 Computer model for predicted flooding in northwest Oregon if sea levels rise 8 feet according to Surging Seas Risk Zone Map.
Source: Climate Central https://ss2.climatecentral.org/#10/45.8365/-123.3202?show=sovi&projections=0-RCP85-SLR&level=8&unit=feet&pois=hide

Physics student

Another example of predictions for flooding during various scenarios of increasing sea levels is for New York City and New Jersey at:

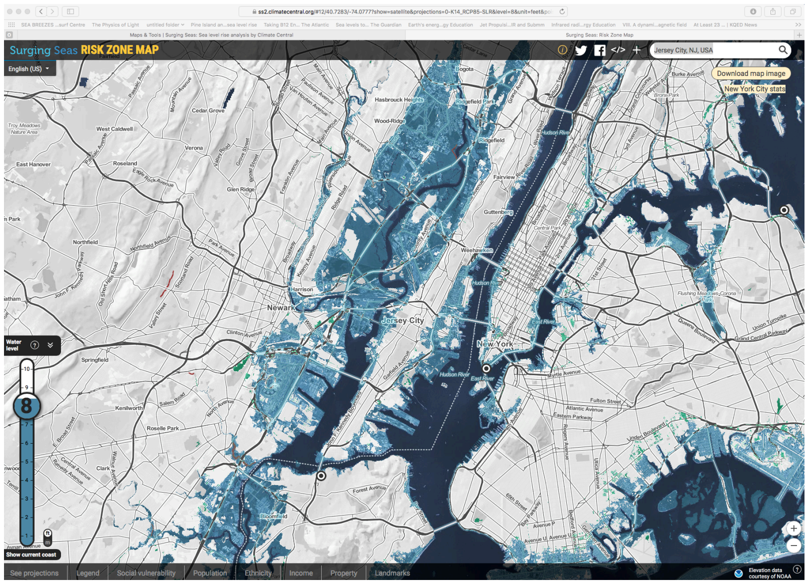


FIG. 4.37 Computer model for predicted flooding in New York City and New Jersey if sea levels rise 8 feet according to Surging Seas Risk Zone Map. Source: Climate Central https://ss2.climatecentral.org/#12/40.7283/-74.0777?show=satellite&projections=0-K14_RCP85-SLR&level=8&unit=feet&pois=hide

A news story about a storm, Hurricane Sandy, illustrates the conditions that may occur if surges from higher sea levels increase areas that become flooded: http://www.nj.com/hudson/index.ssf/2012/10/chaos_in_jersey_city_as_flood.html Some New York City subways flooded with millions of gallons of water during this storm. Repairs took five years: https://www.usnews.com/news/best-states/new-york/articles/2017-06-27/nyc-subway-station-reopens-after-being-flooded-by-sandy Predictions include a repeat of such storms every 25 years: https://www.theatlantic.com/science/archive/2017/10/climate-change-nyc-floods/543708/

Such experiences and predictions of repeats of such storms underlie the concerns being expressed that individuals, communities, and governments must to do whatever possible to reduce the causes of climate change.

Complete Table IV.3 to document what you have learned about the impact of global climate change on rising sea levels.

TABLE IV.3. Central ideas about rising sea levels

TABLE IV.3. Central ideas about rising sea levels			
Sketch of set up modeling causes of rising sea levels	Evidence	Central Ideas	Relevant Vocabulary
	http://oceanservice.noaa.gov/facts/sealevel.html https://www.nasa.gov/goddard/risingseas	A variety of evidence indicates that global sea levels are rising	
	https://climate.nasa.gov/vital-signs/land-ice/	Ice melting on land contributes to rising sea levels	
	https://nsidc.org/cryosphere/quickfacts/seaice.html	Ice melting in the sea does not contribute to rising sea levels	
	https://sealevel.nasa.gov/understanding-sea-level/global-sea-level/thermal-expansion	Thermal expansion of liquid water contributes to rising sea levels	
	http://climatenewsnetwork.net/global-warming-threatens-colder-climate-for-europe/	Ice melting on land or in the sea contributes to changes in density of salt water, which may change ocean currents	
	http://nsidc.org/cryosphere/seaice/processes/albedo.html	Ice is more reflective than liquid water so melting increases energy absorbed from the Sun	Albedo
	http://sealevel.climatecentral.org/	Computer models make predictions of flooded areas feasible	

	https://ss2.climatecentral.org/#12/40.7298/-74.0070?show=satellite&projections=0-K14_RCP85-SLR&level=5&unit=feet&pois=hide; http://www.nj.com/hudson/index.ssf/2012/10/chaos_in_jersey_city_as_flood.html ; https://www.usnews.com/news/best-states/new-york/articles/2017-06-27/nyc-subway-station-reopens-after-being-flooded-by-sandy ; https://www.theatlantic.com/science/archive/2017/10/climate-change-nyc-floods/543708/	Storm surges can be very destructive	
		*	
		*	
		*	

* Include one or more central ideas about rising sea levels that you learn from exploring other resources on the Internet with a friend or family member.

B. Exploring ways to reduce one's own impact on global climate change

Question 4.13 What can you do to reduce your impact on global climate change?

Many of us are unaware of the connection between what seems like a small act on our part and its consequences on the amount of greenhouse gases emitted into the atmosphere.

Going on an errand when the need arises, for example, seems like a reasonable thing to do in order to make progress on the endeavor for which the need has become apparent.

One sometimes makes a judgment, however: Is the time and effort to make a special trip worth it? If the trip involves driving a car, also consider: How much gasoline will the car use? According to the Energy Policy Initiatives Center of the University of San Diego School of Law, each gallon of gasoline releases about 19 pounds of carbon dioxide when burned. Each carbon atom in the gasoline combines with two atoms of oxygen in the air, so the product, a molecule of carbon dioxide, is much heavier than the carbon atom alone. If a typical fill-up is 18 gallons, then every fill-up of the tank is pumping about 340 pounds of carbon dioxide into the atmosphere! (https://epicenergyblog.com/2013/05/24/how-many-pounds-of-carbon-dioxide-co2-does-a-gallon-of-gasoline-produce/).

The University of Michigan Center for Sustainable Systems provides a comprehensive fact sheet about sources of greenhouse gas emissions due to everyday activities involving food, household appliances, and personal transportation. This fact sheet also provides suggestions for shifting to more sustainable actions (http://css.umich.edu/factsheets/carbon-footprint-factsheet):

Each mile driven by the typical passenger car, for example, puts 0.8 pounds of carbon dioxide into the atmosphere so walk, bike, carpool, or use mass transit whenever possible.

Washing laundry in cold rather than hot water can reduce carbon dioxide emissions by up to almost 15 pounds per load, depending upon the source of energy, temperature of the hot water, and type of washing machine.

As shown in Fig. 4.38, choosing what to eat for dinner can make a difference in the amount of carbon dioxide emitted in producing the different types of food eaten.

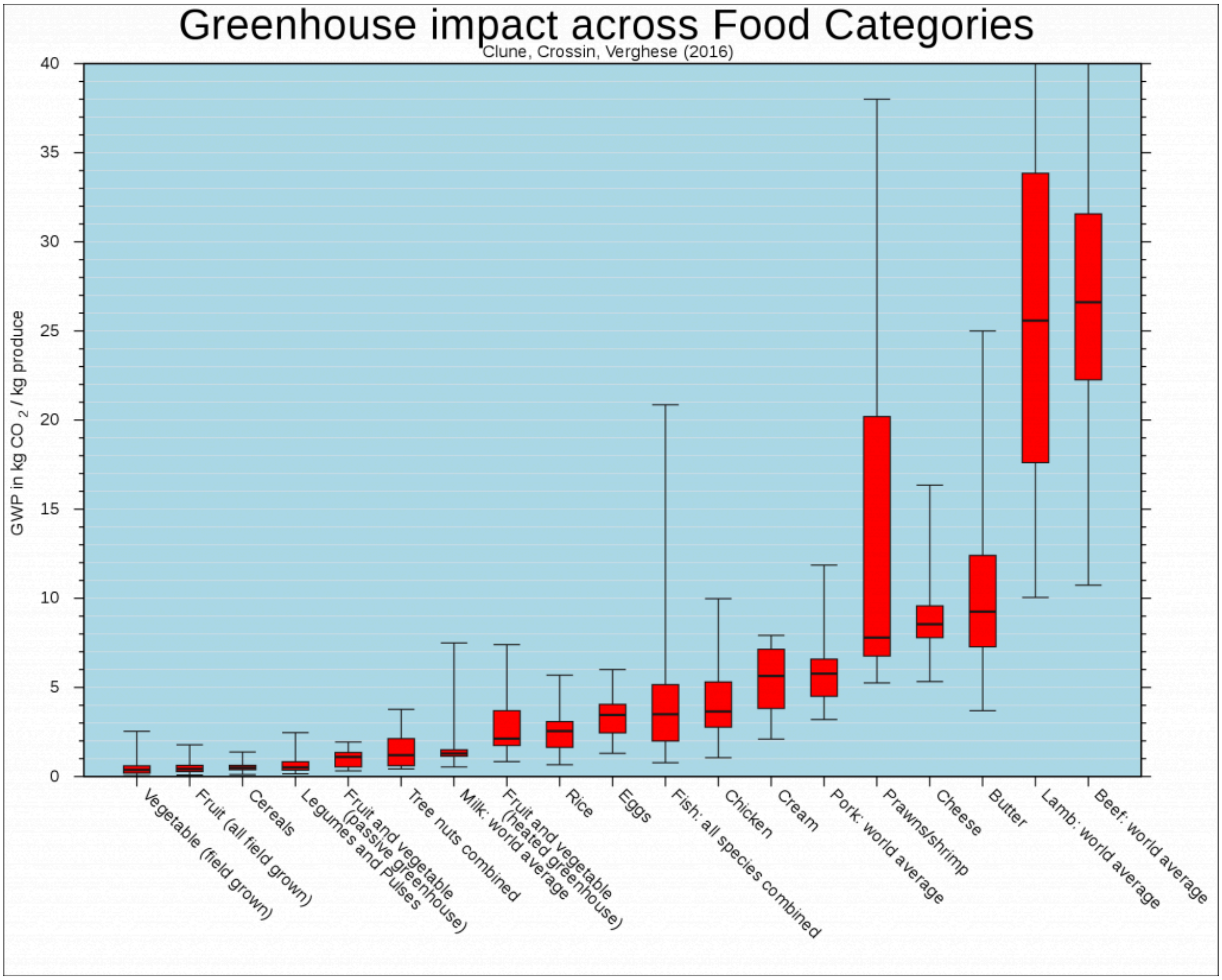


Fig. 4.38 Comparison of Global Warming Potential (GWP) for various food groups. (https://commons.wikimedia.org/wiki/File:Clune2016_food_lca.svg) ([CC BY-SA 4.0](CC BY-SA 4.0))

Stephen Clune, Enda Crossin, Karli Verghese: *Systematic review of greenhouse gas emissions for different fresh food categories.* *Journal of Cleaner Production.* 2016. DOI: 10.1016/j.jclepro.2016.04.082, Table 4.

Such comparisons are complex. Clune, Crossin, and Verghese (2016) have compared the mass of carbon-dioxide emitted from producing a given amount of various foods. Producing a kilogram of vegetables, fruit, or cereals, for example, results in much smaller emissions of carbon dioxide compared with producing a kilogram of lamb or beef meat.

Related information from a recent news item provides a vivid comparison of the number of people an acre of land can feed depending upon the kind of food that is grown there: Willie Riggs, director of Oregon State University Klamath Basin Research and

Extension Center, told commissioners that an acre of wheat feeds 44 people per year; an acre of potatoes feeds 1,355 people per year; an acre feeding dairy cows provides enough milk for around 40,000 half-pint servings; and an acre feeding cows raised for meat feeds around eight people per year. https://www.heraldandnews.com/klamath/preparing-for-drought-commissioners-declare-drought-emergency/article_67c92bd1-0443-5520-931e-cb2428a1fc0d.html
(February 21, 2018 Harold and News, Klamath County)

If the increase in carbon dioxide emissions is causing the increase in global temperature and you want to try to decrease your own *carbon footprint*, how can you do that? There are several online carbon footprint calculators that can help estimate how many *Earths* would be needed if everyone lived like you do.

- Work on one or more of these carbon footprint calculators on your computer, discuss your findings with group members, and present some thoughts about these findings on a white board to discuss with the whole group.

Exploring Internet Resources for Calculating One's Carbon Footprint
What can you do to reduce your ecological / carbon footprint?

Environmental Protection Agency (EPA)	https://www3.epa.gov/carbon-footprint-calculator/
Carbon Footprint LTD (UK)	https://www.carbonfootprint.com/calculator.aspx
Nature Conservatory:	https://www.nature.org/greenliving/carboncalculator/index.htm
International Student Carbon Footprint Calculator	https://depts.washington.edu/i2sea/iscfc/calculate.php
Global Footprint Network Footprint Calculator	https://www.footprintnetwork.org/resources/footprint-calculator/
World Wildlife Fund (now World Wide Fund for Nature)	http://footprint.wwf.org.uk
General information:	
Carbon Footprint Factsheet	http://css.umich.edu/factsheets/carbon-footprint-factsheet
Details about energy use in the United States	
Annual Energy Outlook	https://www.eia.gov/outlooks/aeo/index.php

1. Examples of student work reflecting upon engaging a friend or family member in learning about living in more sustainable ways

A student chose to discuss with her mother some personal changes one can make:

> *For this assignment I decided to talk to my mom about global climate change. She remains the most skeptical person in my life when it comes to climate instability so I decided that she would be the most effective person to talk to. She is always asking "Okay so this is a problem but what the heck am I supposed to do about it?" We went to the website https://www.nrdc.org/stories/how-you-can-stop-global-warming and read through the article together and I wrote down all of the ideas about how to slow global warming that were provided. After we looked through all of the ideas, I asked her what she thought she could do in her life. She said that she could reduce the waste with groceries, unplug devices, buy better light bulbs, and reduce water waste. She said that she was amazed because she thought that in order to help reduce global warming she would have to raise millions of dollars or buy a new house. She had no idea that she could make small changes in her life. During this conversation she was able to "evaluate and communicate information" which is one of the NGSS Science and Engineering Practices. She was presented with this information and then she communicated to me how she believes that she will be able to make a change in her life. She also touched on the NGSS Crosscutting concept of "cause and effect" because we talked about how little changes that we make can have a combined positive effect on the environment.*

Another student was able to use a carbon footprint website with a middle school friend:

> https://www.earthday.org/take-action/footprint-calculator/
>
> *I chose to use this footprint calculator to engage my mom's friend's daughter, S. She is in middle school and knows all about carbon footprints and CO_2emissions. I chose this website because I thought it was a fun activity and it shows how individuals are impacting the Earth. I asked S all of the questions on the survey. Since she does not drive or travel often, most of her impact came from the food she ate which she was very surprised at. She asked, "But I don't have a car, and I recycle, and always turn off the lights. Why does it still say there would have to be 3 Earths [if everyone lived the same way]?" We then researched about the huge impacts that the food industry has on the environment. Especially the meat industry. I then told her about "Meatless*

Mondays" which we talked about in class and she was still so surprised at the fact that meat and packaged food had such a negative effect on the Earth. The footprint calculator was a really fun activity and gives you a lot of scary information, such as an "Earth Overshoot Date." But it does not really show you ways you can reduce your impact on the Earth. I think users would benefit much more if there were a few tips at the end of the test.

I would say the NGSS Science and Engineering Practice that best fits this website is Analyzing and Interpreting Data. The footprint calculator asks for the data on your life, like how far you drive or use public transportation. It then uses that data to tell you how much of Earth's resources you are using as an individual. The NGSS Crosscutting Concept that fits this site is definitely Cause and Effect. You enter in all of the ways you use the Earth's resources and see how it directly affects the Earth's productivity.

After looking at the footprint calculator with S, I started to wonder how I could teach my students about their ecological footprint without making them feel bad about the way they live. I know I felt really guilty when I took this test the first time.

VII. Developing Mathematical Representations of Changing Quantities

The world is full of changing quantities. Key to becoming aware of what is happening is measuring how much a quantity is changing. That knowledge can provide the basis for thinking about what might be happening next and perhaps for perceiving ways to increase positive outcomes or at least minimize negative ones.

This section develops a mathematical way of representing changing quantities. The first activity explores changing quantities in an everyday context, a tossed ball. The next presents evidence for a changing quantity relevant to global climate change and its impact, estimates of how fast glaciers are melting. Development of an analogy between motion and melting graphs guides making projections for how fast glacial ice may be melting in the future.

A. Developing familiarity with motion graphs for a tossed ball

Rolling, kicking, throwing, and catching a ball are familiar activities for most people. To describe mathematically what is happening to the ball, however, one needs some technical skills: ways to label where the ball is, its *position*, to describe how that position is changing, the ball's *velocity*, and to think about how that velocity is changing, its *acceleration.* By looking at graphs of how a ball's position, velocity, and acceleration are changing with time, one can learn a lot about a ball's motion – is it at rest? Moving with constant speed? Speeding up? Slowing down? Similarly, one can learn a lot about how a quantity of interest is changing by looking at analogous graphs for that quantity, such as how fast are the world's glaciers melting?

Question 4.14 How do position, velocity, and acceleration of a tossed ball change with time?

To explore this question, use:

- whiteboard,
- basketball,
- motion detector connected to a computer or graphing calculator
- If a motion detector is not available, use:
- Basketball
- Stopwatch,
- Flat board,
- Meter stick or yard stick
- Book or wood block to incline the flat board

A motion detector works by emitting ultrasound waves that are reflected from an object back to the detector. The detector reports how far away the object is and makes a graph of position (where the object is) versus time (the instant it was there). We use a Go Motion! detector that connects directly to a computer (https://www.vernier.com/products/sensors/motion-detectors/).

- Start by exploring what a motion looks like on a position versus time graph (x vs t) with the vertical axis representing where the object is (x, its position with respect to the motion detector's position), and the horizontal axis representing the time the object was there (t, a clock reading). What can you find out about position vs. time graphs by standing still as well as by moving back and forth in front of the motion detector?
  - What does the position versus time graph look like if you stand still in front of the motion detector? (If you do not have access to a motion detector, lay a meter or yard stick along a flat board, place the ball next to a numbered mark, and note its position there for multiple instants of time read on the stopwatch. Plot that position on a position vs. time graph.)
  - What does the position versus time graph look like if you also stand farther away from the motion detector (or place the ball farther away from the end of the meter stick)?

- What does the height of a point on a position versus time graph represent?

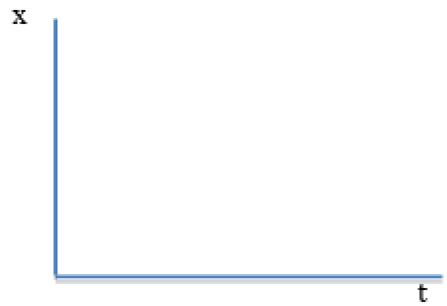


FIG. 4.39 Create position versus time graphs by standing still at different distances in front of the motion detector.

- What does the position versus time graph look like if you hold a large white board in front of you in front of the motion detector and move back and forth? The large white board makes it easier for the motion detector to 'see' you. If you do not have a motion detector, design a way to measure positions and associated clock readings to create a position vs time graph by rolling the ball along the board when the board is flat and also when the board is inclined.
- What does the position versus time graph look like if you (or the ball) move away from the motion detector at a constant velocity? Move away at a higher constant velocity?
- Move toward the detector at a constant velocity? Toward at a higher constant velocity?
- What does the position versus time graph look like if you move away from the detector while speeding up? Move away from the detector while slowing down?
- Move toward the motion detector while speeding up? Move toward the detector while slowing down?
- What does the slope at a point on a position versus time graph represent?
- What does the position versus time graph look like if you turn around (change direction)?
- If you are looking at a position versus time graph for a motion in which someone turns around, how can you tell which point on the graph represents the turn around?

- Take pictures or make accurate drawings of the resulting graphs.

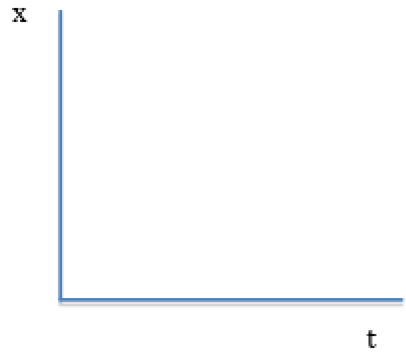


FIG. 4.40 Create position versus time graphs by standing still and by moving back and forth in front of the motion detector with constant and changing velocities.

- Click on "insert graph" in the menu bar of the computer screen and choose velocity to add a velocity versus time graph to the computer screen. Adjust the size of the x vs t and v vs t graphs until both fit on the screen, with the velocity graph underneath the position graph. Line up the origins of these graphs so that an event, such as a turn around, that is represented as happening on the position graph is also represented as happening right underneath on the velocity graph. Change the vertical axis of the velocity graph to go from -2 meters to +2 meters.
- Explore what a motion looks like on a velocity versus time graph (v vs t) with the vertical axis representing how fast the object is moving toward or away from the motion detector (v, its velocity), and the horizontal axis representing the instant the object was passing a point (t, a clock reading). What can you find out about velocity vs. time graphs by standing still as well as by moving back and forth in front of the motion detector?
  - What does the velocity versus time graph look like if you stand still at various positions in front of the motion detector?
  - What does the velocity versus time graph look like if you move back and forth in front of the motion detector? (Or you place the meter stick along the flat board, roll the ball along the board, and record the board's position at particular times, both one way and then the other on the board; then incline the board and roll

the ball up the incline so that it turns around and rolls back down. Use your data to calculate the average velocity Δx/Δt between each set of positions.)

- What does the velocity versus time graph look like if you (or the ball) move away from the motion detector at a constant velocity? Move away at a higher constant velocity?
- Move toward the detector at a constant velocity? Toward at a higher constant velocity?
- What does a positive velocity represent? What does a negative velocity represent?
- What does the height of a point on a velocity versus time graph represent?
- What does the velocity versus time graph look like if you move away from the detector while speeding up? Move away from the detector while slowing down?
- If you move toward the detector while speeding up? Move toward while slowing down?
- What does the slope at a point on a velocity versus time graph represent?
- What does the velocity versus time graph look like if you turn around (change direction)?
- Take pictures or make accurate drawings of the resulting graphs.

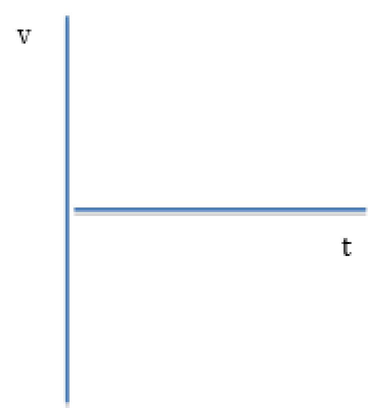


FIG. 4.41 Create velocity versus time graphs by standing still and moving back and forth in front of the motion detector with constant and changing velocities.

- What are some connections between the position vs time and velocity vs time graphs?

- How is a turn around (changing direction) represented on a position vs time graph? On a velocity vs time graph?
- How is speeding up represented on a position vs time graph? a velocity vs time graph?
- How is slowing down represented on a position vs time graph? a velocity vs time graph?

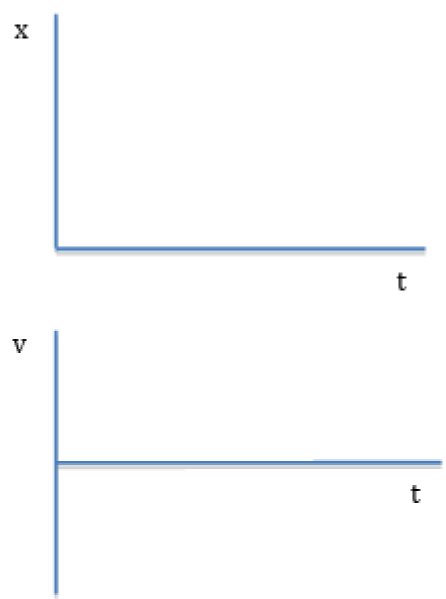


FIG. 4.42 Identify connections among position versus time and velocity versus time graphs.

> To explore the connections among position vs time, velocity vs time, and acceleration vs time graphs, use: motion detector connected to a computer or calculator and a basketball.

- Click on "insert graph" in the menu bar of the computer screen and choose acceleration to add an acceleration versus time graph to the computer screen. Adjust the size of the x vs t, v vs t, and a vs t graphs until all fit on the screen, with the acceleration graph underneath the velocity graph, which is underneath the position graph. Line up the origins so that an event, such as a turn around, that is happening on the position graph is also happening right underneath on the velocity graph and underneath on the acceleration graph. Change the vertical axis of the acceleration graph to read from +12 m/s^2 to -12 m/s^2.

- Explore what a motion looks like on position versus time, velocity versus time, and acceleration versus time graphs with the vertical axis representing where the ball is (x vs t), how fast and in what direction it is moving (v vs t), and how its velocity is changing (a vs t) while moving away from or toward the motion detector, with the horizontal axis representing the instant the object was passing a point (t, a clock reading).
- What can you find out about the connections among these graphs by tossing a ball directly up vertically and then catching it as it falls down within the view of a motion detector?

    - Place the motion detector flat on the floor or a table. Hold the ball over the motion detector. Click on the computer to start the graph.
    - Toss the ball straight up above the motion detector so it stays in the detector's view.
    - Catch the ball before it falls all the way back down onto the motion detector!
    - Make multiple tosses until the computer stops drawing the graph.
    - Look at the position vs time, velocity vs time, and acceleration vs time graphs for each toss. Select the best example from a set of the multiple graphs of the tosses.
    - (If you do not have a motion detector, look at the graphs shown in Fig. 4.44.)

    - Draw the x vs t, v vs t, and a vs t graphs vertically aligned on a white board
    - As you draw, talk with one another about what each feature of each graph means:
      What does the height of a point on each graph represent? The slope? How do these three types of graphs represent an 'event' such as the ball's turning around at the top of a toss?

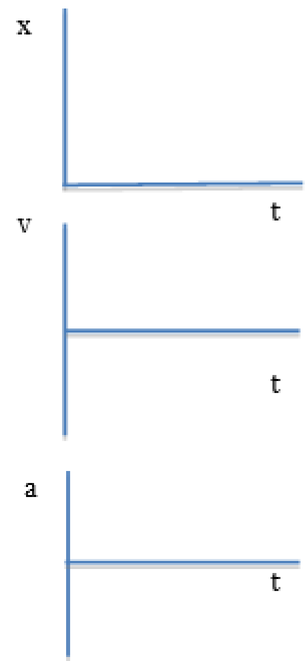


FIG. 4.43 Identify connections among position versus time, velocity versus time graphs, and acceleration versus time graphs.

- How is the ball toss represented on the position versus time graph? the v vs t graph? the a vs t graph?
  - What is the shape of each kind of graph?
  - What does the height at a point represent on each graph? The slope?
  - How is a turn around (change direction) represented on each kind of graph?
  - What are some connections among these graphs?
- Sketch a set of vertically aligned position, velocity, and acceleration graphs for a tossed ball.
- Summarize your understandings by "telling the story" for each graph.

The designers of the *Logger Lite* computer program chose to use the convention that a toss vertically "up" is in the positive direction and that a fall "down" is in the negative direction. Figure 4.44 shows a set of position, velocity, and acceleration graphs for a ball that was tossed vertically, then caught and tossed vertically again, for four tosses.

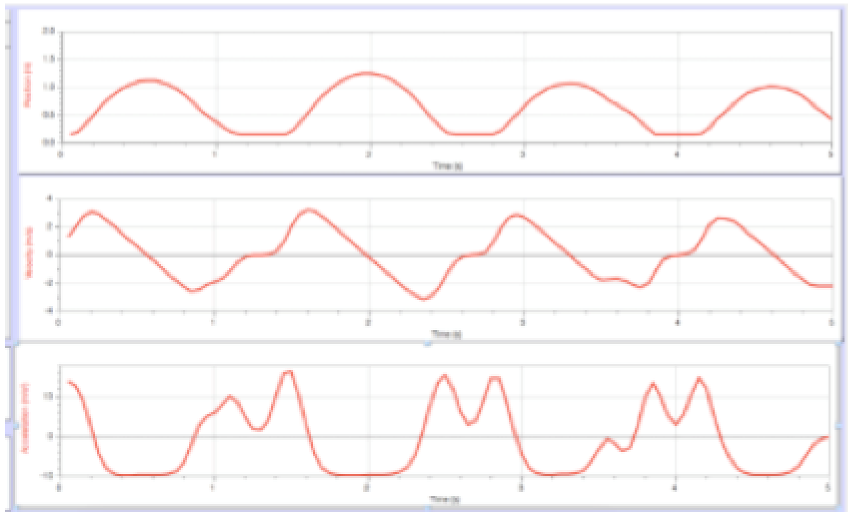


FIG. 4.44 Position, velocity, and acceleration graphs for a vertically tossed ball. ©Vernier Software & Technology-used with permission.

The analysis below focuses on the tosses, that is, the time periods during which the ball was in the air after the ball left the hand and before it was caught. These tosses are represented by the parabolas in the position versus time graph, the straight diagonal lines in the velocity versus time graph, and the flat portions of the acceleration versus time graph.

What story is the x vs t graph telling about where the ball is, its position, during a toss?

Height: The height of a point on the position versus time graph represents the ball's position, how far it is from the motion detector. During the toss, the curved line is a parabola whose height is changing, increasing to a maximum, then decreasing. The parabola represents the changing position of the ball as the ball moves up, away from the motion detector, to a maximum height, turns around (but does NOT stop at the top), and falls back down toward the motion detector until caught. The flat regions of the position versus time graph represent the time during which the ball is held in the person's hand in the same low position above the motion detector between tosses.

Slope: The slope at a point on the position versus time graph represents the rate at which the ball's position is changing, its velocity at that point: During the toss, the slope is changing, the ball is moving a different distance during each unit of time. On the trip "up," the slope is getting less and less steep; the ball is moving shorter and shorter distances during each unit of time. While still moving in the positive direction, "up," the magnitude of the ball's velocity is decreasing, that is, the ball is slowing down while moving "up" in the positive direction. On the trip "down," the slope is getting steeper and steeper; the ball is moving longer and longer distances during each unit of time. While now moving in the negative direction, "down," the magnitude of the ball's velocity is increasing, that is, the ball is speeding up while falling "down" in the negative direction.

What story is the v vs t graph telling about how fast the ball is moving and in what direction, its velocity, during a toss?

Height: The height at a point on the velocity versus time graph represents the ball's velocity: During the toss, the line is a straight diagonal with negative slope: when thrown "up," the ball starts out at a high velocity in the positive direction, slows down in a regular way while still moving "up" in the positive direction, turns around (v = 0), and speeds up in a regular way while falling "down" in the negative direction until caught.

A positive velocity means that the ball is moving in the positive direction, "up" in this case. As the ball moves "up," however, it slows down so the initially large positive velocity from the throw gets smaller and smaller until the ball turns around (v=0) and starts falling "down".

Note that there is no extended time period during which the velocity is zero during the toss; the ball does not "stop" at the top during the turn around. This contrasts with the short time period when the line representing the velocity remains on the horizontal axis, at zero, while the ball is being caught and briefly held before being tossed again.

A negative velocity means that the ball is moving in the negative direction, back toward the motion detector. Although -8 on a number line represents less than -1 on a number line, a velocity of −8 meters/second is much faster than a velocity of -1 meters/second. The minus sign only indicates the direction the ball is going, "down" in this case; the number indicates the magnitude of the velocity, how fast the ball is moving.

In physics, the word *speed* refers to the magnitude of how fast the ball is moving; the word *velocity* refers to both the magnitude and direction of motion. If the ball's velocity is −8 meters/second, its speed is 8 meters/second while the ball is moving in the negative direction.

Slope: The slope at a point on the velocity versus time graph represents the rate at which the ball's velocity is changing, its acceleration at that point: If the slope is constant, the ball's velocity is changing by the same amount during each unit of time. If the slope is constant and negative, the ball's positive velocity is getting slower and slower in a regular way during the “up” portion of the toss; the ball’s negative velocity is getting faster and faster in a regular way during the “down” portion of the toss.

What story is the a vs t graph telling about how fast the ball’s velocity is changing, its acceleration, during the toss?

Height: The height of a point on the acceleration versus time graph represents the ball’s acceleration: During the toss, the line is flat, a straight horizontal line, below the horizontal axis: the ball’s acceleration is negative and constant (about -10 meters/second, every second) throughout the motion, whether the ball is going up or down. This means that during the toss, the velocity of the ball decreased by about 10 meters/second during each second of the trip “up” and increased by about 10/second during each second of the trip “down.” Thus interpreting this graph provides an estimate of the quantity known as the acceleration of gravity, which is often referred to as -9.8 meters/second^2, where the minus sign indicates that the direction of the acceleration is toward the center of the Earth.

Slope: The slope at a point on the acceleration versus time graph represents the ball’s change in acceleration. During the toss, the slope is zero, the ball’s acceleration is not changing, its velocity changes by the same negative amount for each unit of time during the entire toss. In accordance with Newton’s second law, F=ma, the force on the ball is constant, the Earth is pulling on the ball in the same way, with the same gravitational force, in the negative direction toward the center of the Earth, during the entire trip, both up and down. (The jagged peaks on this acceleration versus time graph represent the varying acceleration caused by upward forces exerted on the ball by the thrower in catching the ball, holding it briefly, and then tossing it again.)

One connection among these graphs is that the ‘event’ of the ball turning around is represented by the maximum height of the curved line on the position versus time graph and by the straight diagonal line crossing the horizontal axis at zero on the velocity versus time graph but is not represented at all on the acceleration versus time graph.

These graphs are very powerful tools for understanding what is happening when change is occurring. In particular, is something happening slower and slower or faster and faster?

Whenever you see a curve like the tossed ball (downward curved parabola) something is happening either slower and slower, if the curve is like the first half of the toss (“up”), or faster and faster if the curve is like the second half of the toss (“down”)! Seeing a graph with this shape is an alert that not only is change happening but the rate of change is changing, accelerating. It may be hard to detect a pattern when provided columns of numbers; asking for a graph of the data may make visually salient the need for taking informed action.

B. Becoming aware of melting glaciers

One challenge scientists face is communicating to the public what seems to be happening to the global climate and its impacts. One approach is to develop and provide visual images that vividly convey the changes that are occurring.

Question 4.15 What is the evidence that glaciers are melting?

An example of a change occurring in nature is the melting of glaciers on land. According to the National Snow and Ice Data Center, glacial ice currently covers about 10 percent of the land on Earth. If all the ice on Earth melted, sea levels would rise about 70 meters (230 feet) (see https://nsidc.org/cryosphere/glaciers/quickfacts.html).

When ice melts within a glacier, liquid water flows as streams into the ocean. Glaciers also flow like rivers of ice very slowly toward the ocean. *Calving* occurs when large chunks of ice break off the edge of a glacier. Some glaciers have retreated substantially during the past century, as shown by photographs taken in roughly the same place many years apart. Figure 4.45, for example, shows photographs of Muir Glacier, Alaska, taken in 1941 and 2004 from roughly the same place. These photos were included in the National Aeronautics and Space Administration (NASA) Climate 365 project to inform the public about evidence of climate change (https://climate365.tumblr.com/)

FIG. 4.45 Photographs of Muir Glacier, Alaska, in 1941 and 2004. https://climate.nasa.gov/climate_resources/4/graphic-dramatic-glacier-melt/

According to the National Snow and Ice Data Center, this glacier retreated about seven miles during the 63 years between these photographs. The NASA Climate 365 project is a collaboration of the NASA Earth Science News Team, NASA Goddard and Jet Propulsion Laboratory communications teams, and NASA websites Earth Observatory and Global Climate Change. These photographs were taken by William O. Field on Aug. 13, 1941 (left) and by Bruce F. Molnia on Aug. 31, 2004 (right) and are from the Glacier Photograph Collection. Boulder, Colorado USA: National Snow and Ice Data Center/World Data Center for Glaciology.

Glacier National Park in Montana also has had major losses of glacial ice. There were about 150 glaciers larger than 25 acres there a century ago; now there are only 26 of at least that size (https://www.usgs.gov/news/glaciers-rapidly-shrinking-and-disappearing-50-years-glacier-change-montana). Decreases in the extent of glacial ice are most evident at the time of maximum melt before new snow and ice form during late fall and winter. Fig. 4.46, for example, shows an aerial photograph of Sperry Glacier in late summer with outlines of its perimeter at similar times in 1966, 1998, 2005, and 2015.

- What impact might the decline in the number and extent of glaciers have on water resources in the region?

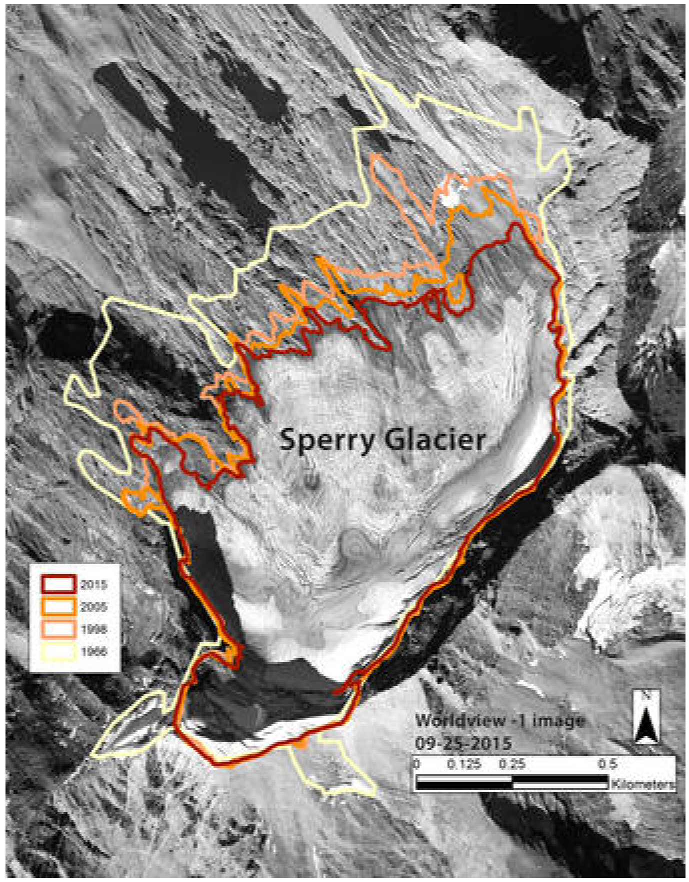


Fig. 4.46 Aerial photograph with outlines showing changes over 50 years in the perimeter of Sperry Glacier in Glacier National Park during late summer in 1966, 1998, 2005, and 2015. US Geological Survey (https://www.usgs.gov/news/glaciers-rapidly-shrinking-and-disappearing-50-years-glacier-change-montana)

Data from satellite images have greatly enhanced scientists' ability to document changes in the forming and melting of sea ice on the oceans as well as glacial ice on land. The National Snow and Ice Data Center (NSIDC) uses satellite data, for example, to monitor daily, monthly, and yearly the extent to which sea ice covers the Arctic Ocean (See: http://nsidc.org/soac/sea-ice-more-information).

Figure 4.47, for example, compares how much sea ice covered the Arctic Ocean during October in 1981 (left) and during October in 2012 (right). Blue represents regions where sea ice covered more area than normal during October, where normal was defined as the average sea ice coverage during the month of October for the period from 1979 to 2015. Red represents regions where sea ice covered less area than normal for the month of October, that is, areas with more open sea water than in the past. Click on http://nsidc.org/soac/sea-ice.html#seaice and the triangle to watch a graphic display of changes from October 1981 to October 2016.

- What impact would more open sea water have on the Arctic Ocean?

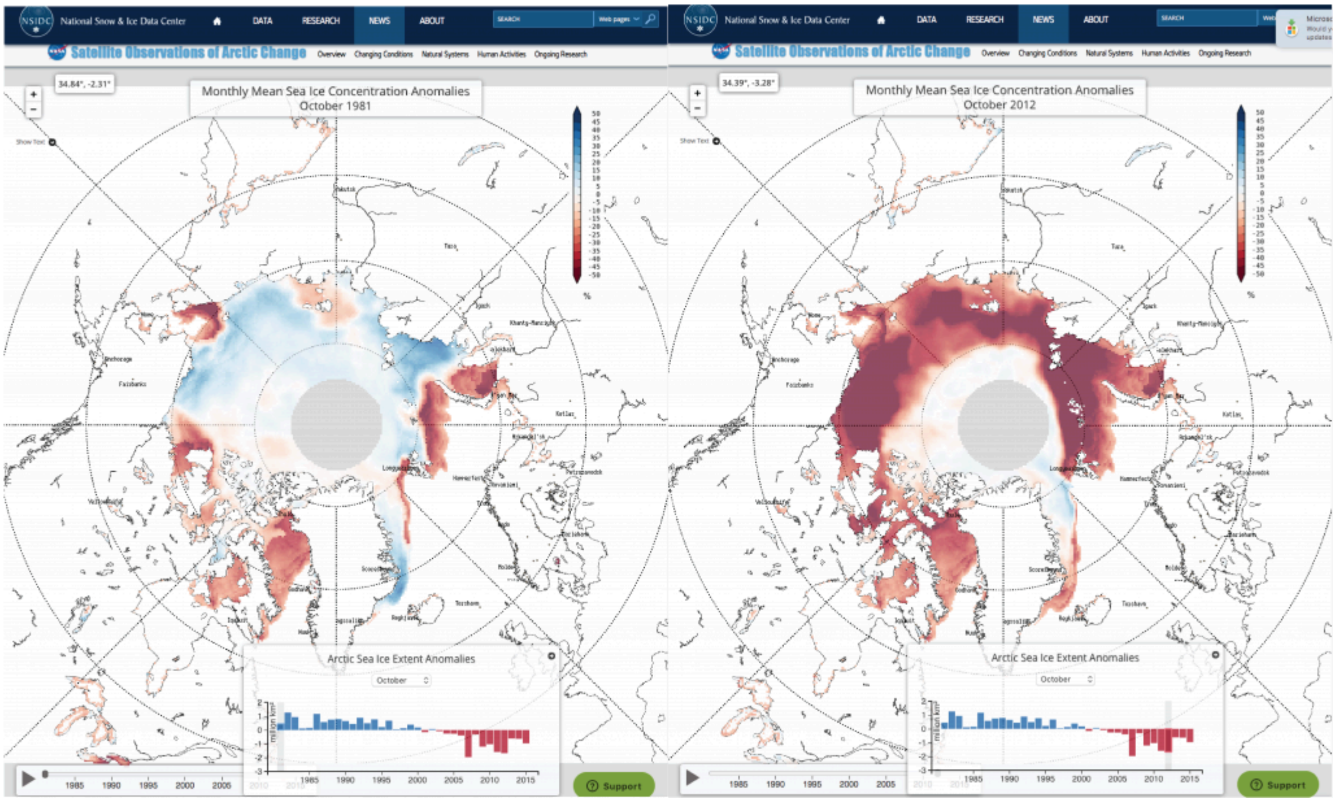


Fig. 4.47 Mean Arctic sea ice concentration anomalies during October 1981 (left) and during October 2012 (right). (The gray central area was not visible to these satellite instruments.) National Snow & Ice Data Center, Satellite Observations of Arctic Change (http://nsidc.org/soac/sea-ice.html#seaice)

Ice reflects up to 70% of incoming solar radiation; open water, however, reflects less than 10%. Therefore, changes in how much sea ice covers Arctic waters, particularly during the summer, have a big impact on how much energy is reflected back out to space or absorbed. Energy absorbed increases both sea surface and atmospheric temperatures. See http://nsidc.org/arcticseaicenews/ for the latest Arctic Sea Ice News and Analysis.

Satellite data also have enabled scientists to document recent acceleration of the movement of glaciers on land toward the Antarctic Ocean due to winds and warm water currents (See: https://climate.nasa.gov/news/2631/wind-warm-water-revved-up-melting-antarctic-glaciers/.) Figure 4.48, for example, represents the velocity of glaciers varying from zero to 4000 meters per year. The area represented by the small black box on the left is shown in detail on the right, with ocean depth (Bathymetry in meters) and arrows representing Antarctic Circumpolar Currents (ACC) bringing warmer ocean water into Marguerite Bay.

- What impact would accelerating glacial ice flow in Antarctica have on global sea levels?

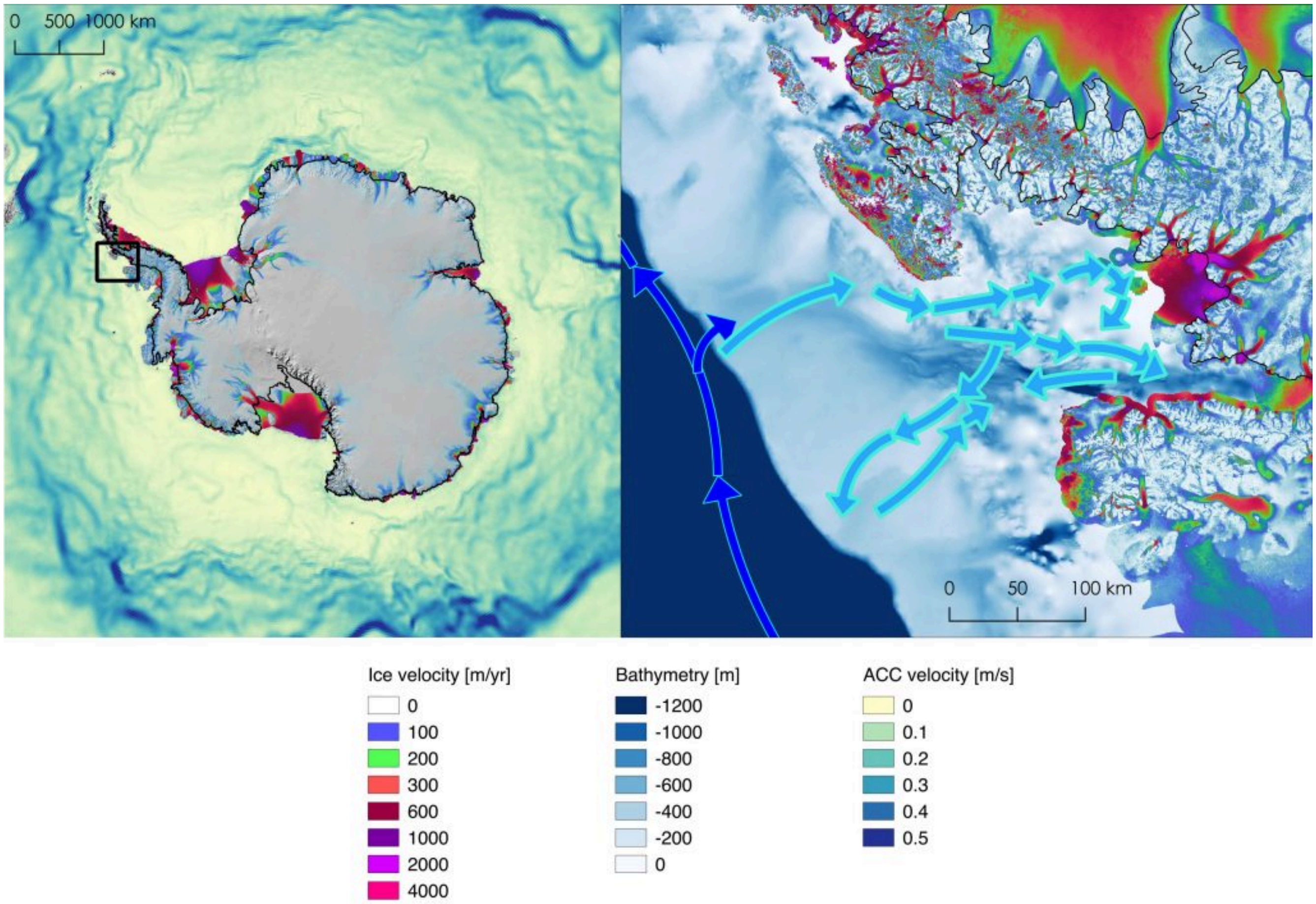


Fig. 4.48 Velocity of glaciers flowing toward the Antarctic Ocean. Credit: NASA/JPL-Caltech. (*https://climate.nasa.gov/news/2631/wind-warm-water-revved-up-melting-antarctic-glaciers/*)

At the interface where glaciers meet open water, large ice chucks can break off and fall into the water as shown in Fig. 4.49. The Oceans Melting Greenland mission explores the role of warm salty Atlantic Ocean in melting Greenland's glaciers from below (https://omg.jpl.nasa.gov/portal/).

Fig. 4.49 Calving of a glacier in Greenland. Image credit: NASA's *Oceans Melting Greenland mission.* (*https://sealevel.nasa.gov/news/74/glaciers-on-the-edge*)

The film, *Chasing Ice*, presents the efforts by James Balog and colleagues at the Earth Vision Institute (https://earthvisioninstitute.org) to document the calving of glaciers in Greenland.

- Watch the trailer for the film at: https://www.youtube.com/watch?v=eIZTMVNBjc4 (2.15 minutes). You may be able to watch the complete one-hour *Chasing Ice* documentary on a streaming service on the Internet. Additional information is available at http://extremeicesurvey.org .
- Also watch part of a TED (Technology, Entertainment, and Design) talk from 14.24 to 18.27 (4 minutes) at http://ed.ted.com/lessons/james-balog-time-lapse-proof-of-extreme-ice-loss . In this Ted talk, *Time-lapse Proof of Extreme Ice Loss*, James Balog presents and interprets the extent of melting ice observed at the Ilulissat Glacier,

Greenland from 1851 to 2008. What did he and his colleagues find out about this glacier?

A video update showing additional ice loss by this glacier in Greenland, from June 2007 to August 2017, is at https://vimeo.com/168243534. In closing the TED talk, James Balog said, "I believe we have an opportunity right now…to face the greatest challenge of our generation, of our century,…to do the right thing for ourselves and for the future, and I hope we have the wisdom to…rise to the occasion and do what needs to be done."

C. Making an analogy between falling balls and melting glaciers

A big question in the 1990s and early 2000s was whether the glaciers on Greenland were growing or shrinking. See a story about scientists' attempts to resolve this issue at https://earthobservatory.nasa.gov/Features/Greenland/greenland.php . New data from the GRACE (Gravity Recovery and Climate Experiment) satellite project were interpreted by Isabella Velicogna (see https://earthobservatory.nasa.gov/Features/Greenland/greenland3.php and https://earthobservatory.nasa.gov/Features/Greenland/greenland4.php).

The graph in FIG. 4.50 presents data derived from the GRACE satellite from 2002 to 2014. The red stars represent June values of the mass of ice.

- What do the downward black lines starting at a red star represent?
- What do the upward black lines ending in the red stars represent?
- In which cycles was more ice formed during the cold season than melted during the warm season?
- In which cycles was more ice melted during the warm season than formed during the cold season?
- The blue curve fits the overall trend of these data. Was the slope of the trend getting steeper? About the same? Getting less steep?
  What does that imply about the rate of melting during this time period?
  Melting faster and faster? Melting about the same? Melting slower and slower?

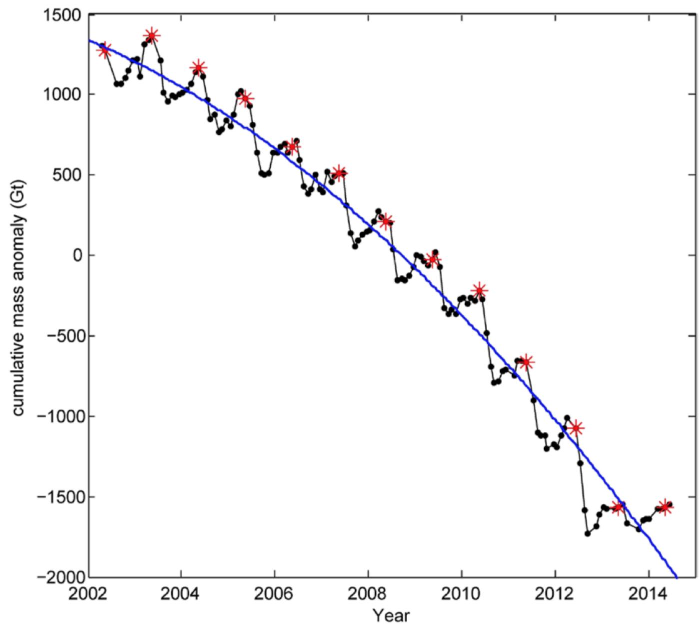


FIG. 4.50 Graph representing the forming and melting of ice on Greenland, 2002 to 2014. Khan et al., "Greenland Ice sheet balance: a review.," Reports on Progress in Physics 78(4), 046801 (2015)

Note that the vertical axis of Fig. 4.50 represents the *cumulative mass anomaly* in gigatons of ice. An *anomaly* is a difference with respect to a reference, often an average value over an extended time period. This graph represents the difference between the total mass of ice on a particular date and a reference total mass represented by the 0 on the vertical axis.

By looking at the graph, for example, one can estimate that the mass of ice in June 2002 was about 1300 gigatons more than the reference mass whereas the mass of ice in June 2013 was about 1500 gigatons less than the reference mass of ice. Between 2002 and 2013, about 2800 gigatons of ice on Greenland melted. The absolute mass of ice in gigatons that is the reference is not provided here.

For a discussion of why changing amounts often are analyzed via anomalies rather than changes in absolute amounts, see https://www.ncdc.noaa.gov/monitoring-references/dyk/anomalies-vs-temperature. Note also that something interesting happened during the ice melts for 2012 and 2014, which raises the interesting issue of what might happen next!

Analysis of ice melting in Greenland is one case. What is happening to glaciers world wide? As shown in Fig. 4.51, the World Glacier Monitoring Service (WGMS) produced similarly shaped graphs representing cumulative mass change for glaciers based on measurements from 1950 to 2018, compared to their masses in 1976 (https://wgms.ch/global-glacier-state/).

Interpret Fig. 4.51:

- What does the horizontal axis represent?
- What does the vertical axis represent?
- What do the lines represent?
- What does the shape of the lines imply about world-wide changes in the mass of glaciers?

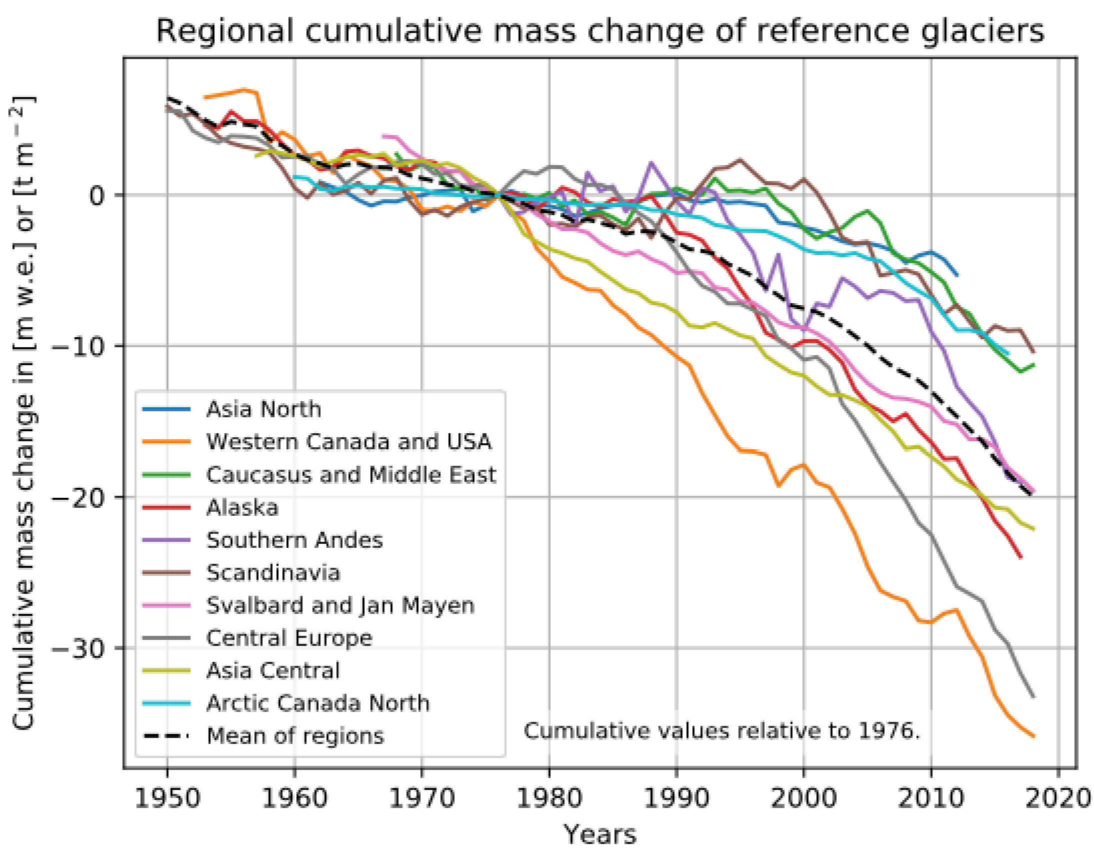


FIG. 4.51 Cumulative mass change of reference glaciers world wide, 1950 to 2018 .World Glacier Monitoring Service (https://wgms.ch/global-glacier-state/)[Reference: WGMS (2017, updated, and earlier reports): Global Glacier Change Bulletin No. 2 (2014-2015). Zemp, M., Nussbaumer, S. U., Gärtner-Roer, I., Huber, J., Machguth, H., Paul, F., and Hoelzle, M. (eds.), ICSU(WDS)/IUGG(IACS)/UNEP/UNESCO/WMO, World Glacier Monitoring Service, Zurich, Switzerland, 244 pp., based on database version: doi:10.5904/wgms-fog-2018-11}\]

The colored line graphs represent data from reference glaciers in ten regions world wide. The dashed black line represents the average cumulative mass change for all ten regions. During 2015-2016, the World Glacier Monitoring Service collected data from more than 130 glaciers around the world (http://wgms.ch/latest-glacier-mass-balance-data/). Of these, 40 were "reference" glaciers for which they had continuous data for more than 30 years.

The difference between the mass of ice gained during the cold season and the mass of ice that melted during the warm season is the annual net mass balance. The plots are cumulative, increasing or decreasing the reference total by how much mass of ice has been added or lost each year since 1950.

• In which parts of the world are the glaciers melting the fastest? The slowest?

Question 4.16 How can familiarity with motion graphs guide making projections for the way glaciers likely will be melting over the next decade(s)?

- Figures 4.50 and 4.51 present data about the amount of glacial ice melt over more than a decade. What do you think will happen in the next decade(s)?
- Compare the position versus time graph for a tossed ball in Fig. 4.44 and the graph representing the mass of forming and melting ice on Greenland in Fig. 4.50.
- Draw the axes for a mass versus time graph as shown in Fig. 4.52. Draw a line on the mass of ice versus time graph to show what has been happening and your projection of what is likely to happen in the next decade(s) based on this analogy with the position versus time graph for a falling ball.
- Below your mass of ice versus time graph, draw the axes for a velocity of melting versus time graph as shown in Fig. 4.52.
- Draw a line on the velocity of melting graph that is analogous to the shape of the graph of velocity versus time graph for a falling ball to make a projection for how the velocity of melting will change in the next decade(s).
- Below your velocity of melting versus time graph, draw the axes for an acceleration of melting versus time graph as shown in Fig. 4.52.
- Draw a line on the acceleration of melting graph that is analogous to the acceleration versus time graph for a falling ball to make a projection for how the acceleration of

melting will change in the next decade(s). Assume that melting ice is a natural process like that of the gravitational pull by the earth on a falling object. It may be or it may not be; the acceleration of the rate of melting ice may decrease OR increase if the people who on live on this Earth do or do not change their ways.

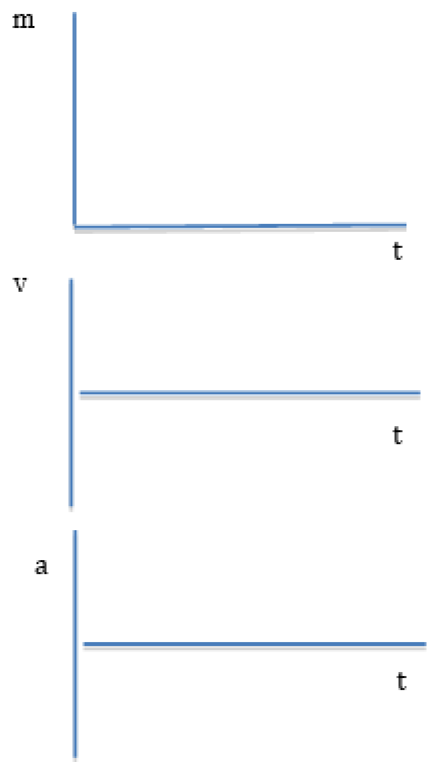
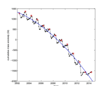


FIG. 4.52 Projection for graphs representing how glaciers worldwide may be melting during the next decade.

- Use Table IV.4a to summarize the analogy between moving and melting phenomena: Draw each graph observed for a tossed ball as well as each graph projected for the melting ice in Greenland.
- What does the height represent for each graph? The slope?

TABLE IV.4a Summary of analogy between moving and melting phenomena

TABLE IV.4a Summary of analogy between moving and melting phenomena					
Falling Ball Observations			Melting Ice Observation and Projections		
Graph	Height	Slope	Graph	Height	Slope
Position vs time			Mass of ice vs time* 		
Velocity vs time			Velocity of melting vs time		
Acceleration vs time			Acceleration of melting vs time		

• Khan et al., “Greenland Ice sheet balance: a review.,” *Reports on Progress in Physics* 78(4), 046801 (2015).
* See also: http://wgms.ch/latest-glacier-mass-balance-data/

1. Example of student work making an analogy between moving and melting phenomena

Developing and using mathematical model of changing phenomena. *By watching the trailer and the TED talk we are able to learn about the changes that are happening in Greenland. The glaciers are melting and falling off into the ocean, through the trailer you could see actual images of this happening and it was unlike anything I had ever seen before. These live images really put climate change into perspective for me and make me realize how quickly it is changing.*

A position versus time graph represents where a tossed ball is during a time interval.

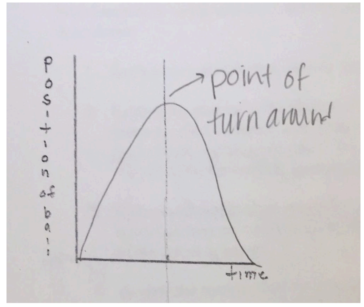


FIG. 4.53 Student graph of observed position versus time for tossed ball.

The shape of this graph is a parabola, which looks like an upside down U. The position of the ball after it leaves the person's hand goes up so the line on the graph has an upward slope and at the point of turnaround it comes back down to the person's hand and the graph goes into a downward motion.

A velocity versus time graph represents how quickly the position of a tossed ball is changing during a time interval.

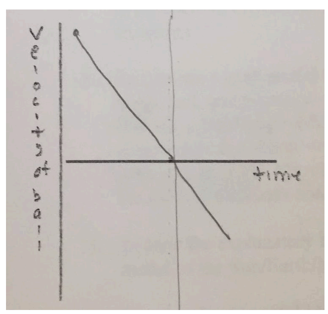


FIG. 4.54 Student graph of observed velocity versus time for tossed ball.

Velocity is how quickly the position the ball is in is changing. Velocity started at a high point but as the ball is being thrown in an upward direction, the velocity is decreasing. When the ball hits the point of turnaround the velocity is zero. When the *ball starts going in a downward direction the velocity is increasing in the negative direction.*

An acceleration versus time graph represents how quickly the velocity of a tossed ball is changing during a time interval.

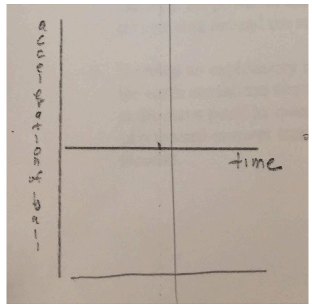


FIG. 4.55 Student graph of observed acceleration versus time for tossed ball.

The force of Earth is always pulling the ball down, which is why the line is in the negative position on the graph. It doesn't change because Earth is always pulling down on the ball during any point of the ball's flight. The "loggerlite" program represents this constant downward pull by having the line be in the negative position.

A mass of ice versus time graph represents how much mass of ice there is during a time interval.

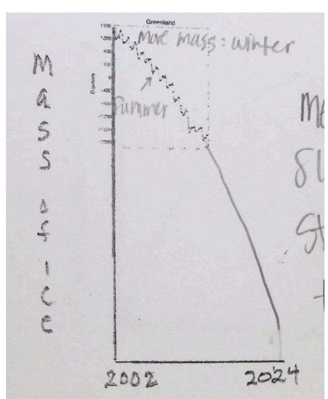


FIG. 4.56 Student drawing of projected mass of ice versus time graph for melting glacier.

This graph starts half way because this is when they just started taking data from 2002-2014. The slope is increasing. The height of the peak is the winter months because once it is frozen again the mass increases. The low point represents more of the ice melt because there is less ice during the warm summer months. Based on the data that has been collected, showing that there is increasingly more ice melting I can predict that by 2024 the graph will continue in the downward slope as I have shown above…

A velocity of ice melting versus time graph represents how quickly the mass of ice is changing during a time interval.

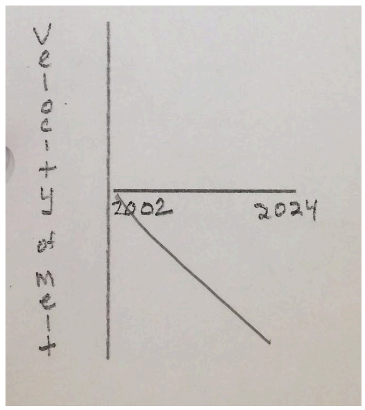


FIG. 4.57 *Student drawing of projected velocity of melting ice versus time graph for melting glaciers.*

The slope (on the mass vs time graph) is increasing when you compare the years 2002-2004 and 2012-2014. The magnitude of the velocity (of ice melting) in this case is increasing, which in return means that the mass is decreasing. This graph shows that every year there is becoming less mass of ice.

Acceleration of the melting ice melting versus time graph represents how quickly the velocity of ice melting is changing during a time interval.

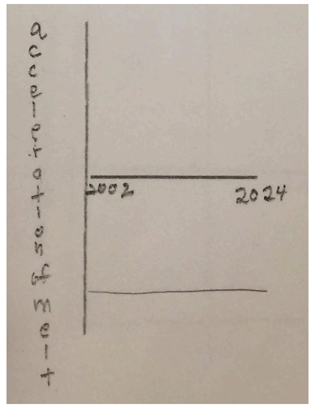


FIG. 4.58 Student drawing of projected acceleration of melting ice versus time graph for melting glaciers.

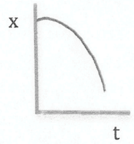
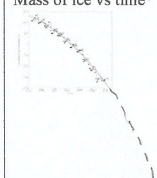
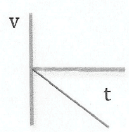
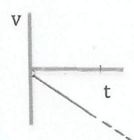
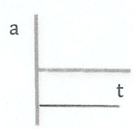
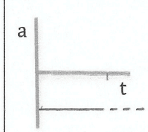
> *The shape of this graph is a straight line in the negative region of the graph. The acceleration is constant, the line does not have any changes to it. Something is causing the ice to melt but in this case we can change it, unlike the force of gravity pulling down the ball.*
>
> ***Making an analogy to a known process can help one predict a similar process in a different context.*** *Using the information we have gathered from these graphs, we can predict other trends as well. In the business world predicting graphs is used all the time to predict the success of businesses or stocks.*
>
> Physics student, Spring 2017

2. *Summary of the analogy between moving and melting phenomena*

Table IV.4b provides a summary of the analogy between moving and melting phenomena. The position versus time, velocity versus time, and acceleration versus time graphs on the left represent the motion of a ball tossed vertically in the air from the instant that the ball starts falling back down until the instant that it is caught before hitting the ground. The heights and slopes of these graphs provide information about this motion as described in the left columns. The ball speeds up as it falls, accelerating at a constant rate because the Earth is pulling on the ball in the same way throughout the toss.

The mass of ice versus time graph on the right represents the observed decrease in the mass of the Greenland ice sheet as observed from 2002 to 2014 (Khan et al., 2015). The dotted line represents a projection for how this ice sheet might continue melting in the future. The heights and slopes of the melting ice graphs provide projections for increasing rate and acceleration of this melting phenomena as described in the right columns. If the shape of the line representing the rate of ice melting is similar to the rate of the ball falling, the rate of ice melting will speed up, accelerating as time goes by. Although the acceleration of the ball is constant, due to the natural process of the Earth pulling on the ball in the same way throughout its fall, the acceleration of the loss of mass due to melting may be modified by human actions, to reduce (or increase) the amount of greenhouse gases in the atmosphere.

TABLE IV.4b Summary of analogy between moving and melting phenomena

Falling Ball Observations			Melting Ice Observation and Projections		
Graph	Height	Slope	Graph	Height	Slope
Position versus time 	**Position**, a number on a number line, where the ball is at a particular instant	**Velocity**, how much the position of the ball changes in one unit of time A number, what the velocity of the moving ball is at a particular instant	Mass of ice vs time* 	**Mass**, a number, how much ice there is at a particular instant	**Velocity of melting**, how much the mass of ice changes in one unit of time A number, what the velocity of melting is at a particular instant
Velocity versus time 	**Velocity**, how much the position of the moving ball changes in one unit of time, A number, what the velocity of the moving ball is at a particular instant	**Acceleration,** how much the velocity of the moving ball changes in one unit of time A number, what the acceleration of the moving ball is at a particular instant	Velocity of ice melting vs time 	**Velocity of melting,** how much the mass of melting ice changes in one unit of time A number, what the velocity of melting is at a particular instant	**Acceleration,** how much the velocity of melting changes in one unit of time A number, what the acceleration of melting is at a particular instant
Acceleration vs time 	**Acceleration**, how much velocity of the moving ball changes in one unit of time A number, what the acceleration of the moving ball is at a particular instant	**How much acceleration changes in one unit of time** (no special name) Is this a natural process with constant acceleration?	Acceleration of melting vs time 	**Acceleration,** how much the velocity of melting changes in one unit of time A number, what the acceleration of melting is at a particular instant	**How much acceleration of melting changes in one unit of time** (no special name) Is this a natural process with constant acceleration? Or can it be modified by human action?

• Khan et al., "Greenland Ice sheet balance: a review.," *Reports on Progress in Physics 78*(4), 046801 (2015).
* See also: http://wgms.ch/latest-glacier-mass-balance-data/

The purpose of this section has been to illustrate the power of mathematics. One can use mathematics to represent something one understands, such as motion phenomena, and then by analogy make projections for interesting phenomena that seem to be behaving in a similar way.

The above projections were for increasing loss of ice in Greenland during the next decade. The graph in Fig. 4.50, however, showed an apparent "lull" in the accelerating loss of ice in Greenland when the mass of freezing of ice during the 2014 winter appeared to have matched the mass of melting ice during the summer of 2013. What has happened since then? See https://www.euronews.com/2019/08/06/before-and-after-pictures-show-greenland-s-rapid-ice-melt-from-space for a news cast during August 2019. See http://nsidc.org/greenland-today/ to find out what is happening "now" when you are reading about this topic.

3. Example of student work reflecting upon engaging a friend or family member in learning about global climate change's impact on melting glaciers.

> *For this activity, I had my friend watch Chasing Ice so that they could see the drastic effects that are happening to ice shelves. She first asked me where this was and I told her that it was in Greenland. She then made a statement and said, "so this doesn't really matter for us then since it is so far away?" I asked her if she really thinks that if the Earth is warming up so much that it is melting this ice, that it is not going to affect us and she said, "well when you put it that way I guess it will." She was very surprised that she didn't already know about this because it seems like an important thing. I told her it is important and many countries are taking steps to stop the effects of global warming because many scientists have said that it is because of human's effects on the Earth. She then asked what she could do and I took her to the website that talked about ways that she could reduce her carbon footprint. She liked the idea of biking places instead of driving. She told me that she couldn't believe how big her carbon footprint was.*
>
> *The NGSS standard that goes with this is engaging in argument from evidence and we did a little bit of this because at first, she didn't think that the melting of the ice would be affecting her and through my argument from evidence of warming, I was able to teach her that it wasn't true. I also used cause and effect because we could see the effect that our carbon footprint and global warming was causing these huge ice shelves to melt in Greenland.*
>
> Physics student, Spring 2017

VIII. Exploring Internet Resources about Taking Action to Address Climate Change Issues

Becoming aware of what seems to be happening world wide with respect to the impacts of global climate change can be quite sobering. It is helpful also to become aware of what individuals, communities, universities, states, the military, government agencies, and countries can do and are doing to address climate change issues.

Question 4.17 What are some ways to take action?

Explore Internet Resources about what ways to take action:

- What can **individuals** do to study global climate change and take action?
  - The Extreme Ice Survey organization, headed by James Balog, has suggestions for individuals interested in taking action: http://extremeicesurvey.org/take-action/
  - The California Air Resources Board has suggestions for taking action: https://www.arb.ca.gov/cc/public/public.htm
  - https://www.epa.gov/climatechange/what-you-can-do-about-climate-change (if you try this one, you will get a message that suggests "we want to help you find what you are looking for." This used to say "Thank you for your interest in this topic. We are currently updating our website to reflect EPA's priorities under the leadership of President Trump and Administrator Pruitt. If you're looking for an archived version of this page, you can find it on the January 19 snapshot." To view this page now go to https://19january2017snapshot.epa.gov/climatechange/what-you-can-do-about-climate-change_.html). For a comment on this situation see: https://www.theguardian.com/us-news/2018/nov/01/epa-website-climate-change-trump-administration

- What can **communities** do to study global climate change and take action?
    - U.S. agency: https://www.epa.gov/sites/production/files/2016-09/documents/community-based-adaptation_handout.pdf
    - Small town: https://www.npr.org/2018/06/11/616944110/more-rain-more-development-spell-disaster-for-some-u-s-cities

- What is a **university** doing to study climate change and take action?
    - OSU Oregon Sea Grant : OSU researchers to help coastal towns cope with natural hazard http://blogs.oregonstate.edu/breakingwaves/2018/08/16/osu-researchers-to-help-coastal-towns-cope-with-natural-hazards/
    - Oregon Climate Change Research Institute: http://occri.net/

- What is a **state** doing to study climate change and take action?
    - Explore the Oregon Department of Energy website about Climate Change in Oregon at http://www.oregon.gov/energy/energy-oregon/Pages/Climate-Change.aspx

- What is the **US military** doing to study global climate change and take action?
    - Go to https://www.cna.org/cna_files/pdf/MAB_5-8-14.pdf
      (You may have to cut and paste this URL into a browser to get it to work or put CNA Military Advisory Board *National Security and Accelerating Risks of Climate Change* in your browser.) Get an overview of this report by scrolling through the pages and reading highlighted sentences to see what is there. Note the military credentials of the authors on page iii and pages 30-35 as well as the experts they consulted on page vi. Select an aspect of the report that is of interest and report briefly on the information provided.

- What is the **US government** doing to study climate change and take action?
    - The US Global Change Research Program was established by Presidential Initiative in 1989 and mandated by Congress in the Global Change Research Act of 1990 to "assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."
      http://www.globalchange.gov

- See Third National Climate Assessment, http://nca2014.globalchange.gov/ the authoritative and comprehensive report on climate change and its impacts in the United States.
- Regional impacts are discussed separately; see impacts on the northwest, for example, at http://nca2014.globalchange.gov/highlights/regions/northwest

- How are **countries** collaborating to study climate change and take action?
  - Explore the website of the Intergovernmental Panel on Climate Change (IPCC) at http://www.ipcc.ch/
  - In particular, look at https://www.ipcc.ch/report/ar5/index.shtml (you may need to cut and paste URL into your browser) "The Fifth Assessment Report (AR5) provides a clear and up to date view of the current state of scientific knowledge relevant to climate change.
    Click on: **Climate Change 2013: The Physical Science Basis**
    Scroll down under Report by Chapters to and click on **13. Sea Level Change**
    Scroll to Table of Contents, (page 1138) to see what is there.
    Then explore a section or sections that seem of interest to you. For example, information about contributions to sea level rise can be found on page 1161 and a chart of projected sea level rises for various coastal cities can be found on page 1198.
  - Coordinating Lead Author of this chapter was Prof. Peter U. Clark, OSU College of Earth, Ocean and Atmospheric Sciences: http://ceoas.oregonstate.edu/profile/clark/
  - United Nations Framework Convention on Climate Change, 2015 in Paris. See: http://unfccc.int/meetings/paris_nov_2015/meeting/8926.php and the international agreement at http://unfccc.int/paris_agreement/items/9485.php.

Critical in these endeavors is the process of *engineering design* in which people, as individuals as well as participants in institutions, define problems and then develop and optimize solutions. (See Appendix I of the *Next Generation Science Standards* (NGSS Lead States, 2013) at https://www.nextgenscience.org/resources/ngss-appendices .) Such focused efforts are necessary both in developing improved ways of documenting what is happening as well as in designing better ways to reduce the causes and impact of increasing global temperatures. Also relevant is understanding the interdependence of science, engineering and technology as well as the influence of engineering, technology and science on society and the natural world. (See Appendix J).

1. Example of student work in reflecting upon exploring Internet resources in class and with a friend or family member

Exploring Internet resources about global climate change:

- *Individuals*: *http://extremeicesurvey.org/take-action/*

  This information was provided by the Extreme Ice Survey. I thought the information was interesting because it talked about having a voice and getting the word out about climate change. I found the facts he provided would be helpful in talking to someone who doesn't believe in climate change and may aid someone in that discussion. I also found the facts to be helpful in my learning about climate change because they were short, easy to read facts that made a big statement, for example: Worldwide, hundreds of thousands of people die each year from climate-related stressors. In a short amount of words they present a scary statistic that people shouldn't ignore.

- *Individuals*: *https://www.arb.ca.gov/cc/public/public.htm*

  The agency presenting this information is the California Air Resources Board. This website was very interesting because it suggested many ways as an individual you can help with climate change by doing things you wouldn't really think of as helping. One that was somewhat surprising to me was washing your clothes in cold water, which is something I usually do anyways to prevent my clothes from shrinking or stretching out. A point it talked about that I found interesting was that these small changes quickly become habit, even though at some point it seemed like it would too much work. The example it used for this was recycling products at your house. When I was younger, we usually threw cans away, and now we always put them in a separate garbage can for recycling and it's just habit. I think this helped my learning because it used very real life examples that are definitely *possible for almost everyone, so it was easy to understand how small changes by everyone can make a big difference.*

- Individuals: https://www.epa.gov/climatechange/what-you-can-do-about-climate-change (To view this go to https://19january2017snapshot.epa.gov/climatechange/what-you-can-do-about-climate-change_.html)

  This resource from the EPA, which offers tips on what you can change to improve your global impact, is really well organized and super easy to find good information from. In particular, you can choose to see what things you can do at home, at work, on the road, and at school to help climate change. Also, the options to which you can use to change are really simple and helpful options.

- Communities: https://www.epa.gov/sites/production/files/2016-09/documents/community-based-adaptation_handout.pdf

  I really liked how organized this document was, and how it showed images and had many highlighted and bullet pointed sections. They stated ways to have cleaner air in cities, which included reducing vehicle emissions by creating areas where people can work, live and play within a walkable area, and upgrading municipal fleets to reduce air pollutants. I really like their idea about making a living space where everything is in walking distance—it got me thinking of ways that entire communities could live in the future where work and home and greenspace were all condensed into a small area. This could solve a lot of problems and leave more space for trees and wildlife- trees are important for reducing carbon emissions as well.

- Oregon State University: http://seagrant.oregonstate.edu/key-issues/resilient-communities-and-economies/climate-change-adaptation

  The university helps support climate change research while also finding ways to use that research to help people find ways to live and work in their everyday lives. I think this is important to making a difference because not everyone will go out of their way to support the issue, but they will be more likely to do small things at home in their everyday lives if they know it will make a difference.

- The State of Oregon: http://www.oregon.gov/energy/energy-oregon/Pages/Climate-Change.aspx

  The state of Oregon partners with multiple agencies to track things like greenhouse gas emissions and how we can reduce them in order to reduce climate change. Oregon also promotes creating electricity with renewable energy instead of materials like coal, which was very interesting to me. By supporting research and trends, Oregon is active in trying to more efficiently create resources for the state in ways that do not harm our atmosphere.

- Military: https://www.cna.org/cna_files/pdf/MAB_5-8-14.pdf

  The military discusses climate change as it relates to foreign affairs. They want to work to end climate change as it is a threat to stability of other countries as an aggravated stressor, enabling violence and terrorist activity. Additionally, it is important that the military is protecting our national security rather than responding to human caused natural disasters.

- US Government: http://www.globalchange.gov

  This website includes multiple different kinds of resources and forms of information. I really liked that it included a tab about understanding climate change because I think understanding the issue is the first step in actually taking action. Overall, this website is very organized and leads me to believe that the US government is taking part in lessoning the effects of climate change not only on our country but on the world as well. This piece of information was specifically surprising to me: "U.S. average temperature has increased by 1.3°F to 1.9°F since 1895, and most of this increase has occurred since 1970. The most recent decade was the Nation's and the world's hottest ever recorded, and 2012 was the hottest year on record in the continental United States. Temperatures are projected to rise another 2°F to 4°F in most areas of the U.S. over the next few decades."

- Collaboration of Countries: http://www.ipcc.ch/

  "Each IPCC Member country has a Focal Point which has been identified by the relevant authorities in the country. IPCC Focal Points prepare and update the list of

national experts to help implement the IPCC work programme. The Focal Points also arrange for the provision of integrated comments on the accuracy and completeness of the scientific and/or technical content and the overall scientific and/or technical balance of drafts of reports." I found this piece of information from the website discussing how countries interact with one another. By giving leaders of each country a specific role, those tasks are more likely to be completed than if there was no communication or designated roles.

Physics students, Winter 2018

- ***Engaging friend(s) and/or family member(s) in learning about the science underlying claims about global climate change.***

I engaged my roommate in learning about the underlying claims of global climate change. I started by asking her what she knew about climate change in general. She admitted that she had heard a lot of kind of jokes about climate change and the occasional tweet here and there, but had never taken the time to actually look into the issue.

I explained to her a couple of the things we had learned in class so far such as greenhouse gas emissions, rising sea levels, and rising temperatures and why each of these are important. I then asked her about each one of the topics such as what do you think OSU, the state of Oregon, the US government, and the nation as a whole does to prevent climate change? We explored the sites I mentioned above together. She specifically thought the one focused on the efforts of the U.S. government was interesting because it gave her a lot of definitions, general information, news reports and many more resources, which provides multiple different perspectives. By reviewing this website she was also convinced that the issue is indeed important and is worth taking the time to research and do small things at home such as save energy and travel efficiently.

I liked discussing this because I felt like I was teaching someone about something that really does matter and is important. This makes me believe that putting the time and effort into science lessons can have not only a positive impact on the learner but on the world. I think this connects with the NGSS science and engineering practice constructing explanations and designing solutions because by doing research, we are able to understand and explain the phenomena to some extent and then come up with a solution based off of the knowledge previously *gained. This also correlates to the cross cutting concept of cause and effect because the way we live and use energy causes the greenhouse gasses that affect the atmosphere.*

Physics student, Winter 2018

IX. Making Connections to Educational Policies

Scientists all over the world have worked hard to understand the causes of changes in the world's climate that are now occurring more rapidly than in the past, the impacts of those changes, and ways to address those issues. They also have worked hard to communicate their findings and interpretations of these findings. Decisions by individuals as well as by policy makers will affect what happens in the years to come. We close this unit with attention to relevant NGSS disciplinary core ideas and understandings about the nature of science.

A. Learning more about disciplinary core ideas articulated in the US *Next Generation Science Standards*

The US *Next Generation Standards* includes *global climate change* as a disciplinary core idea that students should learn about by the end of middle school, that *human activities affect global warming. Decisions to reduce the impact of global warming depend on understanding climate science, engineering capabilities, and social dynamics.*

Question 4.18 What relevant US NGSS disciplinary core ideas have you used in considering the influence of light and thermal phenomena on global climate change?

The US *Next Generation Science Standards* (NGSS Lead States, 2013) suggests disciplinary core ideas for teaching science topics in grades K-2, 3-5, 6-8, and 9-12. These *learning progressions* suggest ways to build disciplinary knowledge throughout schooling. Table IV.5 presents the learning progressions articulated for teaching about disciplinary core ideas related to global climate change. Relevant disciplinary core ideas in physical science include electromagnetic radiation, conservation of energy and energy transfer. Disciplinary core ideas in earth and space sciences include weather and climate and global climate change. Bolded statements are addressed in this course.

- Discuss with your group members ways in which you have used some aspects of the disciplinary core ideas that are relevant to teaching about global climate change.
- Select one of these that has been the most interesting for you during this course and discuss how and what you have learned. Also include in your discussion at least one NGSS science and engineering practice and at least one crosscutting concept that you used while learning about this disciplinary core idea.

TABLE IV.5 Relevant NGSS disciplinary core ideas relevant to teaching about global climate chan

TABLE IV.5 Relevant NGSS disciplinary core ideas relevant to teaching about global climate change				
	K-2	**3-5**	**6-8**	**9-12**
PS4.B Electromagnetic radiation	**Objects can be seen only when light is available to illuminate them.**	**Objects can be seen when light reflected from their surface enters our eyes.**	**The construct of a wave is used to model how light interacts with objects.**	**Both an elec photon mod electromagn common app radiation.**
PS3.A Definitions of energy		Moving objects contain energy. The faster the object moves, the more energy it has. **Energy can be moved from place to place by** moving objects, or through sound, **light,** or electrical currents. **Energy can be converted from one form to another form.**	Kinetic energy can be distinguished from the various forms of potential energy. **Energy changes to and from each type can be tracked through physical** or chemical **interactions**. **The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter.**	**The total en** Energy trans be described associated w particles (ob Systems mov
PS3.B Conservation of energy and energy transfer	**Sunlight warms Earth's surface.**			
Learning Progressions for Earth and Space Science				
ESS2.D Weather and climate	**Weather is the combination of sunlight, wind, snow or rain, and temperature in a particular region and time. People record weather patterns over time.**	**Climate describes patterns of typical weather conditions over different scales and variations. Historical weather patterns can be analyzed**.	**Complex interactions determine local weather patterns and influence climate**, including the role of the ocean.	**The role of r interactions land are the system. Glob predict futu influenced l factors**.

ESS3.D Global climate change	See PS3.B: **Sunlight warms Earth's surface**	See PS3.B: **Energy can be moved from place to place by … light… Energy can be converted from one form to another form.**	**Human activities affect global warming. Decisions to reduce the impact of global warming depend on understanding climate science, engineering capabilities, and social dynamics.**	**Global clima continue to about the gl continually**
• Bolded statements are addressed in this course.				

B. Reflecting upon this exploration of the science underlying claims of global climate change

Scientists base claims about global climate change on evidence. They report their studies in peer-reviewed articles that describe in detail the questions they are asking, why these questions are of interest, what already is known about these issues, how they design their investigations, the results they obtain, and the implications of those findings. Since 1988, the Intergovernmental Panel on Climate Change (IPCC) has provided a way for scientists all over the world to collaborate in assembling and assessing such evidence in order to provide the public and policy makers with the best information possible on which to base decisions. This unit began by developing understandings about infrared radiation and its role in the greenhouse effect, which is an explanation for the natural phenomenon of a warm atmosphere surrounding the surface of the Earth. Students also examined evidence for the recent increase in the global average temperature of that atmosphere, the impact of that increase in temperature on rising sea levels, and ways that individuals, communities, states, nations, and international organizations are taking action to address global climate change issues.

C. Making connections to NGSS understandings about the nature of science

The *Next Generation Science Standards* articulates eight understandings that students should learn about the nature of science (*Next Generation Science Standards* Lead States, 2013, Appendix H) (https://www.nextgenscience.org/resources/ngss-appendices.) :

Scientific investigations use a variety of methods. As discussed in section IV.B, for example, studies of glaciers have ranged from 'on the ground' vivid video recordings of glacial calving events in Greenland such as the *Chasing Ice* documentary to complex analyses of data from satellites monitoring the acceleration of Antarctica's glaciers flowing toward the ocean.

Scientific knowledge is based on empirical evidence. As discussed in section V.A.3, for example, scientists collaborating through the Intergovernmental Panel on Climate Change have provided policy makers with a series of graphs showing the increase in mean global temperature, increase in sea levels, increase in concentrations of greenhouse gases in the atmosphere, and increase in emissions of carbon dioxide from human activities from 1850 to recent times.

Scientific knowledge is open to revision in light of new evidence. As discussed in sections III.A, 2 and 3, development of knowledge about light from the Sun is a good example of this aspect of the nature of science. Such knowledge was limited to light that human eyes can detect until William Herschel explored the heating effects of different colors of the spectrum produced by shining sunlight through a prism. In 1800, he reported that a thermometer placed outside the red end of the spectrum also warmed and attributed this to "*invisible rays from the sun*" that were "*invested with a high power of heating bodies, but with none of illuminating objects.*" Scientists have now observed that energy coming to Earth from the Sun in this form of infrared radiation is almost as much as the energy in light visible to human eyes. In 1801, Wilhem Ritter discovered ultraviolet radiation from the Sun, invisible radiation beyond the violet part of the spectrum. Over the next 100 years, scientists from many different countries contributed to new knowledge about these invisible forms of light. The spectrum now ranges from very large radio waves to tiny gamma rays with "visible light that human eyes can see" being only a very small region of the entire electromagnetic spectrum.

Science models, laws, mechanisms and theories explain natural phenomena. As discussed in section IV.B, for example, the natural greenhouse effect is an explanatory model of what happens when light from the Sun shines on the Earth. As shown in Fig. 4.15, some of the light from the Sun is immediately reflected back to space; some is absorbed and warms the surface of the Earth; some gets emitted back out into the atmosphere as infrared radiation and travels on out to space; some, however, is absorbed by greenhouse gases instead and then re-emitted, with some of that infrared radiation traveling back toward the surface of the Earth. If more energy from the Sun enters than leaves the Earth, the global mean temperature will continue to increase.

Science is a way of knowing. As discussed in section V.A.3, the reports produced by the many scientists participating in the Intergovernmental Panel on Climate Change (IPCC) are examples that *science knowledge is cumulative and many people from many generations and nations have contributed to science knowledge.* As noted above, *the IPCC Fifth Assessment's section on The Physical Science Basis* included 1409 pages prepared by Working Group 1 (*https://www.ipcc.ch/report/ar5/wg1/*).This group included a team of 209 coordinating-lead authors and lead authors, 50 review editors, and more than 600 contributing authors from all over the world. Their work was reviewed by 1089 expert reviewers and 38 governments. The result was a detailed presentation of the consensus about evidence that underlies claims made about climate change by scientists from around the world.

Scientific knowledge assumes an order and consistency in natural systems. In particular, by the end of middle school, students should understand that *science assumes that objects and events in natural systems occur in coherent patterns that are understandable through measurement and observation.* As shown in Fig. 4.20, for example, observation of local mean temperatures all over the world have been combined to show global patterns in the changes in temperature from 1880 to the present, with the past five years being the warmest of the last 140 years. As shown in Fig. 4.51, for example, the World Glacier Monitoring Service is comparing the cumulative mass of ice change in glaciers all over the world based on measurements from 1950 to the present in an effort to identify patterns in what is happening to melting glaciers as the mean global temperature rises.

Science is a human endeavor. The Intergovernmental Panel on Climate Change is an example of the way that scientists all over the world are collaborating with one another to collect and analyze data that provide evidence on which to base understandings about what is happening to the Earth's climate. The IPCC reports demonstrate that *men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers* as well as that *scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination and creativity.*

Science addresses questions about the natural and material world. By the end of middle school, students should understand that *science limits its explanations to systems that lend themselves to observation and empirical evidence.* As implied in section VIII, other aspects of human endeavor also are necessary for individuals, communities, states, nations, and international organizations to take action to address the climate change already underway and predicted for the future. Examples include individuals committing to live more sustainably based on analyzing their own carbon footprints, military experts publicly advocating for ways to prepare for a crisis denied by many, and government officials undertaking unpopular measures to reduce emissions. Such actions embodying the human qualities of commitment and courage as well as curiosity can inspire hope for the future of our planet.

X. Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 4

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 4			
When used	For instructor and demonstrations	For each group of 3	For each student
Unit 4 **Question 4.1 Diagnostic Questions about climate change**			U4H2 Diagnostic question about climate change
Question 4.4. Exploring "seeing" with infrared radiation		Thermal camera or simulation of one via computer such as Mac Photo Booth: Thermal	For each **pair** of students: Slinky to model wave motion (reviewing Unit 3)
Question 4.7 Modeling the greenhouse effect:	2 plastic bins (shoe size) 2 rulers, 2 lamps, 2 moist towels, 2 thermometers (regular, liquid or digital probes), plastic wrap (to cover 1 bin)	If feasible, provide demo equipment for each group instead of doing a demo	
Question 4.11 Modeling effect on rising sea levels of melting ice on land vs in water		2 trays or one large tray like a cookie sheet, 2 frozen dinner trays, 1 flat rock, (If feasiable, blue) ice cubes to put on rock in 1 dinner tray, (If feasible, blue) water to fill trays to the brim, Paper towels if needed	
Question 4.14 Modeling changing processes: falling ball and melting glaciers		Motion detector connected to laptop (for example, https://www.vernier.com/products/sensors/motion-detectors/go-mot/ ($119) Basketball	U4H10 Graph Analogy:Tossed Ball U4H12a Table IV.4a Analogy between Moving and Melting Phenomena Blank U4H12b Table IV.4b with Axes U4H12c Table IV.4b Analogy between Moving and Melting Phenomena Completed

UNIT 5: EXPLORING THE NATURE OF ASTRONOMICAL PHENOMENA IN THE CONTEXT OF THE SUN/EARTH/MOON SYSTEM

Exploring the Nature of Astronomical Phenomena in the Context of the Sun/Earth/Moon System
[latexpage]

Table of Contents

Figures

Tables

I. Introduction

The theme for this course is *what happens when light from the Sun shines on the Earth?* Although labeled the fifth unit, these explorations extend throughout the course rather than occurring only near the end. While exploring these phenomena, you will be:

- ***identifying resources*** such as what you already may have seen in the sky, heard in songs, and studied in school
- ***developing central ideas based on evidence*** that you record in systematic observations of the sky
- ***explaining intriguing phenomena*** such as why the moon seems to change shape and size
- ***developing mathematical representations*** of the arrangement of the Sun/Earth/Moon system
- ***using mathematical representations to estimate a quantity of interest*** such as how soon Earth will be where you are seeing the third quarter Moon 'is' right now in space and
- ***making connections to educational policy***, such as the *Next Generation Science Standards* (NGSS Lead States, 2013), the science standards adopted by many US departments of education.

While learning about the Sun and the Moon, you also will be learning about learning processes as you summarize and reflect upon your explorations. Discussions in class and assignments at home will include integrating science and literacy learning, such as speaking clearly, listening closely, writing coherently, reading with comprehension, and creating and critiquing media.

The main sections present questions with suggestions for exploring topics and for writing reflections about your findings. Text in gray font indicates that these are suggestions; you may think of other ways to explore the topic. Asking your own questions as well as those posed here will enhance learning both about physics and about learning. Check with your instructor if you choose to devise an alternative approach.

Keeping track of what one is doing and thinking is important. In this course, use a template for a physics notebook page on which to record your notes during class. The physics notebook page can help you remember your thoughts *before*, *during*, and *after* an exploration. An experienced elementary teacher, Adam Devittt, designed this notebook page to mirror the structure of *before*, *during*, and *after* reading strategies:

Before starting your exploration, think about and discuss with your group members what you know already about the topic, how you plan to conduct the exploration, and what you think you might find out.

During your exploration, record what is happening, what you are observing, and what you are thinking about what you are observing. Include sketches of equipment and observations. Note any words that are new and their definitions.

After your exploration, record any central ideas that have emerged from your observations and discussions. Also note the evidence on which you have based these ideas. State explicitly how the evidence is relevant and supports the claims you are making in stating the ideas. Also explain why this result is important. Then write a reflection about whatever you want to remember about this experience. In addition, briefly state what you are still wondering in this context.

After class, use your physics notebook pages and any handouts to write a summary of your exploration and findings. Writing such a summary after every class is a good way to prepare for the midterm and final examinations.

Next, to be sure you have understood the physics involved, read this text and some examples of student work. The student authors first wrote drafts, received feedback for ways to enhance content and clarity, and submitted these final versions. Also read about some nuances to be aware of in these contexts.

You may also find helpful students' reflections about teaching friends and/or family members about what they had just learned in class, historical information about ways knowledge about the topic developed, and some relevant aspects of the nature of science in the context of the topic explored. These sections of the text may broaden your understanding of science and of science learning and teaching.

II. Identifying Student Resources

You already know a lot about the Sun, Moon, and the stars from everyday experiences being outside and going to school. You also likely have absorbed information informally from songs, newspapers, books, and the Internet. These are resources on which to build a deeper understanding through systematic explorations in this class.

A. Documenting initial knowledge about the Sun, Moon, and stars

Question 5.1 What do you already know about the Sun, Moon, and stars?

Document your initial knowledge about the Sun, Moon, and stars by responding to the following *diagnostic questions.* Your responses will not be graded. You will answer the same questions again near the end of the unit, compare initial and current responses, and write a reflection about changes in your understandings and about the ways these occurred.

Name________________________________ Date____________

Diagnostic Questions about the Sun, Moon, and Stars

Why does it get dark at night?

Why is it cold in the winter and hot in the summer?

Why does the moon seem to have different shapes at different times?

What do you already know about the Sun?

What questions do you have about the Sun?

What do you already know about the Moon?

What questions do you have about the Moon?

What do you already know about the stars?

What questions do you have about the stars?

Diagnostic Questions: Science & Science Learning

How would you define a “scientific explanation”?

How would you define “inquiry approaches to learning and teaching”?

To what extent are you interested in learning science?

Not interested in learning science	1	2	3	4	5	Interested in learning science

Comment:

To what extent are you interested in teaching science?

Not interested in teaching science	1	2	3	4	5	Interested in teaching science

Comment:

B. Noticing the sky

The key to learning about the sky is to look up whenever outside! Frequently! You can draw on resources from your own experiences, from those interpreted in cultural stories, art, and poetry, and from observations you and companions make, even young children, when noticing and talking about the Moon.

Question 5.2 What do you remember about experiences when you have seen the Sun, Moon, and/or stars?

- Talk with your group members about some of your experiences in watching a sunrise or sunset, seeing the Moon, and/or noticing the stars.
- What did you learn from these experiences?
- How might you increase how often you notice the sky during this course?

Question 5.3 How have people noticed and represented the Sun, Moon, and stars in cultural stories, art, and poetry?

Story-tellers from many cultures as well as artists and poets have offered intriguing interpretations of what they were seeing.

1. The Sun, Moon, and stars as represented in cultural stories

People from many cultures around the world have told stories about the Sun, Moon, and stars (see: http://solar-center.stanford.edu/folklore/Solar-Folklore.pdf). They have observed and pondered changes in where the Sun seems to rise and set, how high the Sun seems to arc across the sky, and how long daylight or darkness lasts. They also have wondered why the Moon seems to change its shape as well as when and where one sees the Moon with respect to the Sun. Also puzzling has been why the stars seem to be arranged the way they are and how they seem to move. People all over the Earth have watched and wondered about such questions (https://www.lpi.usra.edu/planetary_news/wp-content/uploads/2014/05/Multicultural_Astronomy_2013_v7.1.pdf).

People also have "seen" a variety of creatures residing on the full Moon. These have included a human face, a man collecting firewood, a woman and child, a rabbit, a princess, a toad and a tree (see: https://www.theatlantic.com/science/archive/2018/07/the-man-in-the-moon-or-the-rabbit-or-toad-or-or-or/563450/).

In addition, people have envisioned many objects and creatures outlined by the stars (See: https://www.aavso.org/sites/default/files/education/vsa/Chapter3.pdf). Where we live in the northern hemisphere, for example, stars that seem to outline the shape of ladles, the *Big Dipper* and the *Little Dipper*, are often visible even in a city sky. As shown in Fig. 5.1, two stars forming part of the cup of the *Big Dipper* seem to point to a star at the end of the handle in the *Little Dipper*. This star, known as the *North Star*, does not seem to move whereas other stars seem to revolve around it during the night.

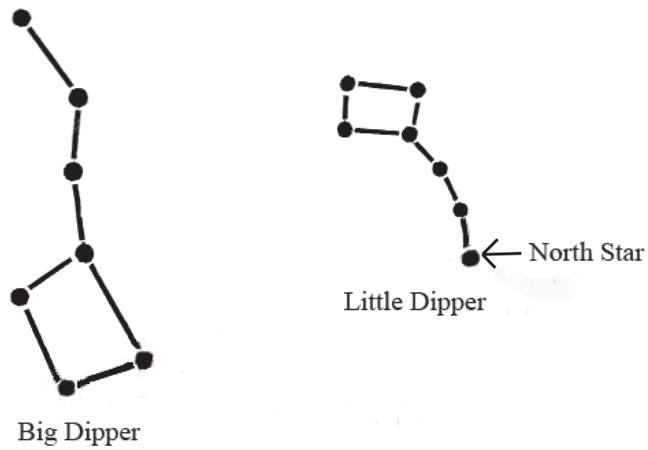


Fig. 5.1 Big Dipper, Little Dipper, and the North Star in the northern sky. Modified from https://commons.wikimedia.org/wiki/File:Constellation_(PSF).png Archives of Pearson Scott Foresman [CC 0]

The stars forming the dippers are contained within the constellations known as *Ursa Major* (*Great Bear*) and *Ursa Minor* (*Little Bear*) as shown in Fig. 5.2. *Ursa* is the Latin word for bear. People of many cultures have associated various animals with these visual patterns of stars and told stories about them (see: https://www.modernconstellations.com/classictau-vir.html#UMa). The *North Star* also is called *Polaris*, from the Latin *Stella Polaris* or *Pole Star* (https://www.lpi.usra.edu/education/skytellers/polaris/). As seen from Earth, this star lies almost directly above the Earth's north pole and appears to be motionless as the other stars seem to revolve around it during the night.

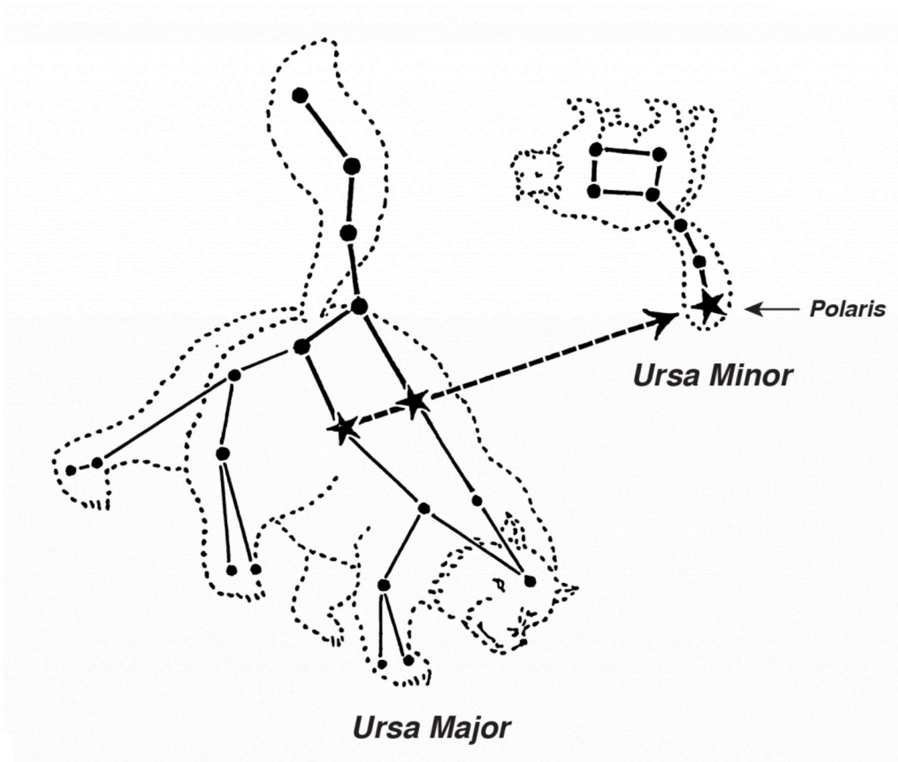


FIG. 5.2 Ursa Major (Great Bear) and Ursa Minor (Little Bear) constellations. Modified from https://commons.wikimedia.org/wiki/File:Dipper_constellations_(PSF).png Archives *of* [Pearson Scott Foresman](#) *[CC 0]*

These star patterns also appear in Native American constellations such as those shown in the Ojibwe Sky Star Map at https://web.stcloudstate.edu/aslee/OJIBWEMAP/home.html. The stars that look like the *Big Dipper* and *Little Dipper* in Fig. 5.1 and part of *Ursa Major* and *Ursa Minor* in Fig. 5.2 form part of the Ojibwe constellations *Ojiig, the Fisher*, and *Manng, the Loon* (See: https://web.stcloudstate.edu/aslee/OJIBWEMAP/OjibweConstellationGuide.pdf).
The big star in the tail of *Maang* represents *Giwedin'anung*, a star around which the other constellations appear to revolve. The Ojibwe constellations shown in the Ojibwe Sky Star Map are superimposed on constellations based on myths from ancient Greek and Roman times such as those shown in Fig. 5.3.

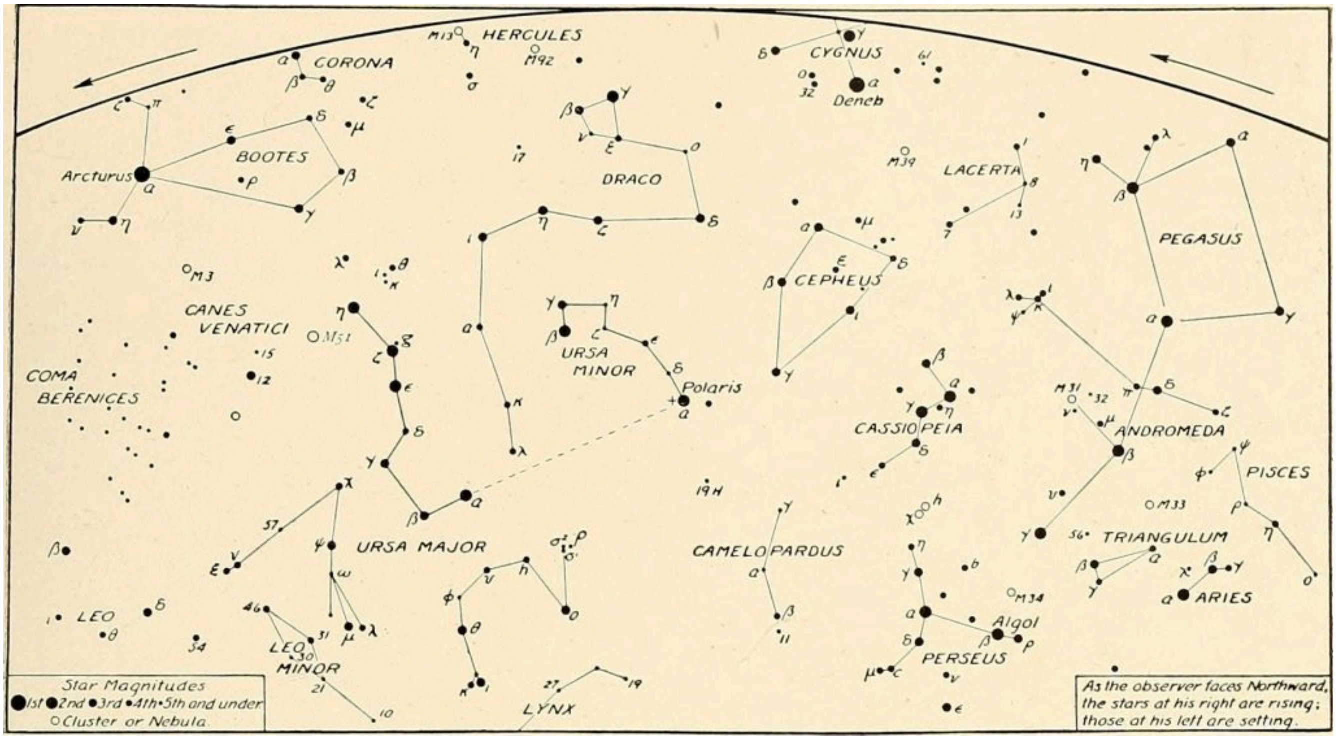


Fig. 5.3 Star chart with constellations based on Greek and Roman myths. Ursa Major and Ursa Minor are shown near the middle of this star chart. A dotted line from the pointer stars in Ursa Major points toward Polaris. From A Beginner's Star Book by Kelvin McKready (G. P. Putnam's Sons, New York, 1912, p. 68). www.flickr.com/photos/internetarchivebookimages/14775905211

If you live in the northern hemisphere, on a clear night see if you can find the Big Dipper, Little Dipper and the North Star. Can you also see Ursa Major, follow this Great Bear's pointer stars to Polaris, and recognize the Little Bear, Ursa Minor? If you can watch for several hours, you can see the other stars appear to revolve around a star that seems to be motionless as shown in Fig. 5.4.

FIG. 5.4 The stars appear to revolve around a star that seems to be motionless in the northern sky. Modified from photograph by Steve Ryan, Groveland, CA. *https://commons.wikimedia.org/wiki/ File:Steve_Ryan_-_Stars_around_Polaris_-_Day_62_(by-sa).jpg* [CC 2.0]

If you live in the southern hemisphere, there is no star in the sky that seems motionless during the night. You can infer where such a point would be, however, by using two bright stars to envision the location of the third apex of an equilateral triangle as shown in https://centralaustralianbushwalkers.files.wordpress.com/2014/12/skymap-south-by-stars-pdf.jpg. You can see the apparent motion of constellations around a point in the sky if you can watch over several hours. On a clear night, also see if you can find the Southern Cross, Centaurus the Centaur with Alpha Centauri, a star system just 4.37 light years away as well as Omega Centauri, a globular cluster, and other celestial sights. (See; https://www.skyandtelescope.com/observing/beginners-guide-to-the-southern-hemisphere-sky/).

2. *The Sun, Moon, and stars represented in art*

Many artists have noticed and portrayed the Sun, Moon, and stars. The Dutch artist

Vincent Van Gogh, for example, included them in many paintings such as *The Sower at Sunset* in 1888 and *The Starry Night* in 1889 as shown in Fig. 5.5 and Fig. 5.6.

Fig 5.5 The Sower by Vincent van Gogh, 1888. [Public domain] https://commons.wikimedia.org/wiki/File:The_Sower.jpg

Fig 5.6 The Starry Night by Vincent van Gogh, 1889. [Public domain] https://commons.wikimedia.org/wiki/File:Vincent_van_Gogh_Starry_Night.jpg

The dominant "star" to the lower right of the cypress tree in Fig. 5.6 has been identified as in an appropriate location to represent the planet Venus at the time the artist was making this painting.

3. The Sun, Moon, and stars represented in poetry

Many poems about the Sun, Moon, and stars reflect primarily upon the writer's emotions, situation, and surroundings. Several poets, however, have described physical aspects of ways that the Sun, Moon, and stars appear to move and/or look.

Robert Louis Stevenson, for example, described the Sun's apparent motion around the Earth as it seems to create on-going experiences of *morning after morning*. Children on one side of the Earth are getting up and playing while those on the other side of the Earth are going to bed.

The Sun Travels By Robert Louis Stevenson

The Sun is not a-bed, when I
At night upon my pillow lie;
Still round the earth his way he takes,
And morning after morning makes.
While here at home, in shining day,
We round the sunny garden play,
Each little Indian sleepy-head
Is being kissed and put to bed.
And when at eve I rise from tea,
Day dawns beyond the Atlantic Sea;
And all the children in the West
Are getting up and being dressed.

A *Child's Garden of Verses*, New York: Charles Scribner's Sons, 1905, p. 35.

http://www.gutenberg.org/files/25609/25609-h/25609-h.htm#THE_SUN_TRAVELS/

In a three-line poem, *Winter Moon*, Langston Hughes commented briefly upon the shape of a crescent moon (see: https://www.worldcat.org/title/dream-keeper-and-other-poems/oclc/36310693/viewport), in *The Dream Keepers and Other Poems* published by Alfred A. Knopf, Inc. in 1932, page 3). In the poem *Invention*, Billy Collins offered a whimsical description of the Moon's changing phases. (see:

https://www.theatlantic.com/past/docs/unbound/poetry/antholog/collins/invent.htm, published in the *Atlantic Monthly* in December, 1998, Volume 282, No. 6, page 92).

A poem by Jane Taylor, set to the French tune *Ah! vous dirai-je, maman*, has been sung as a lullaby for more than two centuries.

The Star

By Jane Taylor

Twinkle, twinkle little star,
How I wonder what you are!
Up above the world so high,
Like a diamond in the sky.
When this blazing sun is gone,
When he nothing shines upon,
Then you show your little light,
Twinkle, twinkle, through the night.
Then the traveler in the dark
Thanks you for your tiny spark;
He could not see where to go,
If you did not twinkle so.
In the dark blue sky you keep,
And often through my curtains peep,
For you never shut your eye,
Till the sun is in the sky.
As your bright and tiny spark,
Lights the traveler in the dark,
Though I know not what you are,
Twinkle, twinkle, little star.

Rhymes for the Nursery, London: Darton and Harvey, 1806

https://www.bl.uk/collection-items/first-publication-of-twinkle-twinkle-little-star/

This lullaby can be thought of as introducing nascent scientific processes: noticing a phenomenon of interest (twinkle, twinkle, little star), questioning (how I wonder what you are), observing (up above the world so high) and starting to think about what one is seeing by making an analogy (like a diamond in the sky). The poem also correlates occurrences (when this blazing sun is gone…then you show your little light…; for you never shut your eye, till the sun is in the sky), and ponders what is not yet understood (though I know not what you are) while celebrating again the phenomenon observed (twinkle, twinkle, little star).

Question 5.4 How early in life does a child start noticing the sky?

4. A young child's observations of the Moon in the sky: Joseph's Moon

Young children often notice what is happening in the sky, as described by a graduate student below:

> *Joseph is my nephew. At the time of this story, he was about 17 months old…My father often takes care of Joseph and I think I was talking about our moon assignments. My father said that he had recently taken Joseph to the nearby park one afternoon and that Joseph had pointed and said, "Moo." My father said he was looking for a cow (not a likely event for this suburban park!)…*
>
> *My father finally realized that Joseph was pointing at the sky and that yes indeed there was a moon in the daytime sky. (When referring to the moon at this time, Joseph would point and say, "Moo.") [Hey! Could this be a relationship between the moon and the cow who jumped over it??]*
>
> *At this point, my sister told a similar story. When Joseph pointed into the daytime sky and said, "Moo," my sister said something like, "There's no moon in the sky, it's daytime." Joseph was persistent though (not that he could necessarily understand his mother yet) and finally brought my sister to realize that there was a moon in the sky during daylight hours. [I'm not sure if Joseph is ready for Grad school yet, but I think that during the fall semester, he made more moon observations than some of the students in our class!]*
>
> *Some Reflections on the Moon [Isn't this what causes the phases?] and Joseph:*
>
> *I suppose what impresses me most is the awareness of a one-and-a-half-year-old child of the moon. At this point in time there seemed to be almost a fascination with the moon. We could say that this is due to it's being a brightly lit object in a dark sky, but the moon is much less obvious in the daytime sky. In fact, I often have to search for the moon in the daytime sky; it usually doesn't just jump out at you…*
>
> *So adults with all their "experience" may take things for granted; things that might not really be true. Joseph's mother and grandfather both, by their comments, indicate*

that they were operating under the rule "The moon only appears at night." Joseph seems to have straightened them out on this point.

I believe that it is a good exercise for students to go back to the basics of observation, to become like a child who has no preconceived rules as to how the world works. All too often in the lab we manage to get what we expect by writing off the "bad" points. In many cases in science history those "bad" points weren't so bad after all and led to advances in science.

Science education graduate student

Question 5.5 How do people talk together about the Moon?

People all over the world see and talk about the moon. For the word for *moon* in more than eighty languages see https://www.indifferentlanguages.com/words/moon . Watching the moon together can provide common ground for students from different cultures to enjoy talking with and learning from one another. For information about a global moon watching project, see http://www.worldmoonproject.org or contact Professor Walter Smith at walter.smith@ttu.edu.

5. Ways of speaking about the Moon in a first-grade bilingual classroom

A first-grade teacher, Deborah Roberts, described what happened when she engaged her students in watching the moon:

More than half of my class is enrolled in a bilingual program that is part of the English for Speakers of Other Languages (ESOL) program in our school; many students wrote their moon journals in Spanish. Parents helped with spelling, and some wrote what their child dictated. Parents felt successful in helping their children in their native language whether it was English or Spanish, and children felt successful in observing the moon. Spanish-speaking students felt confident when sharing their journal with the class. The English speakers were also learning some Spanish; everyone knew luna meant moon and noche meant night. So when someone shared their picture and their entry, anoche yo vi la luna así (last night I saw the moon like this), many non-Spanish speakers understood part of the entry before they saw the picture. Sometimes a Spanish-speaking child would teach the class how to say what he or she wrote.

Deborah Roberts. "The sky's the limit: Parents and first-grade students observe the sky." *Science and Children*, **31**(1), 33-37. (September, 1999).

Some schools choose a theme each year for which all classes in all grades contribute. Watching the moon sometimes has served this role as a context within which students of all ages can participate.

III. Developing Central Ideas Based on Evidence

Ongoing observations of the Sun and the Moon can provide evidence on which to base development of a set of central ideas about the Sun/Earth/Moon system. This process starts with looking up and making observations of the sky on a regular basis. Also important is recording those observations systematically in a sky journal.

A. Observing the shape and location of the Sun and the Moon in the sky

During this course, try to look up whenever you are outside and check out what is happening in the sky.

Question 5.6 Where is the Sun in the sky right now? How does the Sun seem to move across the sky?

- Make a *sky journal* in which to keep track of what you see.

Equipment: We use sky journals made by cutting four pieces of paper (8.5” x 11”) in half to make eight sheets (8.5” x 5.5”), folding those sheets together in half to make pages (4.25” x 5.5”) and stapling the folded pages along the edge.

- The best way to start observing the sky is to go outside and have a look!
  DO NOT LOOK DIRECTLY AT THE SUN! A direct stare at the Sun can damage eyes.
- What do you expect to see in the sky?
- Orient yourself with the *cardinal directions*: Where is North? East? South? West?
  - If not sure, where does the Sun seem to rise? That’s East.
  - Where does the Sun seem to be high in the sky in the middle of the day?

(Where we live, that's South.)

- Where does the Sun seem to set? That's West.
- What's left? (Where we live, that's North.)

You also can use a compass or think about how you get from where you are to somewhere else that is in a known direction. Where we live, for example, a freeway goes many miles directly north or directly south. One can think about North as being the direction one would drive on this freeway toward a major city north of us and about South as being the direction one would drive on this freeway toward a smaller city south of us.

- Face North. Point East
(Where we live, use your right arm, horizontal to the ground, to point East)
Point West
(Where we live, use your left arm, horizontal to the ground, to point West)

- Look up at the sky. What do you see?
(Where we live, maybe some clouds, airplanes, birds)
- Keep your arms pointing horizontally away from your body.
Turn around to face South.
  - Where is your right arm pointing horizontally now?
  (Where we live, right arm is now pointing West)
  - Where is your left arm pointing horizontally now?
  (Where we live, left arm is now pointing East)
  - Notice that these directions are the opposite used on many maps. On maps for which North points "UP", East is to the right, West to the left.

- While facing South, look up at the sky. What do you see?
(Where we live, maybe some clouds, airplanes, birds and during the day usually the Sun and sometimes the Moon!) DO NOT LOOK DIRECTLY AT THE SUN! This can damage eyes.

- WITHOUT LOOKING DIRECTLY AT THE SUN, where is the Sun?
  - Low, middle, high in the sky?

- North? Northeast? East? Southeast? South? Southwest? West? Northwest?

- To create a template for recording your observation:
  - Near the bottom of the page in your sky journal, draw a horizontal line.
  - Label the left end East, the middle South, and the right end West.
  - In the middle, draw a stick figure as shown in Fig. 5.7.

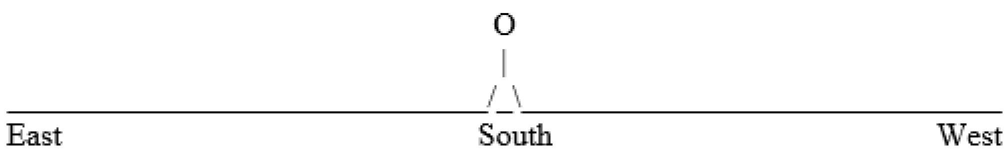


FIG. 5.7 Format for recording an observation of the sky.

(If you live in the Southern hemisphere, label the line (West North East)

- To record what you are seeing, WITHOUT LOOKING DIRECTLY AT THE SUN, point an arm at the Sun and try to estimate the angle your arm is making with the ground.

- Add an arm to your stick figure at an angle that matches the angle of the arm you pointed at the Sun. Also add a sketch of the Sun to your observation.
- Add another sketch of the Sun on your journal page to predict where the Sun will be in the sky at a later time such as an hour or more later in the day.
- Check at that later time that day and record again!
- How does the Sun seem to move across the sky?

Question 5.7 Where is the Moon in the sky right now? How does the Moon seem to move across the sky?

- Keep checking the sky for the Moon. When the Moon is visible, where in the sky is it?
  - Low, middle, high in the sky?

    - North? Northeast? East? Southeast? South? Southwest? West? Northwest?
- What does the Moon look like? Describe in words.
- If you are observing the Moon at night, draw a template for recording your observation in your sky journal as shown in Fig. 5.7. If you are observing the Moon during the day, also record where the Sun is in the sky as discussed above.
- To record where the Moon is in the sky, point an arm at the Moon and try to estimate the angle your arm is making with the ground.
- Add an arm to your stick figure at an angle that matches the angle of the arm you pointed at the Moon.

  If the Sun is also visible, add the stick-figure arm pointing at the Moon so that it connects to a stick-figure-arm pointing at the Sun. DO NOT LOOK DIRECTLY AT THE SUN! The angle formed by the stick-arm pointing at the Sun and the stick-arm pointing at the Moon should match the angle formed by your arms when pointing at the Sun and the Moon in the sky.

- What kind of angle do your arms make when pointing at the Moon and the Sun? (Acute, less than 90°? Right, 90°? Obtuse, more than 90° but less than 180°? Straight, 180°?)

  What kind of angle do the stick-figure arms make? The angle the stick-figure arms make should match the angle your arms make when pointing at the Moon and the Sun.

- Add a sketch of the Moon to where the stick-arm is pointing. Outline the shape of the lit side of the Moon that you see and let the white of the page inside the outline represent the lit portion of the Moon.
- Hold your sky journal up so that your drawing of the Moon seems to be next to the Moon in the sky. Compare your sketch of the Moon with the Moon in the sky:
    - Is the lit side of your Moon sketch the same as the lit side of the Moon in the sky?
    - Is the curve of the lit edge of your sketch of the Moon the same as the curve of the lit edge of the Moon in the sky?
    - Is the size of the lit portion of your sketch of the Moon the same as the size of the lit portion of the Moon in the sky?
    - Revise as necessary to make your sketch of the Moon more accurate.
- Record the date and time on the same page as your observation. Include a.m. or p.m.

- If both the Sun and Moon are visible, the two stick-figure-arms should make an angle that matches the angle your arms are making when pointing at the Sun and Moon. Do they? If not, revise the stick-figure arms to match the angle your arms are making.
- Sketch on your journal page where you predict the Moon will be in the sky at a later time. Do you think the Moon's shape will be the same or different then?
- Check your prediction at that later time. Record what you see.
- How does the Moon seem to move across the sky?

Complete your first observations of the Sun and the Moon before looking at an example of student work and reading about nuances to consider in observing the sky.

1. Example of a student's initial observation of the sky

Figure 5.8 shows a student's first observation, made in class during a morning field trip outside to look up at the sky. This sky journal observation includes:

Line across the bottom of the page that represents the horizon,
Label E for east on the left, S for south in the middle, and W for west on the right
Sketch of the Sun in the southeastern sky
Sketch of the Moon, shown as about half lit on the left, in the southwestern sky
Stick figure with one arm pointing at the Sun and the other arm pointing at the Moon
Angle formed by the arms labeled, as 90°
Time, hour : minute, with a.m. noted
Date, with month, day, and year included
Sketch of prediction for where the Sun would be later at the end of class, about noon
Sketch of prediction for where the Moon would be later at the end of class, about noon.

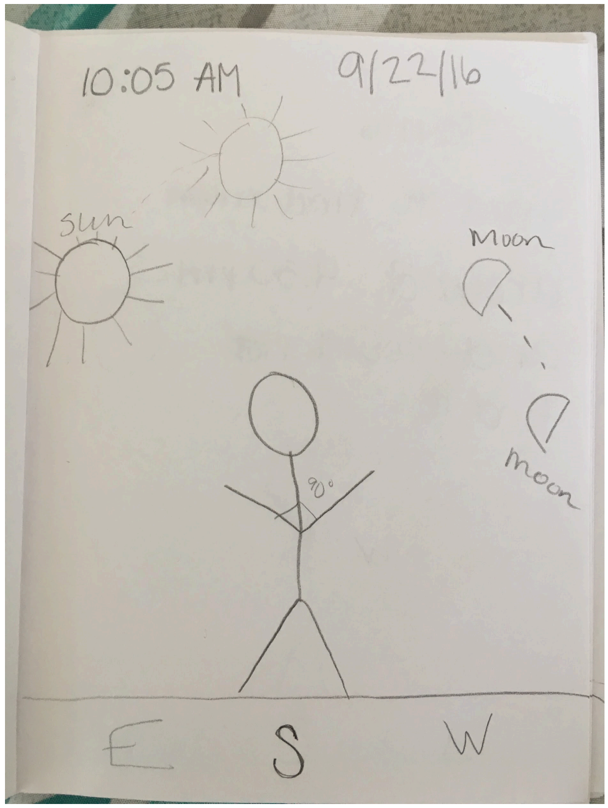


FIG. 5.8 Student's first observation of the sky with predictions for later in the day.

Physics student, Fall 2016

2. Nuances about observing the sky

Although the weather is often cloudy and rainy where we live, we have clear skies during class time occasionally in the term. When this occurs, we go outside, orient ourselves with respect to North, East, South, and West, and make the first sky observation together, at least of the Sun, and if we are fortunate, of the Moon as well. We think it is important to model going on short field trips outside the classroom as a normal part of learning experiences. Although it is best to do the first observation outside as a class, one can discuss inside how to use the sky journal if going outside is not feasible.

On the first sunny class day, we go outside to make an observation together while looking at the sky. We act out estimating the angle that an arm pointing at the Sun makes with the ground, <u>without looking directly at the Sun!</u> and discuss placing a sketch of the

Sun in the appropriate area of the page with respect to its location in the sky. The student who made the observation shown in Fig. 5.8 has not quite drawn the stick-figure-arm pointing directly at the drawn Sun but is close. The arm pointing at the Moon also is not shown pointing directly at the Moon. The student has labeled the angle formed by pointing arms at the Sun and the Moon as 90 degrees, a right angle, although the angle drawn is slightly bigger; if the arms had been drawn pointing directly at the Sun and the Moon, the angle would have been closer to 90 degrees. Although the sketch of the half-lit Moon looks a bit more than half lit, all the necessary information is there. Students' accuracy in making sketches usually improves considerably with practice.

We start right away having students use this somewhat complex format for recording observations in a systematic way. With a 15-week semester, one can afford to say simply 'look for the Moon and record what you see.' With this very general instruction, students likely will experience the bewilderment of not finding the Moon very easily for a month before starting a more systematic observation process. With only a 10-week quarter term, however, we have shifted to this more structured approach immediately. We also provide explicit suggestions for a good time to look at the sky so that the students can start assembling a series of observations of the Sun and the Moon within the first month of the term.

If poor weather interferes, we sometimes use a computer program to simulate what would be seen if we could see beyond clouds and/or rain. (see: http://stellarium.org for an open source version.) It is important for students to become aware of changes in the shape of the moon on at least a weekly basis.

B. Observing the Sun

This section introduces several methods for documenting the Sun's apparent motions and estimating its size.

Question 5.8 How does the Sun seem to move across the sky?

There are several ways to document how the Sun seems to move across the sky. As noted above, one can make multiple observations of the Sun's position in the sky during the same day on a sky journal page. Be sure, however, to <u>avoid looking directly at the Sun!</u>

If feasible, observing where the Sun seems to rise and set documents the beginning and end of the Sun's apparent daily journey across the sky. There also are several ways, based upon observing how the tip of the shadow of a vertical *gnomon* changes during the day. The gnomon, such as a person, post, vertical long leg of a paper clip or nail, should be perpendicular to flat ground in an area likely to be sunny during the middle of the day.

1. Observing where and when the Sun appears to rise and set.

To the extent possible, begin noticing where the Sun seems to be rising and setting where you live:

Equipment: Use a pencil and piece of paper on a clipboard or cardboard.

- Try to observe sunrise at least once a week. Face east and draw a profile of trees and buildings. For each observation at this location, indicate on the sunrise profile where and when the Sun seems to be rising along that profile.
- Also try to observe sunset at least once a week. Face west and draw a similar profile of trees and buildings. For each observation at this location, indicate on the sunset profile where and when the Sun seems to be setting along that profile. Record the date and time for each observation.
- How do rising and setting positions on the profile change over a week? Over several weeks? Months?
- How do the times of sunrise and sunset change over a week? Over several weeks? Months?

2. Observing a student gnomon's shadow during a field trip outside during a sunny class session

Go outside twice during a class session on a sunny day to document how the sun seems to move across the sky. If possible, include an observation at solar noon, when the Sun appears to be at its highest angular altitude in the sky. DO NOT LOOK AT THE SUN!

Equipment: Use chalk, meter stick, protractor, and a video camera to document a student's shadow and your group's thinking.

- Early in the session, choose one member of your group to stand so that the student's shadow falls upon the pavement. The student serves as the *gnomon* for this observation. A gnomon is a vertical object (stick, post, person) perpendicular to the ground whose shadow can be interpreted in terms of its length and the direction to which it is pointing. Other group members use chalk to draw the outline of this gnomon's shadow on the pavement.
- Draw an outline of the student's feet so that the student can stand in the same way in the same spot near the end of class as shown in Fig. 5.9.
- Measure the height H of the student gnomon and the length L of the shadow. Record the date and time of these measurements.
- How do you think the student's shadow will change by the end of class?
    - Shorter or longer or the same length?
    - Pointing further to the right? left? or in the same direction?
    - Why do you think that?
- Mark on the pavement where you think the tip of the person's shadow head will fall by the end of class.
- Why do you think the tip of the shadow will fall there by the end of class? Use the video function of a camera or cell phone to record a group member briefly explaining the reasoning for the group's prediction for where the tip of the shadow's head will be on the pavement by the end of class.

Fig. 5.9 Documenting changes in a group member's shadow on a sunny day near the beginning and end of class.

- When back inside the classroom, make a sketch showing the Sun, student gnomon, shadow, and sunlight.
- Also draw a careful ray diagram with straight lines representing the student gnomon, shadow, and ray of light from the Sun. Be sure to draw the lines representing the gnomon and shadow at right angles as shown in Fig. 5.10.
- What was the angular altitude of the Sun, Angle α (alpha), at the moment that you measured the height of the student gnomon and length of the shadow?

Use a protractor to measure the Sun's angular altitude, Angle α (alpha), on the ray diagram.

Calculate the tangent (H/L) of Angle α, then find Angle α in a trigonometry table or use a calculator that has trig functions such as arctan or $\tan^{-1}$ (the angle for which the tangent is the number calculated by dividing H by L). Compare this estimate for Angle α with the estimate made with the protractor on the ray diagram. Which is the better method for estimating Angle α? Why?

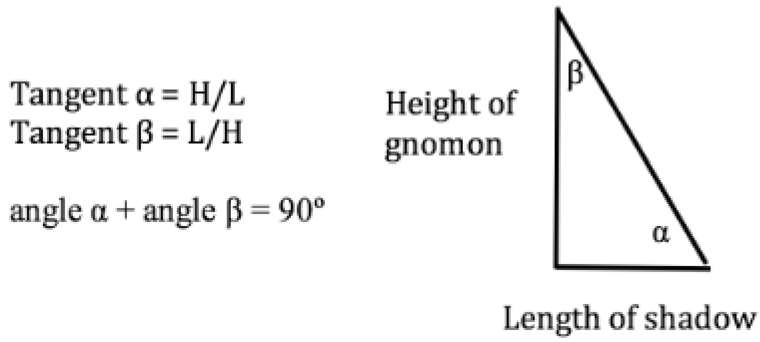


Fig. 5.10 Right triangle formed by gnomon, shadow, and ray of light from Sun.

- Near the end of class, go outside again to observe where the tip of the student gnomon's shadow head is now. Mark the tip of the shadow and measure the shadow's new length. Record the new shadow length and time.
- Make a sketch or take a photo of the gnomon and marked tips of the shadows of the gnomon's head.
- Interpret the change in position of the tip of the student's shadow head in terms of how the Sun appears to have moved across the sky during the time period between observations. DO NOT LOOK DIRECTLY AT THE SUN!
- During the next class session: how did the Sun's angular altitude, Angle α, change during these observations?
- What is the connection between how long the student's shadow is and how high the Sun seems to be in the sky?
- If it was possible to measure the length of the gnomon's shadow at solar noon, what was the Sun's maximum angular altitude, Angle α, on this date?
- Discuss as a whole group, each small group's observations and interpretations.
- Formulate a central idea that articulates findings from this exploration of how the Sun seems to move across the sky during the day.

3. Observing a post gnomon's shadow outside during a sunny day

Go on a field trip outside early in a class session on a sunny day to observe the tip of a shadow cast by a post. DO NOT LOOK DIRECTLY AT THE SUN!

Equipment: Another option is to use chalk to mark the tip of a shadow of a nearby vertical post on the pavement.

- Mark the tip regularly throughout the class session, perhaps every 15 minutes, and if feasible throughout the day.
- Interpret the change in position of the tip of the shadow in terms of how the Sun appears to have moved across the sky during the time period between observations. DO NOT LOOK DIRECTLY AT THE SUN!
- Discuss the observations and possible interpretations.
- Formulate a central idea that articulates findings from this exploration of how the Sun seems to move across the sky during the day.

4. Observing a paper clip or nail gnomon's shadow on a sunny day.

Another option is to make an apparatus for a portable shadow plot for each group as shown in Fig. 5.11.

Equipment: Tape the four edges of a piece of paper to the outside of a manila folder or cardboard. Bend a large paper clip so that a long leg is bent perpendicular to the rest of the clip. The long leg is the *gnomon*. Slip the paper clip on to the middle back edge of the manila folder or cardboard so that the bent long leg is vertical. Tape the clip in place.

Or pound a nail through a thick piece of cardboard or board so that it is perpendicular to the plane of the board.

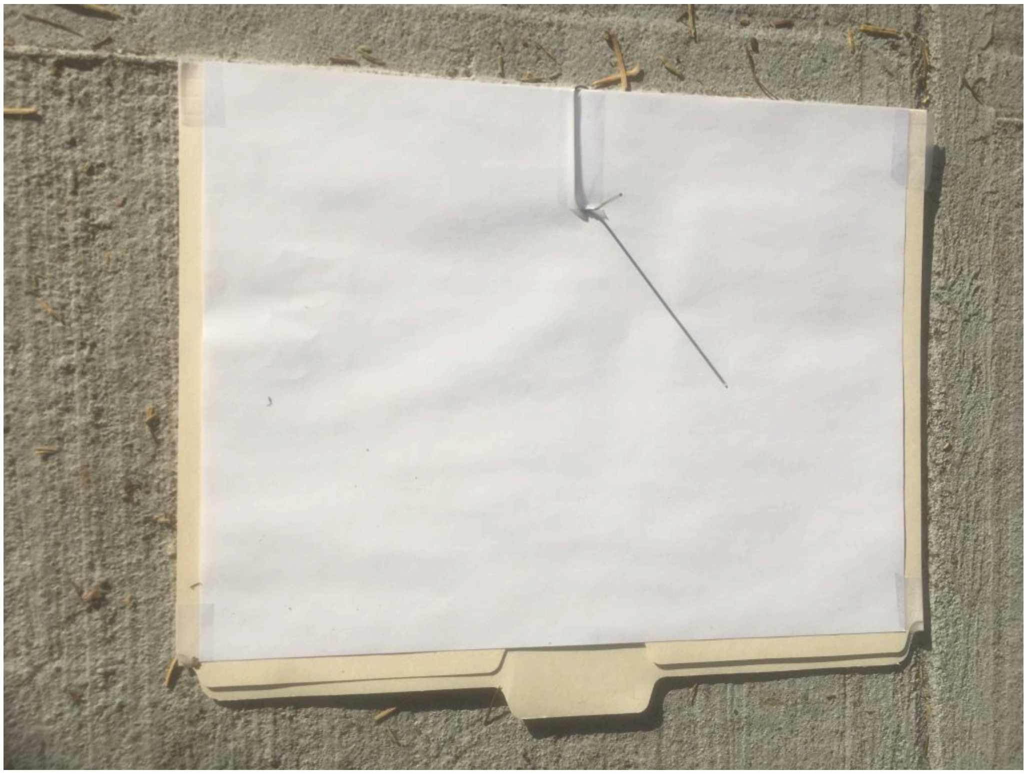


Fig. 5.11 Apparatus for documenting a paper clip's shadow during a sunny day.

- If feasible, instructor starts shadow plot observations for each group as early in a sunny day as feasible.
- On a fieldtrip outside, students gather around a suitable sidewalk crack or wall that forms an East/West line. DO NOT LOOK DIRECTLY AT THE SUN! The instructor demonstrates what to do:
    - Line up a shadow plot apparatus with the east/west crack in sidewalk or on the wall
    - Invite a student to mark the tip of the shadow of the gnomon and label it with the date and time
- Each small group:
    - A member from each group marks the tip of the gnomon's shadow on the group's shadow plot and labels with the time.
    - Other members of each group mark the tip of the gnomon's shadow on the group's shadow plot in given time intervals (such as 15 minutes) and just before all go back inside
    - Members of each group decide when each will briefly leave class and take their

portable gnomon outside to mark the tip of the shadow at given time intervals until the end of class.

- All go outside near the end of class to make last shadow plot observations.
- Interpret the change in position of the tip of the *gnomon*'s shadow in terms of how the Sun appears to have moved across the sky during the time period of observations.
- If feasible, instructor continues shadow plot observations for the groups' portable gnomons until the end of the day.
- During the next session, discuss as a whole group each small group's observations and interpretations.
- Formulate a central idea that articulates findings from this exploration of how the Sun seems to move across the sky during the day.
- If feasible, make shadow plots near the beginning and end of a course and consider differences in shadow plots made at different times, particularly if observations have been made near an equinox and near a solstice. Try to identify the moment of "shortest shadow," which is known as *solar noon* and to compare the Sun's maximum angular altitude, Angle α, at different times during the term.

5. Example of student work about how the Sun seems to move across the sky.

> ***Observing the Sun via shadows.*** *I recorded changes in the shadows cast by the Sun by recording a shadow plot with a paperclip as the gnomon and by recording a shadow plot with a person as the gnomon. Figure (5.12) shows the shadow plot with a paper clip gnomon. Figure (5.13) shows a group member's shadow near the beginning and end of class.*

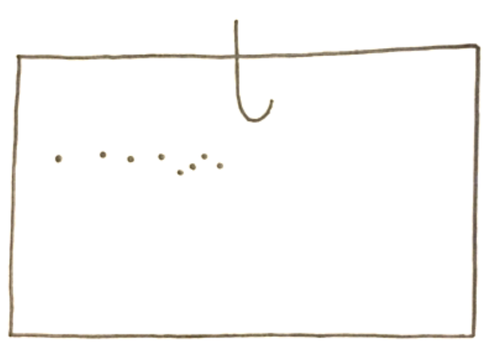


FIG. 5.12 *Student's sketch of shadow plot with a paper clip gnomon.*

For the shadow plot with the paper gnomon, as seen in Figure (5.12), we had a piece of white paper with a paper clip attached to it on the center of one of the long sides of the paper. We placed the piece of paper with the paperclip facing towards us on the sidewalk so that the corner of the paper was lined up to lines in the sidewalk. We then marked a dot where the shadow of the paperclip ended on the paper every 15 minutes, starting at the beginning of class and going until the end of class. I observed that the dots on the paper started on the left and moved closer to the center of the paper as time went on. I also observed that the dots began to get closer together as time went on.

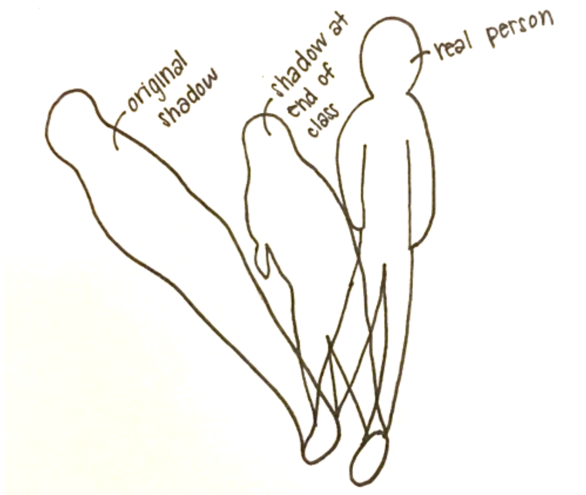


FIG. 5.13 Sketch of group member's shadow on pavement near beginning and end of class.

For the shadow plot with the person as the gnomon, as seen in Figure (5.13), I traced a group member's shadow at the beginning of class. Then at the end of class, my group member stood in the same exact spot and I observed where the new shadow was. I observed that the new shadow was shorter, less skinny, and was turned more to the right than the original shadow.

Physics student, Spring 2016

This class met in the morning, so the student's original shadow was drawn about 10 am. The class ended just before noon. Where we live, the Sun is in the southern sky at noon, so this student's long morning shadow became shorter in length and shifted in direction toward North. One way to find North if lost is to observe the shadow of a vertical stick during a sunny day and identify the direction the shortest shadow is pointing. (See: https://adventure.howstuffworks.com/survival/wilderness/true-north2.htm) .

- If feasible, compare shadow plots made near the equinoxes (March or September) with those made near the solstices (June or December).

Question 5.9 How big is the Sun?

If one glances at the sky when the Sun and Moon are both visible, an easy comparison to make is that the Sun and Moon appear to be about the same size. DO NOT LOOK DIRECTLY AT THE SUN!

To estimate the actual size of the Sun, however, we used pinhole phenomena in Unit 1, VI. If not undertaken in earlier class sessions, on a sunny day make the observations outlined for Question 1.16 to estimate the diameter of the Sun.

> To estimate the diameter of the Sun: As shown in Fig. 1.21 (repeated), this involves making a pinhole in a sheet of aluminum foil held tight in a cardboard frame; making a cardboard screen covered with a sheet of white paper, using a meter stick to separate the pinhole and the screen, tracing the projection of the sun through the pinhole on the screen, and measuring the diameter of the projection.

FIG. 1.21 Student drawing to illustrate using pinhole phenomena to estimate the diameter of the Sun (repeated from Unit 1).

Use the mathematics that describes pinhole phenomena to estimate the Sun's diameter:

$$\frac{W}{D} = \frac{w}{d}$$

$$\frac{\text{Width (diameter) of the sun}}{\text{Distance of the sun from the pinhole}} = \frac{\text{width (diameter) of the projection}}{\text{distance of projection from the pinhole}}$$

Solve for the width (diameter) of the Sun, measure the width (diameter) of the Sun's projection when one meter away from a pinhole, and assume the Sun is about 100,000,000 miles from the Earth. (Note that it is not necessary to convert meters to miles to calculate this estimate.)

C. Generating questions about the Moon and designing ways to explore these questions

Question 5.10 What questions about the Moon do you want to explore?

How will you do that?

After making a few observations of the Moon, generate some questions about the Moon that you might explore:

Equipment for each group: white board marker and eraser for each group member, large white board

- With your group members, generate some questions about the Moon that you could explore together during the next few days by looking at the Moon in the sky rather than by reading books or searching the Internet.
- Decide with your group members on the most interesting of these questions.
- Design your exploration. Who will do what? When? Where? How? Why?
- Record on a large white board your question and your design for exploring this question.
- Plan and briefly practice how each member of the group will participate in stating the question and describing your design for exploring this question.
- Share your question and your plans with the whole group.

- At the beginning of each class session, share with your group members the observations you have made and enjoy seeing theirs. Talk with one another about how your findings inform your question and revise the question, the procedures, and/or the findings as needed.
- During and near the end of this observation period, create with your group members some progress reports:
    - What tentative claims, if any, can you make now?
    - What evidence, if any, can you present to support those claims?
    - What rationale explains how the evidence supports those claims?
    - What still needs to be explored?
    - What have you learned about learning from this exploration so far?

- Complete your summary of your group's question, observations, and interpretations before reading an example of a group's initial question and findings about the Moon. Also read nuances about asking questions, making observations, and reporting findings.

1. Examples of a group's initial questions and findings about the Moon

A student reported the following after the first week of looking for the Moon and comparing observations on March 29 at 9:30 am and April 1 at 8:52 am as shown in Fig. 5.14.

> *An initial question that came to mind when making observations was, does the angle between the sun and the moon change at all?*
>
> *As we can see from the first few observations…the angle present in the first observation is obtuse while angle measure of the third is more acute. This shows that the angle has gotten smaller since the day of our first observation.*

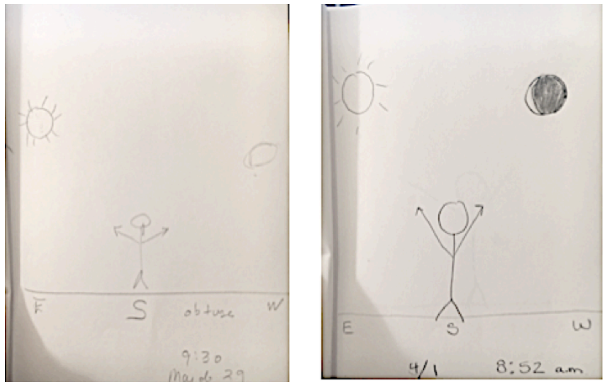


Fig. 5.14 Two sky journal observations of the Moon separated by several days.

Physic student, Spring 2016

Another student’s sky journal observations were slightly different for the same days as shown in Fig. 5.15.

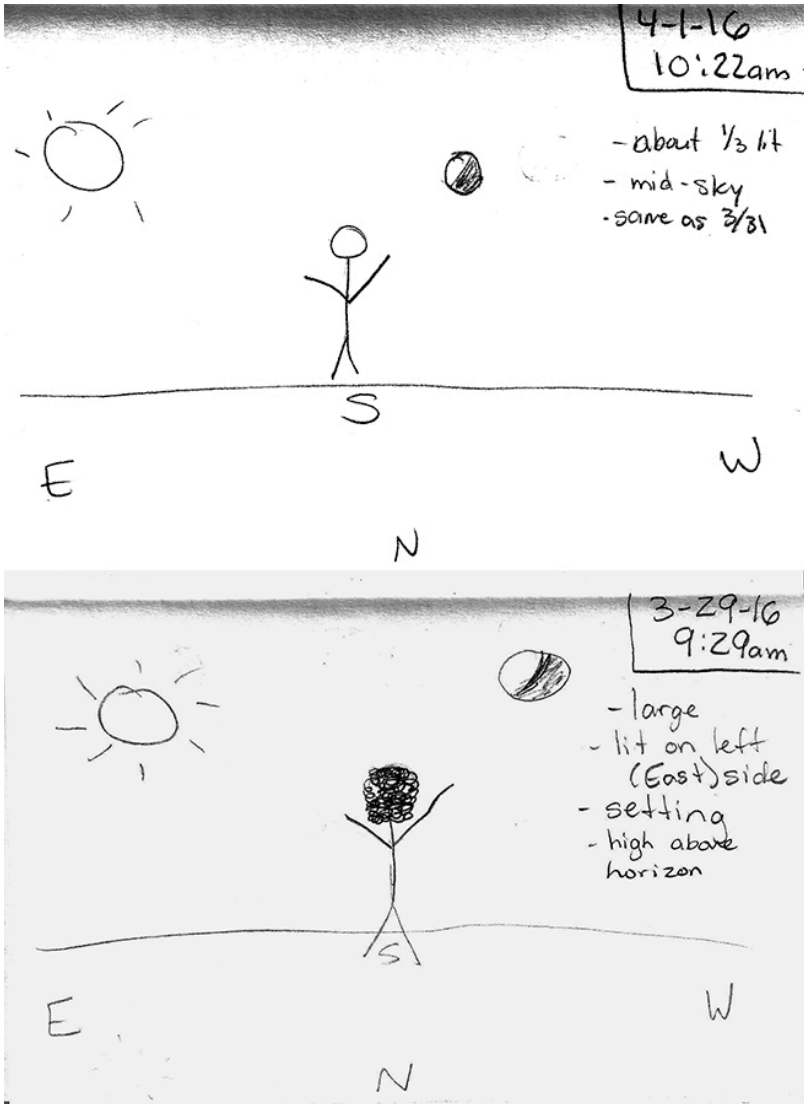


Fig. 5.15 Another set of two sky journal observations of the Moon separated by several days.

Physics student, Spring 2016

This student reported the following questions and conclusions from this first week of observing:

> *When we first saw the moon during class, it was large and was about half-lit on the left, the side the sun was on, and pretty high above the horizon. Some questions I had on that first day were: Will the moon always be lit on the side the sun is closest to? Will the lit part of the moon be bigger or smaller? Will the moon be in a different place tomorrow, next week, and/or next month?*
>
> *I have already found the answers to some of these initial questions through my*

observations of the moon, and thus claims about the moon. First, I have found that the moon, when visible, is lit on the side closest to the sun. Therefore, I can make the claim that the moon is lit by the sun. Second, I have found the lit part of the moon does change size, and it appeared to be a little smaller each day. I have yet to find a powerful idea for this observation, as I am unsure of what causes the shaded part of the moon. Is it a shadow from the earth, or just that part of the moon is facing away from the sun? The third question was answered as well, as the moon was in a slightly different location each day, with the angle of my arms getting smaller. This has led me to make the claim that the moon is always moving.

Another physics student, Spring 2016

2. Nuances about asking questions, making observations, and reporting findings

Both students made the same claim verbally that the angle formed by pointing one arm at the Sun and the other arm at the Moon got smaller between March 29 and April 1. The angle shown by the first student for March 29 is clearly obtuse, however, whereas the angle shown by the second student for this date looks like a right angle. The angle shown by the first student for April 1 is clearly acute whereas the angle shown by the second student for this date still looks like a right angle. The sketch of the Moon shown by the first student for March 29 is more than half lit on the left and shows only the lit portion, whereas the second student stated that the moon was “about half lit on the left” and sketched both the lit and the inferred dark portions of the Moon. This student noted on the sky journal that the Moon appeared to be about one third lit for the later observation.

Compared across all members of the class, these early observations typically differ in the angles drawn for the arms, shapes drawn for the lit portion of the Moon, and placement of the sketch of the Moon in the sky as well as questions asked and claims made. It is important for group members to have time in class to compare their sky journal observations, to become aware of differences in both sketching and thinking. By discussing such differences among themselves, the students typically become more accurate and detailed when making their observations.

Students often come up with questions, experimental designs for making observations, and interpretations of findings that need refinement. Note that scientists do this as well; part of *doing science* is realizing the need to revise what one is asking, to enhance how one is making observations, and/or to reconsider initial interpretations of the data obtained.

Therefore, we do not step in to warn about possible problems in making observations nor comment on interpretations that reflect inaccurate initial drawings.

The intent of this open-ended process is for students to experience both overcoming the pitfalls and enjoying the pleasures characteristic of doing science. A plan to make observations at a time when the Moon will not be visible, for example, will delay gathering data about how the Moon appears, but likely will prompt a new question about when the Moon can be seen. A plan to look for the Moon at 6 p.m. seems reasonable, until one has gone out to look and not seen the Moon even though the sky is clear. This may be because the Moon is not yet above the horizon or it may be that the Moon is above the horizon but the lit portion of the Moon is not visible to the viewer. When students report such a finding, we encourage them to be careful in their language, to state they that "did not see the Moon" rather than that "the Moon was not there."

If students see the Moon but record what they saw later, rather than while looking at the Moon, they may not sketch the shape of the lit portion accurately. We do not comment if we see a sketch of a Moon lit on the right, however, when we know the Moon was lit on the left in the sky; we also do not comment if a sketch of a Moon that is more than half lit looks like a cookie with a bite out of it  instead of like a football . Group members likely will question those observations and prompt a commitment to draw what one is seeing while looking at the Moon rather than drawing later while trying to remember what one saw.

We also initially do not impose vocabulary on observations such as the traditional names for the various phases of the Moon. The descriptive term *half-lit Moon* is acceptable and delays the issue of why such a Moon is called a *Quarter Moon* until the students have enough knowledge from watching the Moon to understand the appropriateness of this designation.

Our experience has been that when students look for the Moon consistently and make observations with only their own concerns about whether these are correctly drawn and labeled, their observations gradually become more accurate without needing critique from an instructor. They also often begin to experience the fun of puzzling about what they are seeing, talking with colleagues about their puzzlements, and making predictions about what will happen next.

Question 5.11 What does the Moon look like today? What will the Moon look like over the next few days?

- Continue looking up at the sky whenever you are outside.

- Whenever you see the Moon, record what you see in your sky journal.
- Make predictions for what happens next:
  - When would be a good time to look for the Moon next?
  - What shape do you think the lit portion of the Moon will be the next time you see the Moon?
  - What type of angle do you think will be formed by pointing at the Sun and the Moon when both are visible? (Acute? Right? Obtuse? Straight?)

Question 5.12 What new question do you and your group members have about the Moon?

- If you have formed new groups, compare observations in your sky journals and listen carefully to the experiences of your new group members as they have been making observations of the Moon.
  - Are there any differences in your observations that need resolving?
  - Are there any similarities that can be articulated as new claims that need confirming?
- Generate a new question about the Moon with your group members.
  The question should be something you can explore by looking at the Moon in the sky rather than by reading books or searching the Internet.

- Design a way to conduct your exploration. Who will do what? When? How? Why?
- Record your question and your experimental design for exploring this question on a large white board.
- Plan and briefly practice how each member of the group will participate in stating the question and describing your design for exploring this question.
- Share your group's question and experimental design with the rest of the class.
- Refine your group's question and design in any ways suggested by hearing other groups' plans if appropriate.
- Continue looking up at the sky whenever you are outside.
  - When would be a good time to look for the Moon?
  - What shape do you think the lit portion of the Moon will be the next time you see the Moon?
  - What type of angle do you think will be formed by pointing at the Sun and the Moon when both are visible? (Acute? Right? Obtuse? Straight?)

- Whenever you see the Moon, record what you see in your sky journal.
- Continue sharing your observations with your group members and discussing how these observations confirm or do not confirm your tentative claims about the Sun and the Moon in answer to your group's new question. Revise question and design as needed.
- Write a clear summary of your group's answer so far to your group's new question.
  - Present the question and evidence, identifying the observations by date, time, and description
  - State clearly how this evidence supports or does not support the claims made.
  - Also if the new evidence is relevant, confirm or disconfirm the claims made earlier about your first group's question.
- Prepare to share your group's new question and interpretations with the whole group. Rehearse with each member of your group participating in some way in presenting the question, procedures, observations, and claims based on the observations.
- Make the presentation as a group and invite questions about any aspects of the question, procedures, observations and claims.

Question 5.13 How does the Moon seem to move across the sky during several hours? during several days?

- When you can see the Moon and expect it to be visible for several hours, record the position of the Moon in the sky at least twice separated by one or more hours.
- How does the Moon seem to move across the sky during several hours?
- On a series of days when the sky is likely to be clear, record the position of the Moon in the sky and its shape at the same time during each of several days.
- How does the Moon seem to move across the sky during several days?
- Support each claim with photos of sky journal entries and discussion of the relevant aspects of these entries.

D. Reviewing observations so far, making predictions, and generating questions

Question 5.14 What have you learned about the Moon from your observations so far? What do you think will happen next?

- Look through your observations in your sky journal. Summarize what you have learned about the Moon so far about:
  - changes in the shape of the lit portion of the Moon you have seen
  - changes in the angle formed by pointing one arm at the Sun and one arm at the Moon
  - changes in the location of the Moon in the sky
  - changes in times when the Moon is visible
- Predict what you think will happen next.
- When your sky journal is full, shift to keeping track of the Sun and the Moon with a regular monthly calendar as shown in Figure 5.16. Fill in the name of the month and number the days.
- As indicated near the bottom of the calendar, for each date that you see the Moon:
  - Draw the shape of the lit portion of the moon
  - Record the time of your observation, including a.m. or p.m.
  - Record the moon's "height" in the sky: is it low? Medium? High?
  - Record the Moon's apparent motion: does it appear to be rising? Moving across the sky? Setting?
  - Record the Moon's direction in the sky: N, NE, E, SE, S, SW, W, NW
  - If the Sun is visible, point one arm at the Sun and one arm at the Moon, draw the angle formed by your arms. Is it acute? Right? Obtuse? Straight?
  - Draw the Sun if visible
  - If the stars or planets are visible, record where the Moon appears to be with respect to a familiar star pattern or bright planet

Sun and Moon Observations **Month:** **Name:**

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday

Draw the shape of the lit portion of the moon.

Record the time of your observation.

Record the moon's "height" in the sky: Is it low? medium high?

Record the moon's apparent motion: Does it appear to be rising? moving across the sky? setting?

Record the moon's "direction" in the sky: N, NE, E, SE, S, SW, W, NW

If the sun is visible, point one arm at the sun and one arm at the moon, draw the angle formed by your arms. Is it acute? right? obtuse? straight?

If the stars are visible, record where the moon appears to be with respect to a familiar star pattern or bright planet.

FIG 5.16 Calendar template for keeping track of the next set of Sun and Moon observations.

- Begin to use the traditional names for the various shapes of the lit portion of the Moon: *crescent* when less than half lit, *quarter* when half lit although this nomenclature may be puzzling, *gibbous* when more than half lit, *full* when fully lit. Also consider whether the phases are *waxing*, becoming more lit, or *waning*, becoming less lit.
- After summarizing your findings so far look at an example of student work and read about nuances in observing the Moon.

1. Example of student work summarizing initial findings about the Sun and the Moon

A student summarized initial findings about the Sun and the Moon as follows:

> ***Continuing to observe the Moon.*** *Figure (5.17) is my next set of observations from my sky calendar.*

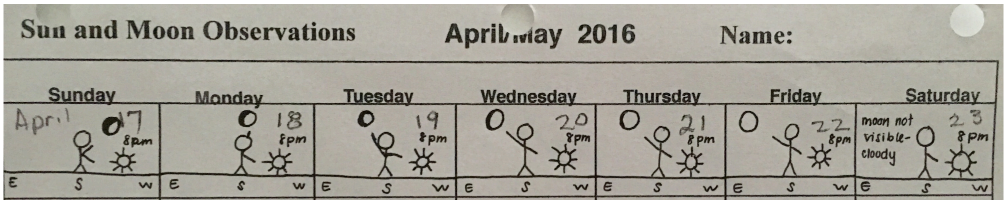


FIG. 5.17 *Student's Observations, April 17–23, 2016*

Stating current question and findings. *The question that I am now exploring with my small group members is, how does the appearance of the moon change in regards to how it is lit and shaded? My role in this exploration is looking for and observing the moon every evening at 8 p.m., which is right before sunset. My procedure is to look for the moon wherever I happen to be at 8 p.m., and then record what I see on my sky calendar. I am finding that the lit part on the right side of the moon increased until the moon was full, which can be seen in my observations above. Since April 17, the lit part on the right side of the moon has been gradually increasing until the moon became full, which I observed on April 22.*

Confirming or disconfirming earlier findings. *One of my previous claims was that the angle between the sun and the moon changes. These new observations support this claim because the angle between the sun and the moon has been increasing. In just these new observations, a right angle is seen on April 17, an obtuse angle is seen on April 18–20, and a straight angle is seen on April 21–22. This shows that the angle between the sun and the moon is changing.*

Another previous claim is that the curve of the line separating the bright and the shadowed parts of the moon changes shape. This claim is supported by this next set of observations because the arch of the line is continually changing as the moon becomes more lit, as seen in the observations in Figure (5.17). Another previous claim is that the side of the moon that is lit up changes. This is also supported by my new observations because in previous observations, the lit part was on the left side of the moon, but in these observations, the lit part is on the right side of the moon.

One last previous claim was that there is a period of time when the entire moon is shadowed. These new observations do not support this claim because I had no observation above in which the entire moon was shadowed.

Summarizing patterns in what we have been seeing. *I am comparing four weeks of data.*

Summarizing changes in the shape of the Moon so far. *At the beginning of the* *term, the left part of the moon was lit, as seen on March 29. The lit part on the left side of the moon continued to decrease until the entire moon was shaded. Then, I could see the moon again on April 9, when the lit part of the moon was now on the right side. The lit part on the right side of the moon continued to increase until there was a full moon that was seen on April 22. So, it seems as though the moon is partially lit, the lit part decreases until the entire moon is shaded, then the other side of the moon is partially lit, and finally, the lit part increases until the entire moon is lit.*

Summarizing changes in the angle formed by pointing one arm at the Sun and one arm at the Moon so far*. At the beginning of the term, the angle between the sun and the moon was an acute angle, as seen on March 30. As the term went on, the angle increased. It became a right angle on April 17, an obtuse angle on April 18, and a straight angle on April 21.*

Summarizing changes in the location of the Moon in the sky*. The moon appears to move only slightly on the same day over several hours. I first looked at 8 p.m., then 9 p.m., then 10 p.m. on April 18. The moon seemed to slowly get higher up in the sky as time went on, but only slightly.*

I have observed the moon at 8 p.m. over several days. The moon appears to be moving more and more east in the sky. The observations above from April 17–April 22 show that the moon is gradually moving from the west to the east when observed at 8 p.m. each night.

Summarizing changes in the times when the Moon is visible so far*. At the beginning of the term, the moon was visible in the morning. On March 29, I saw the moon at 9:29 a.m. and on March 30, I saw the moon at 7:42 a.m. As the term went on, I could no longer see the moon in the morning, such as when I looked on April 3 at 9:39 a.m. and did not see the moon. I began to look right before sunset and I could see the moon. On April 15, I could see the moon at 8:00 p.m. So, at the beginning of the term, the moon was visible in the morning and now it is visible in the evening and at night.*

Making predictions. *I predict that the angle between the sun and the moon will become acute again because the angle started as acute, became right, became obtuse, and then became straight. So, I think that the cycle will continue and that the angle formed will be acute again. I think that the moon will be more towards the west in the sky at 8 p.m. The moon moved more and more east in the sky each day at 8 p.m., so I think that it will start to move more west again. I also predict that the right side of the moon will start to become shaded and that the shaded part of the moon will* *continue to increase, since that is what I saw happen to the shaded part of the moon during the first week of the term.*

Physics student, Spring 2016

2. Nuances about observing the Moon

After observing the Moon for several weeks, most of the students begin to notice and comment upon details that puzzle them. Several, for example, likely will have noticed already the intriguing phenomena raised in Question 5.13, of the Moon seeming to move across the sky from east to west during several hours but from west to east during several days. At this point in the exploration, this becomes a whole class rather than small group question, with the emphasis on everyone verifying these observations.

This intent is made explicit, that when something quite surprising arises, it is helpful to have multiple observations of the effect by different groups to be sure that the surprising effect is replicable. Therefore, all students should have observations of their own that the Moon seems to move east to west over several hours but from west to east over several days. In order to understand *why* this puzzling behavior of the Moon occurs, the students first need to develop central ideas about the Moon based on all the observations they have been gathering, then use these central ideas to develop an explanation. These summaries are tentative interpretations of observations to date. After another set of observations where patterns seem to begin repeating, students will have enough data to make some strong claims about the Sun and the Moon.

E. Identifying patterns based on evidence

Question 5.15 What pattern have you observed in the changing shape of the Moon?

- Compare your observations with your group members' observations.
- When you group has agreed on the pattern of changes in the shape of the lit portion of the moon, draw the shapes on a large white board in order as they appeared in the sky.Draw the outline of a shape with a black marker; let the white of whiteboard be the filler that represents the lit portion.

- Write the traditional name of each shape underneath. These are called the *phases of the Moon*. A traditional order is to list them as new (not seen), waxing crescent, 1st quarter, waxing gibbous, full, waning gibbous, 3rd quarter, and waning crescent.
- What is the shape of the lit portion associated with each phase of the Moon?
- What is the pattern of how the shape of the lit portion of the Moon seems to change?

Question 5.16 What pattern have you observed in the angle formed by pointing arms at the Sun and Moon when both are visible?

- Under each phase, draw stick figures with arms forming the kind of angle observed. (Acute? Right? Obtuse? Straight?)

- What is the pattern of how this angle seems to change?

Question 5.17 How are the changing shape of the Moon and the changing angle related?

- Based on the evidence of your observations, make and support a central idea about the way the shape of the lit portion of the Moon seems to change during its phases.
- Based on the evidence of your observations, make and support a central idea about the way the angle formed by pointing at both the Sun and the Moon seems to change.
- Based on the evidence of your observations, make and support a central idea about the connection between the shape of the lit portion of the Moon and the angle formed by pointing at both the Sun and the Moon.

Question 5.18 What pattern have you observed in the relation of the lit side of the Moon and the location of the Sun?

- Based on the evidence of your observations, make and support a central idea about the relation between the lit side of the Moon and the position of the Sun in the sky.

F. Making predictions for when a phase of the Moon will rise and

set

Question 5.19 How can you predict when a phase of the Moon will rise, transit, and set?

It is a lot easier to observe the Moon systematically if one can predict when and where to look for the Moon in the sky.

1. Creating a Sun clock and using it to predict when the Moon will rise, transit, and set

One way to make predictions for rising and setting times for the Moon is to use the angle that the Moon seems to make with the Sun as seen from Earth. To do so, one needs to identify specific positions of the Sun with particular times.

- Create a *sun clock* as shown in Fig. 5.18 by drawing a circle with a horizontal diameter.
    - If observing in the northern hemisphere, label the left end of the diameter East and the right end West.
    - Also label the left end of the diameter as "rising position for the Sun"
    - Label the top of the circle "transiting position for the Sun"
    - Also label the right end of the diameter as "setting position for the Sun"

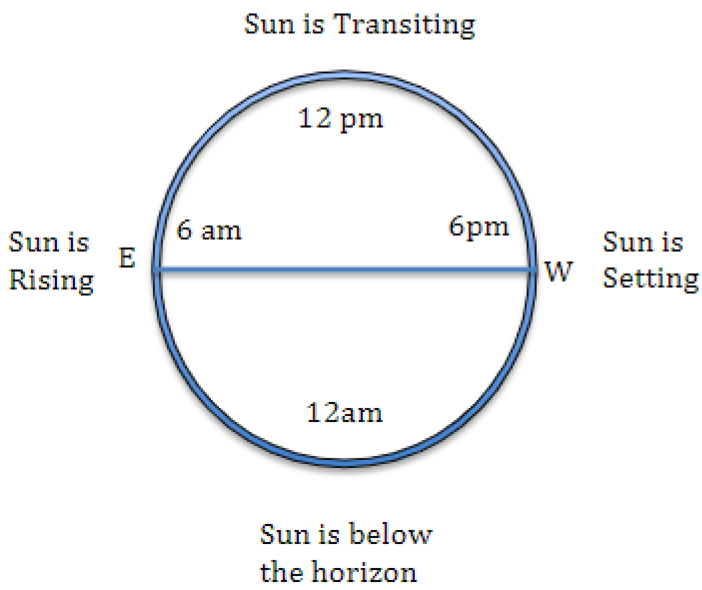


Fig. 5.18 Model of a Sun Clock with rising, transiting, and setting positions as seen in the northern hemisphere. (If observing in the southern hemisphere, label the rising position, East, on the right and the setting position, West, on the left.)

The arc of the circle above the diameter from East (rising position) to top of the circle (transiting position) to West (setting position) represents day, when the Sun is above the horizon. In this model of a sun clock, as shown in Fig. 5.18, we are envisioning the Sun moving along the top half of the circle, rising in the East, moving high across the sky, and setting in the West all in a *clockwise* direction as seen from the northern hemisphere or counterclockwise as seen from the southern hemisphere.

The arc of the circle below the diameter from West (setting position) to bottom of the circle to East (rising position) represents night, when the Sun is not visible. In this model of a sun clock, we are envisioning the Sun continuing to move along the bottom half of the circle, setting in the west, moving along the bottom of the circle during the night, and rising in the east. We are not claiming that the Sun actually does this, only that we can envision such a model.

- Ignore daylight saving time and assume times appropriate for equinoxes (late March, late September) when the Sun rises at about 6 a.m., is high in the sky (transiting) at about noon, and sets at about 6 p.m. Label the sun clock with these times for the Sun at these positions. Assume the position of the Sun at the bottom of the circle would be at midnight, 12:00 a.m. Also indicate about where the Sun would be at intermediate times, such as 9 a.m., 3 p.m., 9 p.m., and 3 a.m. Note that this sun clock represents a way of envisioning where the Sun seems to be located in the sky (or not in the sky) over a 24-hour period.

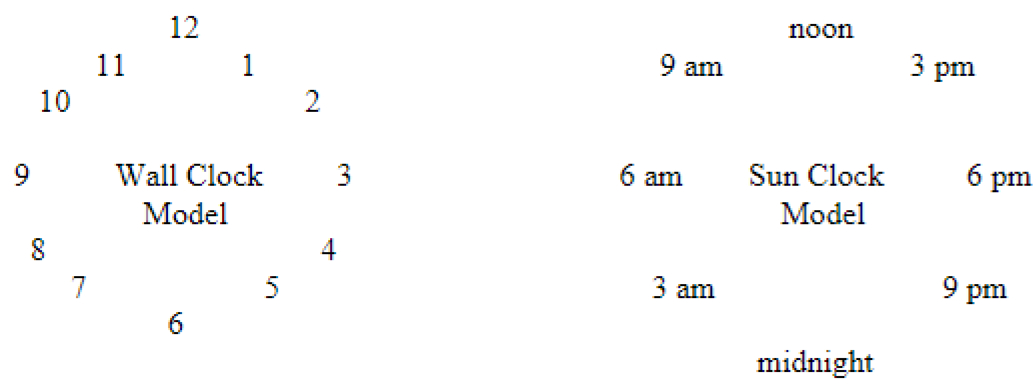


FIG. 5.19 Model of a wall clock on the left; model of a Sun clock on the right with times associated with the Sun's position in the sky when looking South in the northern hemisphere.

- How is this 24-hour sun clock similar to the traditional 12-hour clock one sometimes sees on walls and watches? How is it different?

- Now use the sun clock to predict rising, transiting, and setting times for each phase of the Moon. Start with a phase for which an easy angle is formed by pointing at the Sun and the Moon. Start, for example, with a First Quarter Moon. When does a first quarter Moon rise? Transit? Set?

- Based on your observations, what angle is formed by your arms when pointing at the Sun and a First Quarter Moon?
- To predict the rising time for a First Quarter Moon, act out with your arms where the Sun and the Moon would be in the sky:
  Stand up and orient yourself to face South, if you live in the northern hemisphere (or North if you live in the southern hemisphere). Point an arm to the East toward an imagined rising First Quarter Moon.
- Where would the Sun be? Would the Sun be "ahead" of the Moon, already visible in the sky? Or would the Sun be "behind" the Moon, not yet visible? Point your arms

toward an imagined Moon and Sun with your arms forming a right angle.

- To use the sun clock, look at what time a Sun would be at the place where you are pointing. This is an estimate of the time when a First Quarter Moon is rising.
- To predict when a First Quarter Moon is high in the sky and easy to see, when it is transiting, point your "Moon" arm up toward an imagined First Quarter Moon and your "Sun" arm toward an imagined Sun with your arms forming a right angle.
- To use the sun clock, look at what time a Sun would be at the place where your "Sun" arm is pointing. What time is the Sun at this position on the sun clock? This is an estimate of the time when a First Quarter Moon is transiting.
- To predict when a First Quarter Moon is setting, point your "Moon" arm toward an imagined First Quarter Moon setting and your "Sun" arm toward an imagined Sun with your arms forming a right angle. To use the sun clock, look at what time a Sun would be at the place where your "Sun" arm is pointing. What time is the Sun at this position on the sun clock? This is an estimate of the time when a First Quarter Moon is setting.
- Summarize when a First Quarter Moon is visible while rising, moving high across the sky, and setting. When is a good time to look for one, to see one high in the sky?

- You now have a tool for predicting when and where to look for the Moon during any phase.
  Use this tool to predict rising, transiting, and setting times for all the phases of the Moon: new moon, waxing crescent, first quarter, waxing gibbous, full, waning gibbous, third quarter, and waning crescent.
- Organize your predictions in a table such as Table V.1

TABLE V.1 Summarizing findings about the phases of the Moon

TABLE V.1 Summarizing findings about the phases of the Moon

Shape								
Name	New	Waxing crescent	First quarter	Waxing gibbous	Full	Waning gibbous	Third quarter	Waning crescent
Stick Figure								
Angle	0	0 <acute<90	90	90<obtuse<180	180	180>obtuse>90 or 180<obtuse<270	90 or 270	90>acute>0 or 270<acute<360
Waxing/ Waning								
Rising								
Transiting (High)								
Setting								

- On each stick figure, label which hand is pointing to the Moon, which to the Sun.
  - During which phases is the Sun to the East of the Moon? To the West of the Moon?
  - During which phases does the Moon seem to chase the Sun across the sky?
  - During which phases does the Sun seem to chase the Moon across the sky?
- When are the waxing phases mostly visible? The waning phases?
- State the predictions for each phase:

- When can each phase be seen rising, moving high across the sky, and setting?
- Indicate which phases seem to occur over a period of time as the angle sweeps through a range of values.
- Indicate which phases seem to occur just at an instant as the angle seems to have a particular value.

Table V.1 summarizes findings to date and provides detailed information to guide further explorations. Requiring considerable waving of the arms as students generate predictions for rising, transiting, and setting times, this session has been dubbed *Moon Dance 1*.

Table V.2 summarizes the central ideas about the Sun and the Moon inferred from these observations.

TABLE V.2 Central Ideas about the Sun and the Moon

TABLE V.2 Central Ideas about the Sun and the Moon

Sketch of set up	Evidence	Central Ideas	Vocabulary
		The shape of the lit portion of the Moon that we see from Earth changes in a regular pattern.	
		The angle formed by pointing one arm at the Moon and one arm at the Sun changes in a regular pattern related to the changing shape of the lit portion of the Moon that we see.	
		The lit side of the Moon is always on the same side as the Sun.	

		The angle formed by pointing one arm at the Sun and one arm at the Moon is useful for predicting when and where to look for the Moon.	
		The Moon is visible at different times depending upon its phase.	

Complete your responses to questions 5.15-5.19 and Tables V.1 and V.2. Then summarize what you have learned before looking at an example of student work estimating rising, transiting, and setting times for a 1st quarter Moon as well as an example summary of central ideas about the Sun and the Moon.

2. Example of student work illustrating how to predict rising, transiting, and setting times for a first quarter Moon.

> *To be able to determine where the moon will be at specific times, one can develop and utilize a 'sun clock'. The sun clock is able to 'tell time' based on where the sun seems to be in the sky (or below the horizon) over 24 hours. For example, if you were looking for a 1st quarter moon, we know the angle between the sun and the moon is 90 degrees and the moon is lit on the right. Therefore, by putting your right arm towards the sun, 90 degrees behind that is where the moon will be. Therefore, the 1st quarter moon will rise at 12 pm, will be high in the sky at 6 pm, and will be setting at midnight as shown in the figure* (5.20).

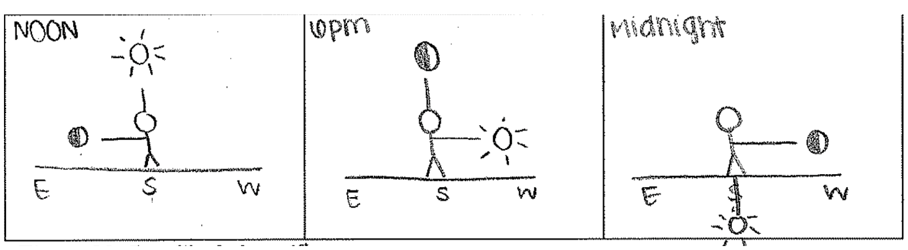


FIG. 5.20 Predicting rising, transiting, and setting times for a 1st quarter Moon.

3. Example of student work summarizing central ideas about the Moon

A student summarized central ideas about the Moon as shown below:

Continuing to observe the Moon. *Figure (5.21) presents my observations from my sky calendar so far.*

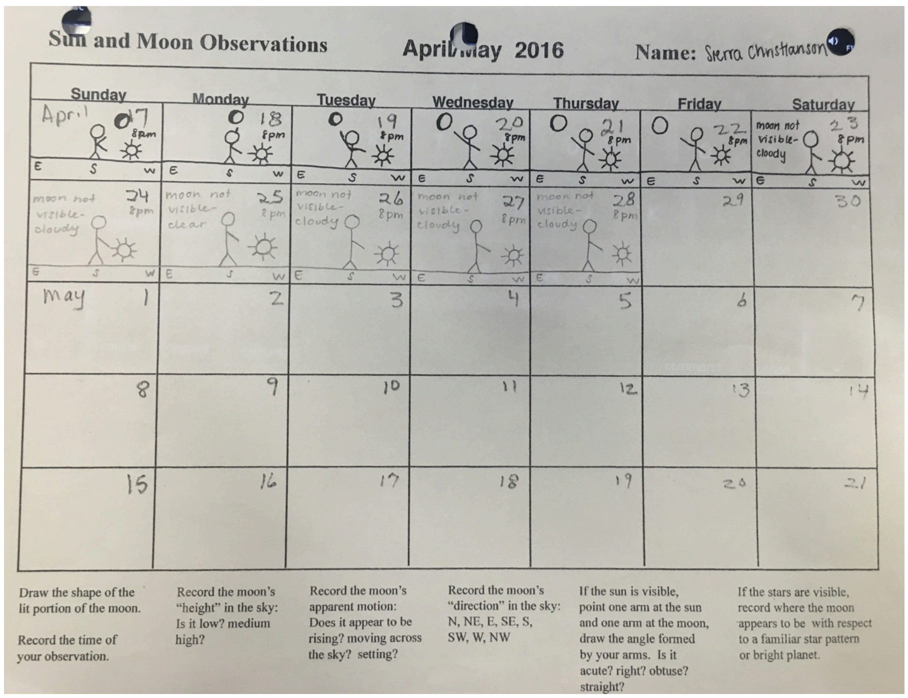


FIG. 5.21. *Student's observations of the Moon, April 17-28, 2016.*

During the week of April 17, I looked for the moon at 8pm, which is right before sunset. The lit part of the moon was on the right and it continued to increase until there was a full moon on April 22. The angle between the sun and the moon continued to increase, changing from an obtuse angle into a straight angle. When there was a full moon, the angle between the sun and the moon was a straight angle. Since then, I have not been able to see the moon due to it being cloudy.

Developing Central Ideas Based on Evidence

This section will discuss ideas about the moon, as well as the evidence that *supports those ideas. (Figure 5.22) is a chart made in class. Each row of this table presents a different idea. Those ideas will be discussed below.*

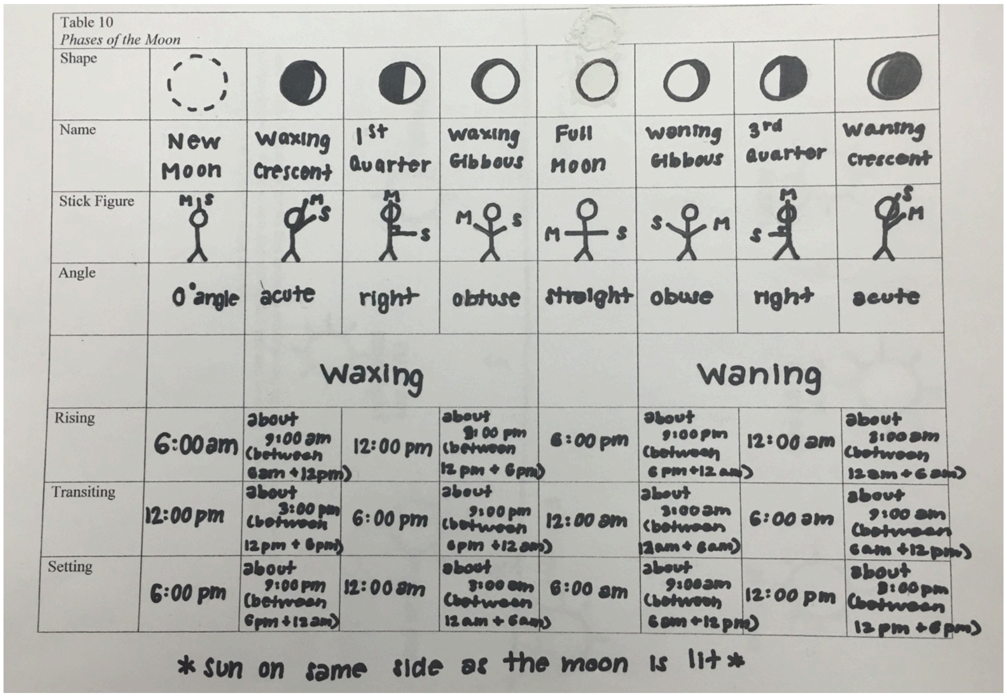


Table 10
Phases of the Moon

Shape								
Name	New Moon	Waxing Crescent	1st Quarter	waxing Gibbous	Full Moon	waning Gibbous	3rd Quarter	Waning Crescent
Stick Figure	M S	M S	M S	M S	M S	S M	M S	S M
Angle	0° angle	acute	right	obtuse	straight	obuse	right	acute
		Waxing				Waning		
Rising	6:00 am	about 9:00 am (between 6am + 12pm)	12:00 pm	about 3:00 pm (between 12 pm + 6pm)	6:00 pm	about 9:00 pm (between 6 pm + 12 am)	12:00 am	about 3:00 am (between 12 am + 6 am)
Transiting	12:00 pm	about 3:00 pm (between 12pm + 6pm)	6:00 pm	about 9:00 pm (between 6pm + 12 am)	12:00 am	about 3:00 am (between 12am + 6am)	6:00 am	about 9:00 am (between 6am + 12 pm)
Setting	6:00 pm	about 9:00 pm (between 6pm + 12 am)	12:00 am	about 3:00 am (between 12 am + 6 am)	6:00 am	about 9:00 am (between 6am + 12 pm)	12:00 pm	about 3:00 pm (between 12 pm + 6 pm)

* sun on same side as the moon is lit *

FIG. 5.22 *Student's entries in a table summarizing findings about the phases of the Moon.*

The shape of the lit portion of the Moon that we see from Earth changes in a regular pattern. *There are 8 different phases of the moon. In the New Moon phase, the moon is completely shaded, so there is no lit portion of the moon that we see.*

In the Waxing Crescent phase, there is a growing small portion, (say about ¼), on the right side of the moon that is lit.

In the First Quarter phase, the right half of the moon is lit.

In the Waxing Gibbous phase, there is a growing big portion, (say about ¾), on the right side of the moon that is lit.

In the Full Moon phase, the entire moon is lit.

In the Waning Gibbous phase, there is a decreasing big portion, (say about ¾), on the left side of the moon that is lit.

In the Third Quarter phase, the left half of the moon is lit.

In the Waning Crescent phase, there is a decreasing small portion, (say about ¼), on the left side of the moon that is lit.

A general description of the pattern observed is that the moon is completely *shaded and then the right side of the moon slowly becomes more and more lit until the entire moon is lit. After the entire moon is lit, the right side of the moon slowly becomes more and more shaded until the entire moon is shaded again.*

The angle formed by pointing one arm at the Moon and one arm at the Sun changes in a regular pattern related to the changing shape of the lit portion of the Moon that we see. *The stick figures in the chart above have one arm pointing at the moon and one arm pointing at the sun. The arms make an appropriate angle for each phase. There is a different figure for each of the phases.*

In the New Moon phase, there is a 0° angle between the moon and the sun.

In the Waxing Crescent phase, there is an acute angle between the moon and the sun.

In the First Quarter phase, there is a right angle between the moon and the sun.

In the Waxing Gibbous phase, there is an obtuse angle between the moon and the sun.

In the Full Moon phase, there is a straight angle between the moon and the sun.

In the Waning Gibbous phase, there is an obtuse angle between the sun and the moon.

In the Third Quarter phase, there is a right angle between the sun and the moon.

In the Waning Crescent phase, there is an acute angle between the sun and the moon.

A general description of the pattern observed between this angle and the lit portion of the moon we see is that the greater the lit portion of the moon, the greater the angle between the sun and the moon. The smaller the lit portion of the moon, the smaller the angle between the sun and the moon.

The lit side of the Moon is always on the same side as the Sun. *There are several observations that support this claim. On March 29 at 9:30 am, I observed that the sun was on the left side of the moon and the lit part of the moon was on the left.*

On April 2 at 9:15 am, I observed that the sun was on the left side of the moon and the lit part of the moon was on the left.

On April 11 at 7:45 am, I observed that the sun was on the right side of the moon and the lit part of the moon was on the right.

On April 19, at 8:00 pm, I observed that the sun was on the right side of the moon and the lit part of the moon was on the right.

A summary of this pattern is that when the sun is on the right side of the moon, the right side of the moon is lit and when the sun is on the left side of the moon, the left side on the moon is lit.

The angle formed by pointing one arm at the Moon and one arm at the Sun is useful for predicting when and where to look for the Moon. *Figure (5.23) is a model of a sun clock.*

This sun clock can be used to generate predictions for rising, transiting (high in the sky), and setting times for various phases of the moon as shown in Table (V.2). We can use the sun to tell approximately what time it is. The suns above the horizon represent where we see the sun at certain times and the suns below the horizon represent where we can envision the sun being located at certain times. This allows us to use the sun as a 24-hour clock.

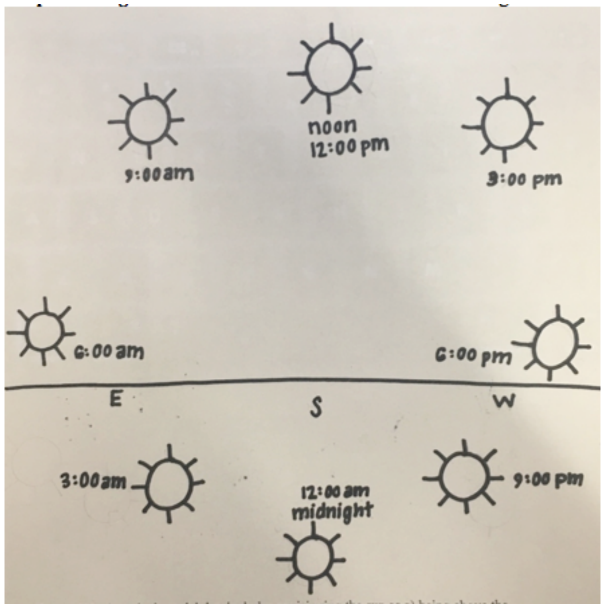


FIG. 5.23 Student's sketch for a sun clock.

Since the moon rises on the East side of the horizon, in the same position of the sun at 6 am on the sun clock, we can use the angle between the sun and the moon to predict about the time that the moon rises. For example, during a First Quarter phase, there is a right angle between the sun and the moon, with the sun on the right side of the moon. So, looking at the sun clock, you look at what time the sun makes a right angle with the 6 am time, with the sun on the right side of the moon. The sun makes a right angle with the 6 am time at the 12 pm time, so during a First Quarter phase, the moon rises at 12 pm.

During a Waning Crescent phase, there is an acute angle between the sun and the moon, with the sun on the left side of the moon. So, looking at the sun clock, you look *at what time the sun makes an acute angle with the 6 am time, with the sun on the left side of the moon. The sun makes an acute angle with the 6 am time at about 3am, so during a Waning Crescent phase, the moon rises at about 3 am, or sometime between 12 am and 6 am.*

Since the moon transits high in the sky, in the same position of the sun at 12 pm on the sun clock, we can use the angle between the sun and the moon to predict about the time that the moon transits. For example, during a Full Moon, there is a straight angle between the sun and the moon, with the sun on the right side of the moon. So, looking at the sun clock, you look at what time the sun makes a straight angle with the 12 pm time, with the sun on the right side of the moon. The sun makes a straight angle with the 12 pm time at the 12 am time, so during a Full Moon, the moon transits at 12 am.

During a Waning Gibbous moon, there is an obtuse angle between the sun and the moon, with the sun on the left side of the moon. So, looking at the sun clock, you look at what time the sun makes an obtuse angle with the 12 pm time, with the sun on the left side of the moon. The sun makes an obtuse angle with the 12 pm time at about 3 am, so during a Waning Gibbous moon, the moon transits at about 3 am, or between 12 am and 6 am.

Since the moon sets on the West side of the horizon, in the same position of the sun at 6 pm on the sun clock, we can use the angle between the sun and the moon to predict about the time that the moon sets. For example, during a Waning Crescent phase, there is an acute angle between the sun and the moon, with the sun on the left side of the moon. So, looking at the sun clock, you look at what time the sun makes an acute angle with the 6 pm time, with the sun on the left side of where the moon is. The sun makes an acute angle with the 6 pm time at about the 3 pm time, so during a Waning Crescent phase, the moon sets at about 3 pm, or between 12 pm and 6 pm.

During a New Moon phase, there is a 0° angle between the sun and the moon. So, looking at the sun clock, the moon and the sun will be in the same location in the sky. This means that during a New Moon phase, the new moon sets at 6 pm.

***The Moon is visible at different times, depending on its phase.** Waxing moons are mostly visible during the day and some of the night, from about 9:00 am to 3:00 am, depending on whether it is a Waxing Crescent or a Waxing Gibbous moon. Full moons are mostly visible from the evening to the early morning, from about 6:00 pm to 6:00 am.*

Waning moons are mostly visible during the night and morning, from about 9:00 pm to 3:00 pm, depending on whether it is a Waning Gibbous or a Waning Crescent *moon. Based on my observations, there was a Third Quarter moon on March 31 at 9:32 am. There was a New Moon from April 5 until around April 8, at least the Moon was not visible although the sky was clear. There was a First Quarter moon on April 15 at 8 pm. There was a Full Moon on April 22 at 8 pm. It has been too cloudy for me to see the moon recently, but I predict that there was a Third Quarter moon recently in the past day or two. Through my observations, I learned that a full cycle takes about a month. Next, I predict that the shaded part of the moon will continue to increase until there is a new moon.*

My observations can support the claims mentioned in (Fig. 5.22). I observed a new moon around April 7 when I looked for the moon in the morning and in the night and it was not visible, even though the sky was clear.

I observed a Waxing Crescent moon on April 11 at 7:45 pm and the angle between the sun and the moon was acute.

I observed a First Quarter moon on April 15 at 8:00 pm and the angle between the sun and the moon was right.

I observed a Waxing Gibbous moon on April 18 at 8:00 pm and the angle between the sun and the moon was obtuse.

I observed a full moon on April 22 at 8:00 pm and the angle between the sun and the moon was straight.

I observed a Third Quarter moon on March 31 at 9:32 am and the angle between the sun and the moon was right.

I observed a Waning Crescent moon on April 2 at 9:15 am and the angle between the sun and the moon was acute.

I have not yet observed a Waning Gibbous moon. According to my observations, there should have been one recently, but it has been cloudy the past week, which made it so I couldn't see the moon. I should try to observe the Waning Gibbous moon a few days after the next full moon, between around 9:00 pm and 9:00 am.

Physics student, Spring 2016

Also consider the durations of the various phases of the Moon, their connections to the format of calendars, and ways in which this process of developing ideas about the phases of the Moon, based on evidence, has modeled the nature of science.

Question 5.20 What is the duration of each phase of the Moon?

- There are eight phases of the Moon. Do the phases occur at a particular instant or over a period of time?

- New: an instant, when angle = 0 degrees
- Waxing crescent: during an increasing acute angle between 0° and 90°, about a week
- First quarter, an instant, when angle = 90 degrees
- Waxing gibbous, during an increasing obtuse angle between 90° and 180°, about a week
- Full, an instant, when angle = 180 degrees
- Waning gibbous, during a decreasing obtuse angle between 180° and 90° (or increasing between 180° and 270°), about a week
- Third quarter, an instant, when angle = 90° (or 270°).
- Waning crescent, during a decreasing acute angle (or increasing between 270° and 360°), about a week

- The phases begin to repeat in about 29.5 days. Why do we have "weeks" in our calendar? "months"? (See https://www.timeanddate.com/calendar/days/7-days-week.html)

Question 5.21 What aspects of the nature of science have students experienced so far?

Table V.1 summarizes observations and interpretations based on a full cycle of the Moon's phases. The students generated and explored their own questions as well as issues guided by the instructor and course curriculum. The process was incremental, with on-going daily observations, brief discussions during many class sessions, homework assignments to report new data and interpretations, and a culminating session in which small groups developed central ideas about the Sun and the Moon based on the accumulated evidence. The students then used a model of the relation between the Sun and the Moon as seen from Earth to make predictions for rising, transiting, and setting times for each phase of the Moon.

This was a long process, at least five weeks with considerable time and effort. Was it worth it? There are computer programs that students can use to simulate the entire sequence of the Moon's changing phases within a much shorter time period by gathering data from the computer rather than from the sky. From our perspective, when weather permits, engaging students in actually looking for the Moon in the sky over this extended time period is preferable. This process models the nature of science in sharpening skills in recording observations accurately, generating questions of interest based on these observations, looking for patterns in the data, discussing various interpretations, and using those to make predictions of when and where to see the moon to maximize the likelihood of observing the phenomena being studied.

The central ideas about the Sun and the Moon, based on observational evidence, provide the basis for the next step: developing explanatory models for three interconnected phenomena: day and night, the phases of the moon, and the Earth's seasons. This extended experience throughout the term is intended to foster deeper understandings of the Sun/Earth/Moon system as well as of the nature of science and perhaps a greater sense of satisfaction whenever the students see the Moon throughout their lives.

IV. Using Central Ideas to Develop Two Explanatory Models For Day And Night

This section develops two models for explaining the daily observation that when the Sun is above the horizon, during *day*, one can see things, one's world outside is well lit; after the Sun is below the horizon, during *night*, one's world outside is dark unless illuminated by artificial lighting.

Question 5.22 Why does it get dark at night?

Two models offer explanations for why it gets dark at night: the *Fixed Earth, Revolving Sun model* and the *Fixed Sun, Rotating Earth model.*

A. Developing the *Fixed Earth, Revolving Sun* explanatory model for day and night

What does the Sun seem to be doing during a day and night? One can observe the Sun seem to rise in the east in the early morning, climb in an arc until high in the sky at about noon, continue to move across the sky while sinking in an arc, and set in the west before it gets dark at night.

After the sun sets, the sky is dark for many hours. One cannot see where the Sun seems to have gone at night. One could infer, however, that the Sun continues its daily journey of revolving in an arc around the other side of the Earth.

This Earth-centered perspective, with the Sun revolving daily around a fixed Earth, is also known as a *geocentric* model as shown in Fig. 5.24. The prefix *geo-* refers to the Earth and *centric* refers to something that is at the center, something around which other things revolve.

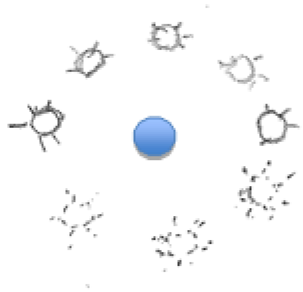


FIG. 5.24 Fixed Earth, Revolving Sun explanatory model for day and night.

Equipment: To act out this model, use your head as representing the Earth and a fist as representing the Sun.

- How can you move your fist to act out this model?
    - In the northern hemisphere where we live, stand facing South. East is to the left; West is to the right.
      In the southern hemisphere, stand facing North. East is to the right; West is to the left.
    - Make a fist to represent the Sun.
    - Point your fist horizontally toward the east to represent the rising Sun.
    - Move your fist upward in an arc until it is pointing high to represent the sun moving toward being high in the sky at noon.
    - Continue moving your fist in a downward arc until it is pointing horizontally toward the west to represent the setting Sun.
    - Continue moving a fist in an arc down behind your back toward what can be thought of as the Sun's position at midnight (change fists to do this).
    - Move your fist in an arc up until it is pointing horizontally at the Sun's rising position in the east (change fists to do this).
- What evidence supports this model?
    - What do you see if you keep track of where the sun seems to be in the sky during the day?
    - What perspective do you hear if someone uses language such as sunrise and

sunset to refer to the sun's apparent daily arrival and departure?
- How are people acting if they look toward where the sun 'is' in the sky in order to estimate the time?
- On what basis have instruments like a sundial been designed? For a sundial simulation, see: https://www.britannica.com/technology/sundial. For information about ancient sundials, see http://sundials.org/index.php/all-things-sundial/ancient-sundials).

These all reflect a model of the Sun revolving daily around a fixed Earth.

This is a very helpful model! We used it ourselves, along with the angle formed by pointing one arm at the Sun and the other arm at the Moon, to make predictions about when and where to look for each phase of the Moon. To make a sun clock, we labeled the positions where we see the Sun in the sky with the associated times and continued the pattern of such associated times when we envisioned the Sun continuing to move in a circle below the horizon as shown in Fig. 5.23 (repeated).

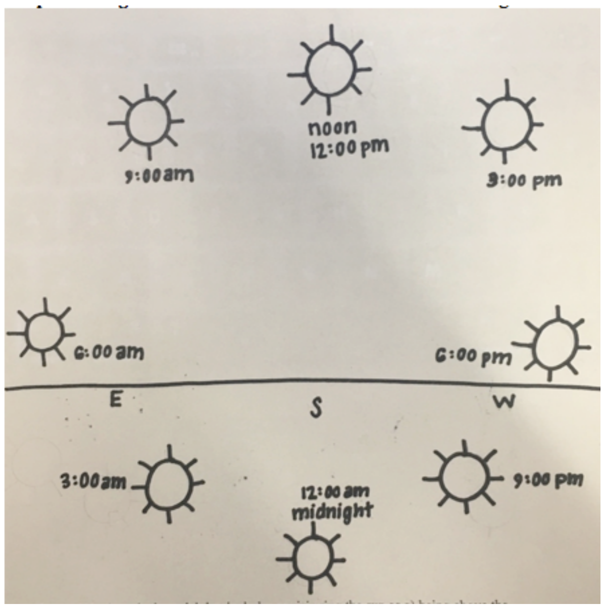


FIG. 5.23 (repeated) Student's sketch for a sun clock.

People have believed in this model, that the Earth is at rest in the center of the universe, for thousands of years. Aristotle, a Greek philosopher (384 BC – 322 BC), for example, built upon earlier ideas by Plato and Eudoxus to propose that the Moon, Sun, planets, and fixed stars all revolve around the Earth on a series of concentric transparent crystalline spheres. (see: http://www.pas.rochester.edu/~blackman/ast104/aristotle8.html).

Ptolemy, a Greek astronomer who lived in Egypt during the 2nd century (85-165 AD), tried to summarize everything known about astronomy at that time. He presented a complex mathematical Earth-centered model that predicted well the motions of the Sun, Moon, planets and stars (see: http://www.polaris.iastate.edu/EveningStar/Unit2/unit2_sub1.htm). His writings, a series of books known as the *Almagest*, were accepted for about 1400 years.

B. Developing the *Fixed Sun, Rotating Earth* explanatory model for day and night

An alternative model is harder to envision. How might the Earth be moving that makes the Sun seem to be revolving daily around the Earth? If a lamp representing the Sun is fixed in place, how can you move yourself to make the lamp seem to appear and disappear? Spin! By spinning your body around in a circle, you can make the lamp seem to 'rise' and 'set'.

As shown in Fig. 5.25, a spinning Earth represents the fixed Sun, rotating Earth explanatory model for day and night.

FIG. 5.25 Fixed Sun, Rotating Earth explanatory model for day and night.

Equipment: To act out this model, use a lamp without a shade in a dark room as

representing the Sun, your head as representing the Earth, and your arms as forming a horizon. Also use a globe of the Earth and Internet resources about a Foucault pendulum and Coriolis effects.

- How can you move your body to act out this model?
    - Stand with both arms forming a horizon by being stretched out horizontally at your sides, with your head facing forward. Move so that the lamp seems to be rising, transiting, and setting although it remains fixed in place.
    - Start by standing with a hand pointing at a lamp representing the Sun; this represents your position on a rotating Earth for which the Sun is just coming into view at the eastern horizon at about 6 a.m.
    (In the northern hemisphere where we live, point East with your left hand; in the southern hemisphere, point East with your right hand.)
    - Continue holding your arms out horizontally at your sides while turning your body until you are facing the lamp; this represents your position on a rotating Earth for which the Sun appears to be high in the sky at about noon.
    - Continue turning your body until your other hand is pointing at the lamp; this represents your position on a rotating Earth for which the Sun is passing out of view at the western horizon at about 6 p.m.
    - Continue turning your body until your head is facing away from the lamp; this represents your position on a rotating Earth for which the Sun is completely out of view at about midnight.
    - Continue turning your body until your hand is again pointing east at the lamp; this represents your position on a rotating Earth for which the Sun is just coming into view again in the eastern horizon at about 6 a.m.
- What evidence supports this model?

None to which we have direct access in this course. So far, this is just a theoretical idea that we have been acting out with the movements described above.

An everyday way to help students visualize the Fixed Sun, Rotating Earth model, however, is to take advantage of equipment frequently found in classrooms: a globe of the Earth.

- Tape a stick figure on the globe, at the place representing where you live

◦ Turn out the lights, turn on a lamp without a shade, spin the globe and watch the stick figure spin in and out of the light shining on it from the lamp.

Note that this is another illustration of the proposed model of a rotating Earth rather than evidence that supports its confirmation.

This is known as the *heliocentric* model. The prefix *helio-* refers to the Sun and *centric* refers to something that is at the center, something around which other things revolve.

Later in this course, you will develop a logical argument in favor of the Fixed Sun, Rotating Earth model. Meanwhile, here is some information about physical evidence for the Fixed Sun, Rotating Earth model that can be obtained with resources outside this course:

- To observe an effect of the rotation of the Earth, visit a Foucault pendulum as shown in Fig. 5.26. (See https://en.wikipedia.org/wiki/List_of_Foucault_pendulums for suggestions of where one can see such a pendulum. There is one, for example, at the Portland Oregon Convention Center, https://www.youtube.com/watch?v=6oYvffE6iGY , http://www.seattleastronomy.com/blog1/2011/10/the-worlds-biggest-foucault-pendulum/) Watch as a pendulum on a long cable swings back and forth. After a while the pendulum will appear to be swinging in a different direction as the floor has rotated underneath it as indicated by the fallen pegs in Fig. 5.26.

FIG. 5.26 Foucault pendulum at Museu de les Ciències, Valencia, Spain by Daniel Sancho. This file is licensed under the Creative Commons Attribution-Share Alike 2.0 Generic license.

- To watch a Foucault pendulum in action via the Internet (see: https://www.geophysik.uni-muenchen.de/outreach/foucault-pendulum) or simulated (https://www.classzone.com/books/earth_science/terc/content/visualizations/es0403/es0403page01.cfm?chapter_no=visualization.)

Léon Foucault (1819-1868) demonstrated the Earth's rotation in this way in Paris in 1851 (https://www.aps.org/publications/apsnews/200702/history.cfm).

Another effect of the Earth's rotation involves weather. Storms in the northern hemisphere swirl counterclockwise whereas those in the southern hemisphere swirl clockwise. Gustave Coriolis, (1792-1843), a French mathematician and engineer, explained this effect. For information about the Coriolis effect, see: https://www.youtube.com/watch?v=i2mec3vgeaI and https://www.nationalgeographic.org/encyclopedia/coriolis-effect/

For a real-time demonstration of the Coriolis effect, download a free version of the app *my radar*, open, scroll through "layers" until you see "wind," click on wind, broaden the view until you can see the oceans in both hemispheres and watch how the winds swirl. The red dots indicate earthquakes.

- How do the wind patterns shown in Fig. 5.27 indicate where the equator is?

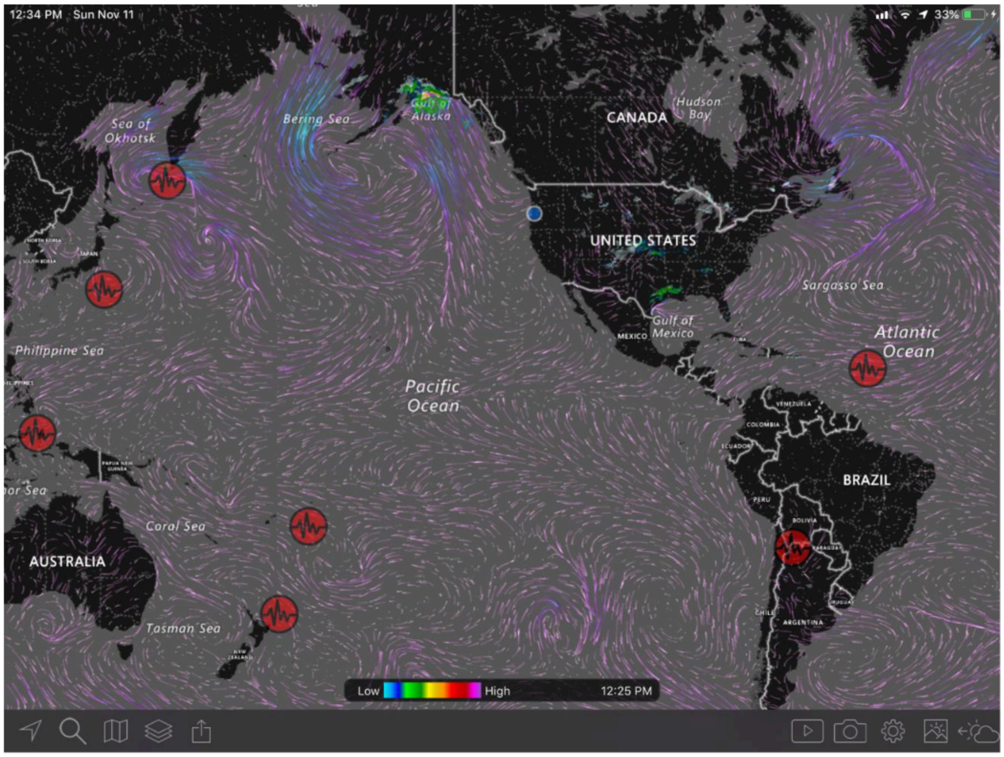


Fig. 5.27. Example wind patterns in the northern and southern hemispheres. https://www.myradar.com

See https://www.jpl.nasa.gov/spaceimages/details.php?id=pia20365 for examples of ways that such wind diagrams can help develop understandings of El Niño events.

- Make sketches illustrating the two explanatory models for day and night.
- Also complete entries in Table V.3. Then write a summary of what you have learned before reading an example of student work about explanatory modes for day and night. Also available is a brief introduction to historical interpretations of these phenomena.

TABLE V.3 Developing Two Explanatory Models for Day and Night

TABLE V.3 Developing Two Explanatory Models for Day and Night/th>			
URL/Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
http://www.polaris.iastate.edu/EveningStar/Unit2/unit2_sub1.htm		Fixed Earth, Revolving Sun Explanatory Model: Sun seems to move east to west, revolving around the Earth each day. Moon, planets, stars also seem to do this.	Aristotle (384-322 BC) Ptolemy 2nd century AD Sun clock model Revolve Geocentric model
http://ian.umces.edu/blog/2014/01/14/nicholas-copernicus-and-the-copernican-revolution/ (scroll to assumption #5) https://www.classzone.com/books/earth_science/terc/content/visualizations/es0403/es0403page01.cfm?chapter_no=visualization http://education.nationalgeographic.com/education/encyclopedia/coriolis-effect/?ar_a=1 https://www.youtube.com/watch?v=i2mec3vgeaI		Fixed Sun, Rotating Earth Explanatory Model: Sun seems to be fixed. Moon, planets, stars also seem to be fixed over 24 hours Earth rotates on its axis.	Copernicus (1543 AD published book) Foucault pendulum Coriolis effect Spinning globe model Rotate Heliocentric model

1. Example of student work about developing two explanatory models for day and night

In representing the Fixed Earth, Revolving Sun exploratory model as shown in Fig. 5.28, the student drew a stick figure to represent a person on a fixed earth. An arm points to the east, where the Sun seems to rise; next the arm points high in the sky, where the Sun seems to be about noon; and then the arm points to the west, where the Sun seems to set. To complete this representation, the arm finally swings down and around back up to the rising position in the east to represent the Sun continuing its journey below the horizon

In representing the Fixed Sun, Rotating Earth explanatory model, the student wrote, *Sun represented by light on stool, moon represented as basketball held in one place. I am earth and I rotate counterclockwise. Left hand = rising, facing = high, right hand = setting; *facing south.*

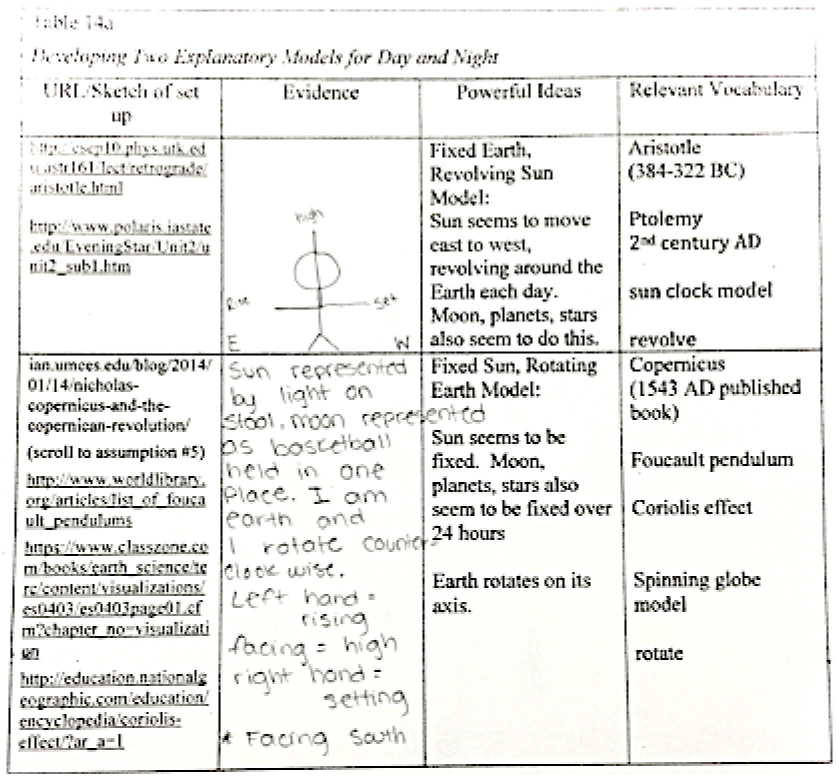


Table 14a

Developing Two Explanatory Models for Day and Night

URL/Sketch of set up	Evidence	Powerful Ideas	Relevant Vocabulary
http://csep10.phys.utk.edu/astr161/lect/retrograde/aristotle.html http://www.polaris.iastate.edu/EveningStar/Unit2/unit2_sub1.htm		Fixed Earth, Revolving Sun Model: Sun seems to move east to west, revolving around the Earth each day. Moon, planets, stars also seem to do this.	Aristotle (384-322 BC) Ptolemy 2nd century AD sun clock model revolve
ian.umces.edu/blog/2014/01/14/nicholas-copernicus-and-the-copernican-revolution/ (scroll to assumption #5) http://www.worldlibrary.org/articles/list_of_foucault_pendulums https://www.classzone.com/books/earth_science/terc/content/visualizations/es0403/es0403page01.cfm?chapter_no=visualization http://education.nationalgeographic.com/education/encyclopedia/coriolis-effect/?ar_a=1	Sun represented by light on stool, moon represented as basketball held in one place. I am earth and I rotate counter-clock wise. Left hand = rising facing = high right hand = setting * Facing South	Fixed Sun, Rotating Earth Model: Sun seems to be fixed. Moon, planets, stars also seem to be fixed over 24 hours Earth rotates on its axis.	Copernicus (1543 AD published book) Foucault pendulum Coriolis effect Spinning globe model rotate

FIG. 5.28 *A student's entries in a table about explanatory models for day and night.*

Developing two explanatory models for day and night. *…we discussed two explanatory models for day and night. We demonstrated these ideas by using our arms, a basketball, a light, and…our bodies to represent the Sun, the Moon, and the…earth.*

A Fixed Earth, Revolving Sun Model can explain day and night. *As we have observed, the sun seems to rise in the east, move high across the sky, and set in the west. During this motion we stay 'right here' on a fixed earth. This sounds familiar because this model is what we typically think: the sun rises and sets…In class we* *modeled this by pointing one arm out with our hand representing the sun and then moving that arm in a circle to represent the sun rising, high in the sky, and setting.*

A Fixed Sun, Rotating Earth Model also can explain day and night. *In this model the Sun is thought of as "just there" and we on the earth are moving. We modeled this in class by holding both arms straight out to our side, with one pointing at the lamp, then rotating in place so that the lamp (sun) seemed to rise, be high in the sky, and set while we spun around. First one arm pointed to the lamp (rising) and then (we were) facing the lamp (noon) and the other arm pointed to the lamp (setting) and then (we were) facing away from the lamp (midnight) and continuing to turn so the other arm was once again pointing at the lamp (rising).*

Physics student

2. Interpreting two different models for the same phenomenon

Having two different models that explain the same phenomenon frequently occurs as one is exploring something of interest systematically. Eventually arguments based on evidence may lead to confirming one explanation as more likely than the other. However, both can be useful in particular contexts.

When enjoying a beautiful sunset, for example, it is easy to "see" the Sun sinking toward the horizon and hard to envision oneself instead as whizzing by a fixed Sun. The Fixed Earth, Revolving Sun model seems attractive in that one can daily observe the Sun apparently rising, moving high across the sky, and setting instead of thinking of oneself as spinning by the Sun while on the surface of a rotating Earth. The Fixed Earth, Revolving Sun model also can be useful, as in our formal process for predicting when and where to look for the Moon as summarized in Table V.1.

The history of ideas about the Earth's rotation is connected to ideas about the Earth's relation to the Sun. In the early 1500's, a Polish astronomer, Nicholas Copernicus (1473-1543), wrote in Latin about his assumptions that the Earth spins on its axis as it revolves around the Sun, rather than the firmament (sun, moon, planets, and stars) revolving around the Earth:

5. *Whatever motion appears in the firmament arises not from any motion of the firmament, but from the earth's motion. The earth together with its circumjacent elements performs a complete rotation on its fixed poles in a daily motion, while the*

firmament and highest heaven abide unchanged. (translation)

6. *What appear to us as motions of the sun arise not from its motion but from the motion of the earth and our sphere, with which we revolve about the sun like any other planet. The earth has, then, more than one motion. (translation)*

Nicolaus Copernicus, Commentariolus

(http://ian.umces.edu/blog/2014/01/14/nicholas-copernicus-and-the-copernican-revolution/).

This perspective was so controversial, however, that Copernicus did not publish his ideas until 1543. His book *On the Revolutions of the Heavenly Sphere* appeared shortly before his death.

Almost a century later, in 1632, Galileo (1564-1642) published a book, *Dialogue*, later titled *Dialogue Concerning the Two Chief World Systems*, in which he presented a discussion among three individuals about the generally accepted geocentric Ptolemaic system and the heliocentric Copernican system. In 1633, the Roman Catholic Church banned Galileo's writings, including this book, and placed him under house arrest until his death in 1642.

During the 350th anniversary of Galileo's death, in 1992, Pope John Paul II addressed the Pontifical Academy of Sciences about "the Galileo case." He reported the findings of a committee that had concluded that Galileo's preference for the Copernican perspective was correct. (See https://www.nytimes.com/1992/10/31/world/after-350-years-vatican-says-galileo-was-right-it-moves.html). In his speech to the Academy, Pope John Paul II said,

12. *Another lesson which we can draw is that the different branches of knowledge call for different methods. Thanks to his intuition as a brilliant physicist and by relying on different arguments, Galileo, who practically invented the experimental method, understood why only the Sun could function as the centre of the world, as it was then known, that is to say as a planetary system. The error of the theologians of the time, when they maintained the centrality of the Earth, was to think that our understanding of the physical world's structure was, in some way, imposed by the literal sense of the Sacred Scripture. Let us recall the celebrated saying attributed to Baronius: "Spiritui Sancto mentem fuisse nos docere quomodo ad coelum eatur non quomodo coelum gradiatur."* In fact the Bible does not concern itself with the details of the physical world, the understanding of which is the competence of human experience and reasoning. There exist two realms of knowledge, one which has its source in*

Revelation and one which reason can discover by its own power. To the latter belong especially the experimental sciences and philosophy. The distinction between the two realms of knowledge ought not to be understood as opposition. The two realms are not altogether foreign to each other; they have points of contact. The methodologies proper to each make it possible to bring out different aspects of reality.

Pope John Paul II, 1992

Pope John Paul II, Address to the Plenary Session on 'The Emergence of Complexity in Mathematics, Physics, Chemistry and Biology' 31 October 1992, (Vatican City: the Pontifical Academy of Sciences). http://www.accademiascienze.va/content/accademia/en/magisterium/johnpaulii/31october1992.html

*Galileo also had quoted this saying in a letter to the Grand Duchess Christina of Tuscany in 1615: *I would say here something that was heard from an ecclesiastic of the most eminent degree: "That the intention of the Holy Ghost is to teach us how one goes to heaven, not how heaven goes."* (lines 373-376, bottom of page 5) https://hti.osu.edu/sites/hti.osu.edu/files/galileo_galilei.pdf

In this address, Pope John Paul II drew a clear distinction between the realm of religious faith and the realm of the experimental sciences while offering respect for both. The methodology of science involves making claims based on evidence and presenting arguments that explain the rationale for why the evidence supports the claim.

V. Using Central Ideas to Develop an Explanatory Model for the Phases of the Moon

As noted in II.B.4, *Joseph's Moon*, even very young children are aware of the Moon and able to communicate what they are observing. That the Moon often is visible during the day is a surprise to many adults. After starting to notice the Moon during the day, many also become puzzled that the Moon sometimes seems to chase the Sun across the sky but sometimes the Sun seems to chase the Moon. Also intriguing after more systematic observation is the paradox that the Moon seems to move like the Sun, from east to west over several hours, but in the opposite direction, from west to east, over several days.

These are examples of the increasing complexity typical of scientific endeavors, in which more detailed observations prompt deeper pondering and questioning. This section explains these observations in the context of developing an explanatory model for the Moon's changing phases. We then consider how the Moon appears to us here on Earth compared to how the Moon would appear if we could look down upon the Moon, Earth, and Sun from above the solar system. The section also discusses the causes of solar and lunar eclipses and concludes with exploring Internet resources about the Moon to share with a friend or family member.

Question 5.23 Why does the Moon seem to have different shapes at different times?

This section begins with a review of relevant central ideas, next presents a report on a child's insights about the Sun and the Moon, and then proceeds with developing an explanation for the Moon's changing phases as seen from here on Earth.

A. Reviewing central ideas about the relationship between the Sun and the Moon

What central ideas developed so far describe the relationship between the Sun and the Moon?

- The Sun is always on the same side as the lit side of the Moon.
- The shape of the lit portion of the Moon that we see from Earth changes in a regular pattern:
  Where we live in the northern hemisphere, the shape of the lit portion of the Moon grows from a crescent lit on the right (waxing crescent), to half lit on the right (first quarter), to more than half lit on the right (waxing gibbous), to fully lit; then decreases to more than half lit on the left (waning gibbous), half lit on the left (third quarter), to a crescent lit on the left (waning crescent), to no moon visible (new moon). In the southern hemisphere, the shape of the lit portion of the Moon changes in a similar pattern but from lit on the left (waxing phases) to lit on the right (waning phases).
- The angle formed by pointing one arm at the Moon and one arm at the Sun changes in a regular pattern related to the changing shape of the lit portion of the Moon that we see:
  As the lit side of the Moon seems to get bigger, the angle gets bigger until the Moon is fully lit and the angle is a straight angle; as the lit side of the Moon seems to get smaller until not visible, the angle gets smaller until the angle is zero.

B. Building upon a child's insights about the phases of the Moon

Andy diSessa (1986) described an experience that he had one day as a child. He was tossing a ball up and catching it when he happened to notice both the moon and the ball as he looked up in the sky. When he tossed the ball straight up so that it was high enough to seem to be near the moon, he suddenly realized, "*I was seeing the phase of my little tennis ball/moon and that it was the same as the phase of the real moon!*" If feasible, we try to schedule modeling the phases of the moon on a sunny day when students can replicate this experience by seeing the lighted side of a ball next to the moon they are seeing in the sky. (We provide balls on sticks that the students hold in their hands rather than tossing their balls.)

diSessa, A. (1986). "Artificial worlds and real experience." *Instructional Science*, **14**, 207-227. (p. 213).

C. Developing an explanatory model for the phases of the Moon

As a first step in explaining the changing phases of the Moon, consider the following:

- What is the source of the light that shines on the Earth from the Moon?
- What phase is the Moon in today?
- What do you expect to see in the next few days?

Equipment: To model the phases of the Moon, go outside on a sunny day or use a lamp without a shade to represent the Sun in a dark room; use a small ball (golf ball, ping pong ball, Styrofoam ball) on a stick to represent the Moon, and your head to represent the Earth.

- If outside, DO NOT LOOK DIRECTLY AT THE SUN!
  If inside, stand well away from a lamp without a shade in a dark room.
- How can you hold up your ball so that the lit portion of the ball looks like the current lit portion of the Moon in the sky?
- How can you move your ball to see on the ball here on Earth all of the phases of the Moon that you have been observing in the sky?
  - For example, hold the ball up so that the Sun (or the lamp) is shining on the ball to light the ball as a **waxing crescent** ball.
    What is the angle formed by pointing one arm at the Sun (or lamp) and the other arm holding out the ball?
  - What phase will the Moon have next?
  - How can you move the ball to match a **first quarter Moon?**
    What is the angle for arms pointing at the Sun and first quarter Moon?
  - How can you move the ball to match a **waxing gibbous Moon?**

What is the angle for arms pointing at the Sun and a waxing gibbous Moon?

- How can you move the ball to match a **full Moon?**
  What is the angle for arms pointing at the Sun and a full Moon?
  To avoid a lunar eclipse hold the ball a little above your shadow.
- How can you move the ball to get it to look like a **waning gibbous Moon**?
  What is the angle for arms pointing at the Sun and a waning gibbous Moon?
- How can you move the ball to get it to look like a **third quarter Moon**?
  What is the angle for arms pointing at the Sun and a third quarter Moon?
- How can you move the ball to get it to look like a **waning crescent Moon**?
  What is the angle for arms pointing at the Sun and a waning crescent Moon?
- How can you move the ball to get it to "look" like a **new Moon**?
  What is the angle for arms pointing at the Sun and a new Moon?
  To avoid a solar eclipse hold the ball a little above your view of the lamp.

- How have you moved the ball to replicate seeing on the ball the same pattern of changing phases here on Earth that you have observed on the Moon in the sky?
- What can you infer is the cause of the changing phases of the Moon?
- Make a series of sketches that illustrate how you used the Sun (or a lamp without a shade as a model of the Sun), a ball on a stick, and yourself to model the phases of the Moon.

This explanatory model for the phases of the Moon can be summarized as:

The phases of the Moon are caused by the Moon revolving around the Earth.

- Take the perspective of looking down on this Sun/Earth/Moon system from above:
  - Model this in a dark room lit by a lamp with no shade.
  - Hold one hand out in front of your body, thumb up, so you are looking down on the thumb from above. Let the thumb represent the Earth.
  - Hold a ball in the other hand to represent the Moon. Move the ball around your thumb while looking down on both.
  - For each phase, look at the side of the ball that is facing toward the lamp. How is it lit?
  - For each phase, look at the side of the ball that is facing away from the lamp. How is it lit?

- What does this imply about the shaded side of a phase of the Moon as seen from Earth?

Complete entries in Table V.4. Then write a summary of what you have learned before reading an example of student work about developing an explanatory model for the phases of the Moon.

TABLE V.4 Developing an Explanatory Model for the Phases of the Moon

TABLE V.4 Developing an Explanatory Model for the Phases of the Moon

Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
		Light from the Sun is reflected from the Moon toward the Earth	
https://starchild.gsfc.nasa.gov/docs/StarChild/questions/phases.html		The phases of the Moon are caused by the Moon revolving counterclockwise around the Earth about once a month as seen from our location in the northern hemisphere.	

		The side of the Moon facing the Sun is always fully lit.	
		The shaded side of a phase of the Moon is the shadow of the Moon on itself. It is not the shadow of the Earth.	

1. Examples of student work developing an explanatory model of the phases of the Moon

The Sun is the source of light from the Moon on the Earth. *Through our knowledge that the Moon does not appear to be fully lit, based on our observations, we can infer that this light is not coming from the Moon but from another source.*

We can also surmise that from these observations we see the lit portion of the Moon to be always on the same side as the Sun, so the Moon's light is coming from the Sun.

We infer that light rays from the Sun are bouncing off the Moon in all directions from the surface of the Moon that is facing the Sun; some of these light rays travel in the direction of Earth when some of the lit part of the Moon's surface is facing Earth.

The phases of the Moon are caused by the Moon revolving counter-clockwise around the Earth about once a month as seen from our location. *Going to the roof of a building you can create a replication of what happens with the Earth, Sun and Moon. The Sun was the Sun and I was me standing on Earth and I used a physical model of the Moon (a ball) to represent the Moon.*

By holding the ball directly in front of the sun, in front of my face, this represented new moon. (The ball blocked the light of the Sun from my eyes.)

By moving the ball to the left at an acute angle from the sun we were able to see the depiction of the waxing crescent moon on the ball.

We did this at each stage as we simulated a revolution of the ball around the "earth" to see all the phases of the moon until the ball was in front of us and the sun, creating a new moon once again.

This could also be done in a darkened room with a light from a lamp representing the Sun, but if you are doing this method you have to remember to back up across the room to get the right effect on the ball.

From these activities here on Earth we can infer that we see the changing phases of the Moon in the sky because ***the Moon is REVOLVING around the Earth.***

Physics student, Fall 2014

Another student included a set of diagrams that showed the Sun as well as a student holding a ball on a stick in such a way as to show the lit portion on the ball for each phase of the ball. The angles formed by pointing toward the Sun (in the sky or toward a lamp in a dark room) and holding out the ball were the same as observed in the sky for the phases when pointing one arm at the Sun and the other arm at the Moon.

As shown in Fig. 5.29, the student was able to create on the ball the phases seen as waxing crescent, first quarter, waxing gibbous, and full Moon in the sky.

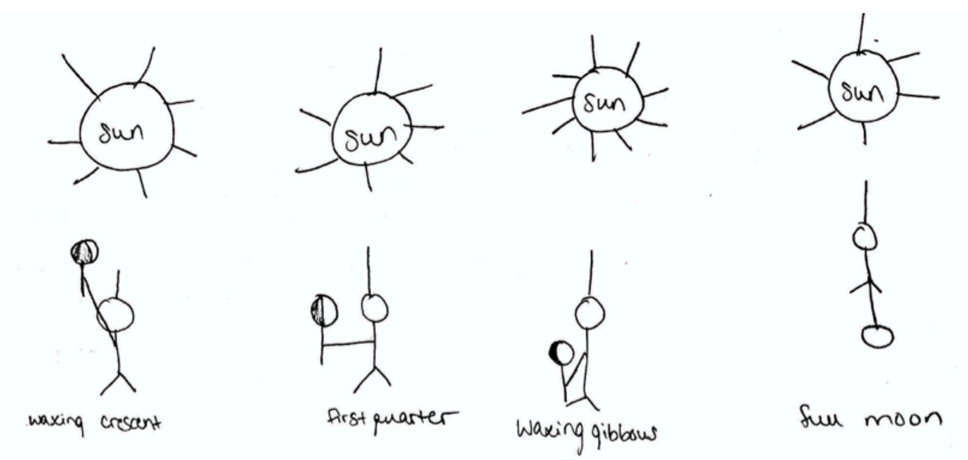


FIG. 5.29 *Student using a ball on a stick to model the waxing phases of the Moon.*

As shown in Fig. 5.30, the student also was able to create on the ball the phases seen as waning gibbous, third quarter, waning crescent, and new Moon in the sky.

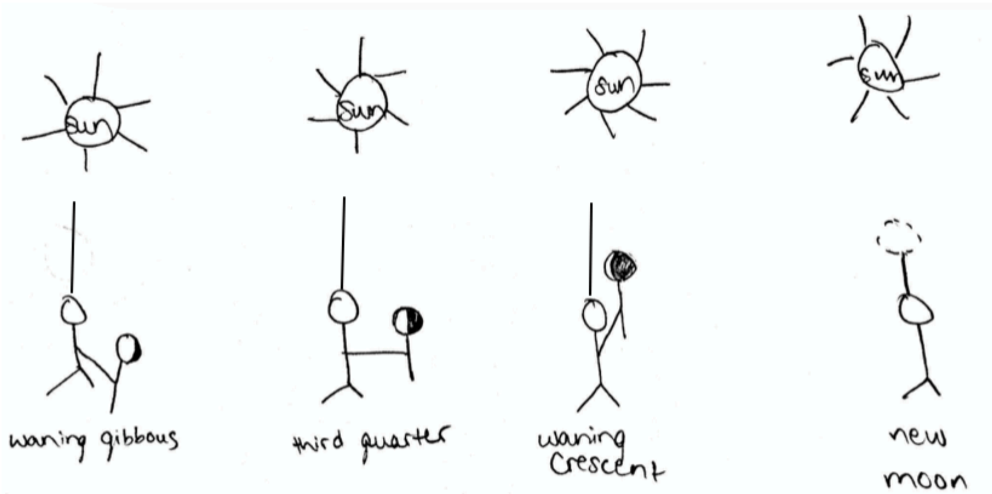


FIG. 5.30 Student using a ball on a stick to model the waning phases of the Moon.

Physics student, Fall 2016

Figures 5.29 and 5.30 suggest why this process has been dubbed *Moon Dance 2*.

To model the phases of the Moon as seen from above the solar system, the students held out their thumbs and looked down as they moved their balls around their thumbs. This showed clearly that in all positions the side of the ball facing toward the lamp was always fully lit and that the side of the ball facing away from the lamp was always dark. A student reflected upon the experience of looking down on the ball as it revolved around the thumb as follows:

> ***The side of the Moon facing the Sun is always fully lit.*** *In class students were given a ball on a stick. This ball was small, approximately the size of a ping pong ball. Students were asked to picture their thumb as the earth, and to revolve the "moon" around our "earth". While doing this a lamp was placed on one side of the room and turned on to represent the sun. As students revolved their moon around their earth they were able to see that in fact there is always half of the moon being lit, the portion that is pointing towards the sun. However, due to the position of the moon in reference to the earth we cannot always see this full lit portion.*
>
> ***The dark side of the moon is the shadow of the Moon on itself.*** *Students learned in one of our early lessons that there are two types of shadows, there is a shadow cast by an object blocking light from traveling on its intended path, and there is a shadow formed on the back of the object that is blocking the light. The dark side of the moon is actually the shadow formed on the back of the object blocking the light, the moon.*

Physics student, Fall 2015

When asked why the moon seems to have different shapes at different times, many people attribute the shaded side of a phase of the Moon to the shadow of the Earth. This may be because they associate shadows with situations in which light from a source is blocked by a barrier. In this case, however, the barrier is the Moon itself. This is similar to the shadow on the back side of a barrier placed between a lamp and a screen, as in Question 1.6 and Fig. 1.8 in Unit 1.

D. Explaining a paradox based on detailed observations of the Moon

Question 5.24 Why does the Moon seem to move east to west during several hours but west to east during several days?

- Discuss a paradox that has emerged from detailed observations of the Sun and Moon
    - Present observations that indicate that the Moon seems to move from east to west during several hours.
    - Also present observations that indicate that the Moon seems to move from west to east during several days.
    - Explain this paradox using the explanatory models developed for day and night and for the phases of the Moon.
- What does this explanation imply about the status of the two models for day and night?

Complete entries in Table V.5. Then write a summary of what you have learned before reading an example of student work about developing an explanation of the paradox that the Moon seems to move from east to west during several hours but west to east during several days.

TABLE V.5 Explaining a Paradox Based on Detailed Observations of the Moon

TABLE V.5 Explaining a Paradox Based on Detailed Observations of the Moon			
Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
		The Moon seems to move east to west during several hours because the viewer on the surface of the Earth is moving, spinning by the Moon as the Earth rotates daily on its axis.	
		The Moon seems to move west to east during several days because the Moon actually IS moving as it revolves counterclockwise around the Earth as seen from our location in the northern hemisphere.	

1. Example of student work resolving the paradox about the apparent movements of the Moon

In figure (5.31) below, we were drawing a model for our observations of the sky over several hours. When we watch the sun and moon over several hours, the sun seems to rise in the east, move across the sky in an arc shape, and then set in the west. The moon seems to do the same by rising in the east, transitioning across the sky in an arc and setting in the west. This model makes it appear as if, for day and night, the planet Earth is stationary and the sun and moon are revolving around the earth each 24 hours. This model is easy for one to wrap the brain around, as it is what we initially observe, and it is in the language we learned to describe what we see, the sun rises, the sun sets. This model is challenged, however, by the second model, figure (5.32).

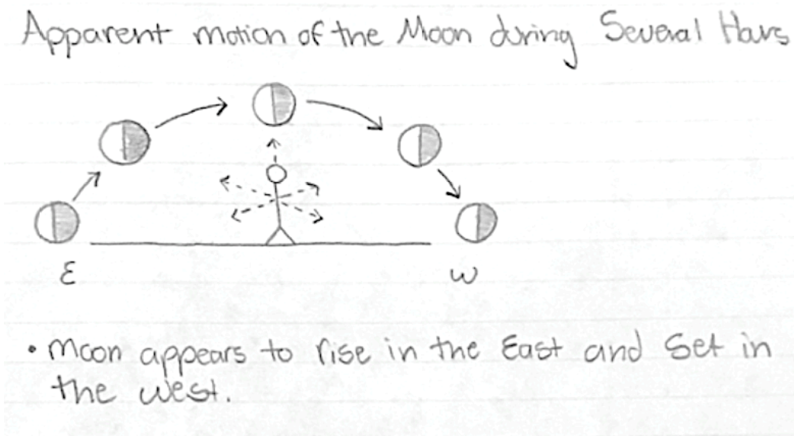


FIG. 5.31 Student sketch of 3rd quarter moon appearing to move east to west during several hours.

In figure (5.32), *we were drawing a model for if one was to watch the sky over several days, observing at the same time each day. In this model, the moon seemed to move from west to east, contrary to the first model. If someone were to look at the moon over many days at 6 pm, where we live they would see a waxing crescent moon low in the southwestern sky, then a first quarter moon high in the southern sky, followed by a waxing gibbous moon midway up in the southeastern sky, and finally a full moon rising in the east. This model makes it seem as if the moon is revolving around the earth from west to east over about two weeks.*

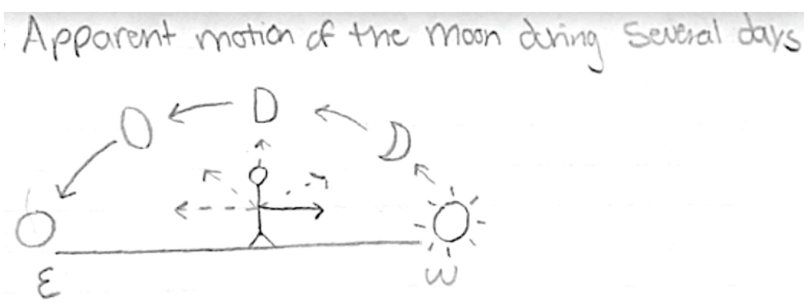


FIG. 5.32 Student sketch of subsequent phases appearing to move west to east during several days when viewed from the same location at the same time such as 6 pm each day.

These two models pose a paradoxical situation where the moon both seems to be moving across the sky from east to west, and west to east. How can this be? Well it *is important to understand that, although we can more easily accept the stationary Earth model in figure* (5.31), *that model does not make it the best. In order to explain this paradox, we need to be able to accept (the following).*

The sun is still and it is the earth that is moving by rotating on its axis. If we remain in the same location on the earth as it first rotates by the sun, the sun seems to rise in the east. As (*our location on) the earth rotates directly by the sun, the sun seems to be moving high across the sky, around noon. Finally, as (our location on) the earth spins all the way past the sun, the sun seems to set, and the daylight ends. When our location on* Earth *rotates away from the sun, it becomes night.*

The same happens with the moon. The earth's first rotation by the moon shows the moon appearing to rise. As *(our location on) the earth spins directly by the moon, the moon seems to be transitioning across the sky in an arc.* As *(our location on) the earth finally spins all the way past the moon, the moon seems to be setting. This model is a way to defend the apparent daily east to west motion of both the sun and moon due to the earth's daily rotation on its axis.*

In class, we used ping pong balls on a stick to represent the moon and a lamp to represent the sun…With the ball on the stick physical model representing the moon we replicated the changing phases of the moon. By moving the ball in an orbit around our heads, we could see the waxing crescent ball, first quarter ball, waxing gibbous ball, full ball, waning gibbous ball, third quarter ball, waning crescent ball, and new ball.

From these models, we can infer that the moon is moving from west to east over about two weeks, caused by the moon revolving around the earth. We also could see that the fixed sun, rotating earth model was the truer model. The apparent east to west movement during the day is only due to the earth spinning on its axis. That is how we have explained this paradoxical situation.

Physics student, Fall 2016

Note the difference in meaning between the two words describing the motions involved here:

REVOLVE: one object moves around another; the Moon REVOLVES around Earth roughly once a month (29.5 days)

ROTATE: spinning on an axis; the Earth ROTATES once daily

2. Acting out the explanation of this paradox

Playing the roles of an observer on Earth, of the Moon, and of the Sun in the paradox can help build understandings of what the paradox is and how it can be explained:

Equipment: Small groups of three students work together to act out this paradox: use a flashlight to represent the Sun and a ball to represent the Moon; one person plays the role of an observer on Earth, another person holds the ball and plays the role of the Moon, the third person holds the flashlight and plays the role of the Sun.

- Where should the "Moon" person stand with respect to the "Sun" person and the "Earth" person in order to model the current phase of the Moon?

- For a first quarter Moon, for example, the "Moon" person should stand so that the "Earth" person can form a right angle by pointing arms at the "Sun" person holding the flashlight and at the "Moon" person holding the ball. As shown in Fig. 5.3, this could model a rising first quarter Moon .

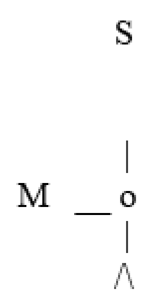


FIG. 5.33 Modeling a rising first quarter Moon as seen when the transiting Sun is high in the southern sky at our location in the northern hemisphere.

- These positions model an observer at our location who is looking at a rising first quarter Moon and pointing arms at the Sun and the Moon, where the arms form a right angle. What time is it when the first quarter Moon is in the rising position?

- How can you model the apparent east to west daily motion of the Moon? There are two models:
  - One model is the *Fixed Earth*, *Revolving Sun* model. What would the "Earth Person" do to act out this model? What would the "Sun" person do? What would the "Moon" person do?
  - The "Earth" person would just stand there, for example, while watching the "Sun" person and the "Moon" person moving quickly in a circle around the "Earth" one time. Which way would they move: clockwise or counterclockwise?

  - The other model is the *Fixed Sun*, *Rotating Earth* model. What would the "Sun" person do to act out this model? What would the "Earth" person do? What would the "Moon" person do?
  - The "Sun" person would just stand there, for example, as would the "Moon" person for now. The "Earth" person would model a rotating Earth. How would the "Earth" person do that? .

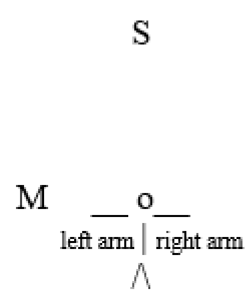


FIG. 5.34. Modeling the apparent east to west motion of a first quarter Moon due to the rotation of the Earth (as seen from our location in the northern hemisphere).

  - As shown in Fig. 5.34, the "Earth" person could start by modeling what happens when the first quarter Moon appears to be rising. Instead of using arms at right angles to point at the Moon and the Sun, the "Earth" person would hold both arms stretched out to the side to represent the horizon. One arm would represent looking east, the other arm would represent looking west. Wherever the "Earth" person faces would represent looking high in the sky (south in the northern hemisphere, north in the southern hemisphere).

- In this starting position, the "Earth" person would be pointing the "looking east" arm at the "Moon" person while facing the "Sun" person. This would model a first quarter Moon rising in the east while chasing a transiting Sun high in the sky at noon.
- After rotating a quarter turn, the "Earth" person would be facing the "Moon" person while pointing the "looking west" arm at the "Sun" person. This would model a first quarter Moon transiting high in the sky while chasing a setting Sun at about 6 p.m.
- After rotating another quarter turn, the "Earth" person would be pointing the "looking west" arm at the "Moon" person while facing away from the "Sun" person. This would model a first quarter Moon setting in a dark sky with the Sun not in sight at about midnight.
- After rotating another quarter turn, the "Earth" person would be pointing the 'looking east" arm at the "Sun" person while facing away from the "Moon" person. This would model a rising Sun with the Moon not in sight at about 6 am.
- The next quarter rotation would return to the initial position modeling a rising first quarter Moon with a transiting Sun high in the sky at about noon.
- During one rotation by the "Earth" person, both the "Sun" person and the "Moon" person will appear to the "Earth" person as having risen, transmitted, and set even though neither moved at all.

- Practice both models, with each person playing each role, until all are confident about understanding both models for explaining the apparent east to west daily motion of the Moon.

Now consider what is happening during the apparent motion of the Moon from west to east over several days as illustrated in Fig. 5.32.

- How can you model the apparent west to east motion of the Moon over several days? There are two models:
  - One model is the *Fixed Earth, Revolving Sun* model. What would the "Earth Person" do to act out this model? What would the "Sun" person do? What would

the “Moon” person do?

- The “Earth” person would just stand there, watching while the “Sun” person and the “Moon” person move quickly in a circle around the “Earth” many times. If starting in the first quarter phase, for example, the “Moon” person would appear to be chasing the “Sun” person but slowing down, falling more and more “behind” the “Sun” person during each of the 7 cycles (days) until full Moon ; however, after the full Moon phase, the “Sun” person would appear to be chasing the “Moon” person, but speeding up, getting closer and closer to the “Moon” person during each of the next 7 cycles (days) until the 3rd quarter Moon. Such complicated slowing down and speeding up motions, with the Moon and Sun changing who seems to be chasing whom, seem problematic.
- The other model is the Fixed Sun, Rotating Earth model. What would the “Sun” person do to act out this model? What would the “Earth” person do? What would the “Moon” person do?
- The “Sun” person would just stand there, watching while the “Earth” person rotates in place with arms outstretched representing the rotating horizon. As the “Earth” person’s arm representing the eastern horizon swings by, the “Moon” person would seem to be rising.
- As the “Earth” person’s face turns toward the “Moon” person, the “Moon” person would seem to be transiting.
- As the “Earth” person’s arm representing the western horizon swings by, the “Moon” person would seem to be setting.
- As the “Earth” person turns away, the “Moon” person would seem to disappear from sight,
- As before, during one rotation of the “Earth” person, the “Moon” person would seem to be moving from east to west, rising in the east, transiting high in the sky, and setting in the west during each cycle.
- Now, however, the “Moon” person would also move, slowly revolving around the “Earth” person. The “Sun” person would continue to just stand in the same place.
- During the first 7 “Earth” person rotations, however, the “Moon” person would revolve to the full Moon position and after another 7 “Earth” person rotations, the “Moon” person would revolve to the 3rd quarter Moon position, which would appear to the “Earth” person as moving west to east as shown in Fig. 5.32.
- Such motions do not require the complexity of a Moon slowing down and a Sun speeding up while changing positions relative to each other. This model involves only an Earth spinning on its axis in a consistent way with a Moon revolving in

its orbit around the Earth, also in a consistent way.

Be sure to shift roles so that all three members of the group play all three roles.

- Discuss with one another which model of the Sun, Earth, and Moon system makes the most sense in this situation: the Fixed Earth and Daily Revolution of the Sun and Moon around the Earth? Or the Fixed, Sun, Daily Rotating Earth, and Monthly Revolution of the Moon around the Earth?

- Summarize concisely what the paradox is and how it can be explained.

Students can conduct this activity without a ball if the "Moon" person's face is regarded as representing the Moon. Another possibility is to have students stand as a group, far enough apart to model rotating Earths, while one student revolves around the group while holding a ball representing the Moon revolving around the Earth and while a lamp simply remains in place.

This complex process of acting out the explanation of the Moon apparently moving east to west over several hours, due to the daily rotation of the Earth, and actually moving west to east over several days, due to the revolution of the Moon around the Earth, has been dubbed *Moon Dance* 3.

E. Considering other aspects of the Moon's motion

Several questions typically arise after students have experience observing the moon and explaining what they have seen. These include whether the moon rotates while it revolves and what the Moon's phases look like from other places.

Question 5.25 Does the Moon rotate while it revolves around the Earth?

- Observe the features visible on the Moon that you see during each phase. (see: https://www.space.com/10610-moon-craters-skywatching-tips.html)
- Do the locations of particular craters seem to change? Is the crater named for Copernicus, for example, always in the same place on the Moon as seen from your

location (midway somewhat to the left of the center as seen from our location)?

- Stand in pairs. One of you model the rotating Earth while the other models the revolving Moon as in Question 5.24. The person modeling the revolving Moon should keep facing the Earth during a complete revolution.
- Start in the new moon position. If the person modeling the revolving Moon always faces the person modeling the Earth, is the "Moon" rotating while revolving?
    - In the new moon position, if the person modeling the revolving Moon is facing the person modeling the Earth, what part of the room is the "Moon" person seeing?
    - In the 1st quarter position, if the person modeling the revolving Moon is facing the person modeling the Earth, what part of the room is the "Moon" person seeing now?
    - In the full moon position, if the person modeling the revolving Moon is facing the person modeling the Earth, what part of the room is the "Moon" person seeing now?
    - In the 3rd quarter position, if the person modeling the revolving moon is facing the person modeling the Earth, what part of the room is the "Moon" person seeing now?
- How many times does the person modeling the Moon rotate while revolving once around the person modeling the Earth?

Question 5.26 What do the phases of the Moon look like from other places on the Earth?

> Equipment: Have available a globe representing the Earth.

- Invite friends or relatives in other places to look for the Moon and alert you when they see it. Are they seeing what you are seeing? The same phase? Lit in the same way? At the same time?

A first-grade teacher, Akiko Kurose, engaged her students in watching the Moon in Seattle. Stella (a pseudonym) continued watching the Moon while visiting Australia with her parents for about a month. The city of Melbourne in Australia is in the southern hemisphere, near the bottom of a typical globe of the Earth as shown in Fig. 5.35. The city of Seattle in the United States is in the northern hemisphere near the top of a typical globe of the Earth. A line around the middle of the globe represents the *equator*.

FIG. 5.35 Globe showing Melbourne in Australia in the southern hemisphere and Seattle the United States in the northern hemisphere. Modified from https://www.flickr.com/photos/healthebay/8139426732/in/photostream/. CC BY-NC-SA 2.0

When Stella returned to Seattle, she and her classmates compared their observations of the waxing crescent Moon as shown in Figs. 5.36 and 5.37.

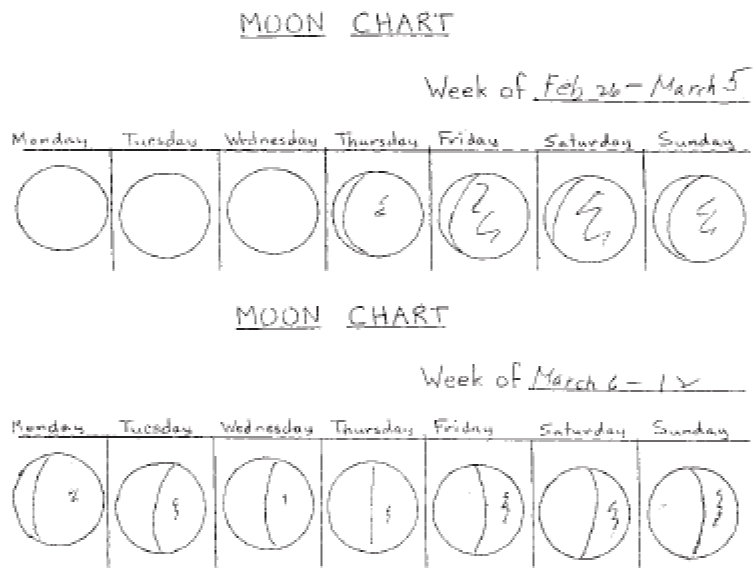


FIG. 5.36 *Observations of the waxing crescent moon in Australia.*

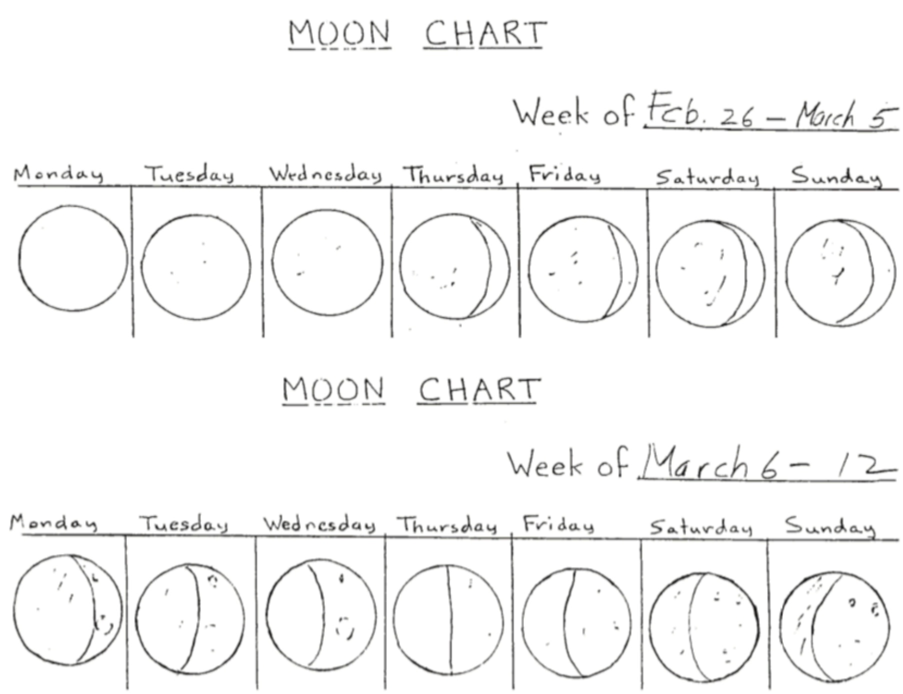


FIG. 5.37 *Observations of the waxing crescent moon in Seattle.*

The teacher was participating in a study in which she routinely audiotaped conversations about science in her class. She reported the following:

…For discussion, we used a globe and a map on the floor. Australia is in the southern and Seattle in the northern hemisphere. Some of the children lay on the floor and realized that if they are upside down something lit on the right looks as if it is lit on the left:

Teacher: Stella, do you want to tell us about your observations in Australia?

Stella: The waxing crescent moon was facing the other way.

Teacher: The waxing crescent moon was facing the other way?

Why do you think it was facing the other way?

Stella: It was on the other side of the world.

The children and I found Australia and Seattle on a globe. Then Stella drew her observation on the board, a crescent moon curved on the left.

Student: It's like the waning crescent.

Student: I thought it was like this! (The child turned upside down.)

Teacher: That's right. When he lies down on the ground he sees it the opposite way.

Then we discussed how the waxing crescent moon would look in Canada.

Student: Right side up.

Teacher: What do you mean right side up?

Student: The way we see it.

Teacher: Do you mean the way we see it in Seattle?

Student: Uh, huh.

Teacher: In Australia, do you think they would think they're upside down?

Student: No. Maybe. Stella thought so.

Teacher: For them, they would think that they're right side up, wouldn't they?

It's just that they see it from a different perspective.

We also discussed how the moon would look in Florida and other places.

Student: My dad's been to Brazil.

Teacher: How do you think you would see the moon there?

Remember where the equator is. Make a hypothesis.

Student: The way Stella saw it in Australia.

Teacher: The way that Stella saw it in Australia….

So it depends upon where you are on earth.

Student: How does it look if you're on the equator?

This was a new and unexpected question, a fascinating one that none of us had thought about before. The teacher reflected upon this experience:

The children's experiences in our daily moon gazings over a period of several months *also nurture their abstract thinking and questioning skills…These experiences engender thoughts about the moon from different places, granting the students the gift of a global perspective. Engagement in this type of abstract thinking and questioning has become part of our class culture, in which virtually all of the children participate.*

Akiko Kurose, "Eyes on science: Asking questions about the Moon on the playground, in class, and at home." *Inquiring into inquiry learning and teaching in science* , edited by James Minstrell and Emily van Zee (American Association for the Advancement of Science, Washington, DC, 2000). (pp. 139-147). https://www.aaas.org/sites/default/files/s3fs-public/InquiryPart2.pdf

These children were very familiar with the Moon from on-going observations together on the playground when the moon was visible during the day and from observations with their families when the moon was visible in the afternoons and evenings or mornings before school. They also were familiar with global thinking from celebrating the multiple countries represented by students in the class, the daily opening activity in which they sang a song in several languages, the world map painted on the floor on which they could choose to sit on different countries, and the globe, which was a familiar reference tool in their explorations of literature and art.

F. Developing representations of the Sun/Earth/Moon system as seen from space

This course has emphasized the exploration of physical phenomena, development of central ideas based on evidence, and the use of these central ideas to develop explanatory models for intriguing phenomena. Through extensive observations and on-going discussions of the Moon and its relation to the Sun, students have produced detailed insights into when and where to look for each phase of the Moon, explained these changing phases, and resolved a complex paradox that emerged from detailed observations. All of this has been based upon the perspective of an observer here on Earth. This section turns toward developing a wider view.

Question 5.27 How are the Sun, Earth, and Moon arranged in space?

Moving one's perspective from what one is seeing oneself to what one would see if one were somewhere else is a complex process. This section provides a report of a child's spontaneous wonderings involving various perspectives and guides students in exploring how the Sun, Earth, and Moon are arranged in space.

1. Building upon a child's spontaneous wonderings

Andy diSessa (1986) continued his story by reflecting upon multiple perspectives that he generated during his experience as a child in tossing a ball and seeing the same phases on both the ball and the moon. He remembered being impressed that even though the moon seemed to be far away, it was "*on the scale set by the distance to the sun, just a next-door neighbor distance*" to him and his ball. This realization led him to imagine himself "*as a viewer far enough away to see the moon and ball as right next to one another in relation to the sun.*" Then he began wondering about the Earth and concluded "*It too must have the same illumination.*" The next section takes up this issue of multiple perspectives, of exploring more explicitly about how things look from space.

diSessa, A. (1986). "Artifical worlds and real experience."*Instructional Science*, **14**, 207-227. (p. 213).

2. Exploring the arrangement of the Sun, Earth, and Moon in space

Equipment: Use a quarter Moon as an example, a lamp with no shade in a dark room, and a basketball to try to reproduce here on Earth what you have seen in the sky.

In order to make connections between how each of the Moon's phases look on Earth and how they each look from space, we need to know how the Sun, Earth, and Moon are arranged in space. An easy phase to think about is a quarter Moon as shown in Fig. 5.38.

- What is the angle formed by pointing your arms at the Sun and a quarter moon?
- When we consider the Sun and a full Moon, how do their sizes compare? (DO NOT LOOK DIRECTLY AT THE SUN!
- How might the Sun, Earth, and Moon be arranged in space?

When solar eclipses occur, the Sun and full Moon appear to be about the same size. This suggests they might be roughly the same distance away from Earth as shown here:

M

S E

Or the Sun might be close to Earth and the Moon far away as shown here:

M

S E

Or the Sun may be far from Earth and the Moon close by as shown here:

M

S E

FIG. 5.38 Three possible arrangements for the Sun, Earth, and Moon in space.

- How can you decide which of these arrangements of the Sun, Earth, and Moon is the case?
- Consider modeling here on Earth what you see in the sky during a quarter Moon:
    - Stand next to a lamp without a shade but do not turn it on yet.
    - Touch the lamp with one hand stretched out.
    - Hold out the ball with the other hand stretched out so the ball and lamp are equally far away.
    - Hold your arms at a right angle as shown in Fig. 5.39.

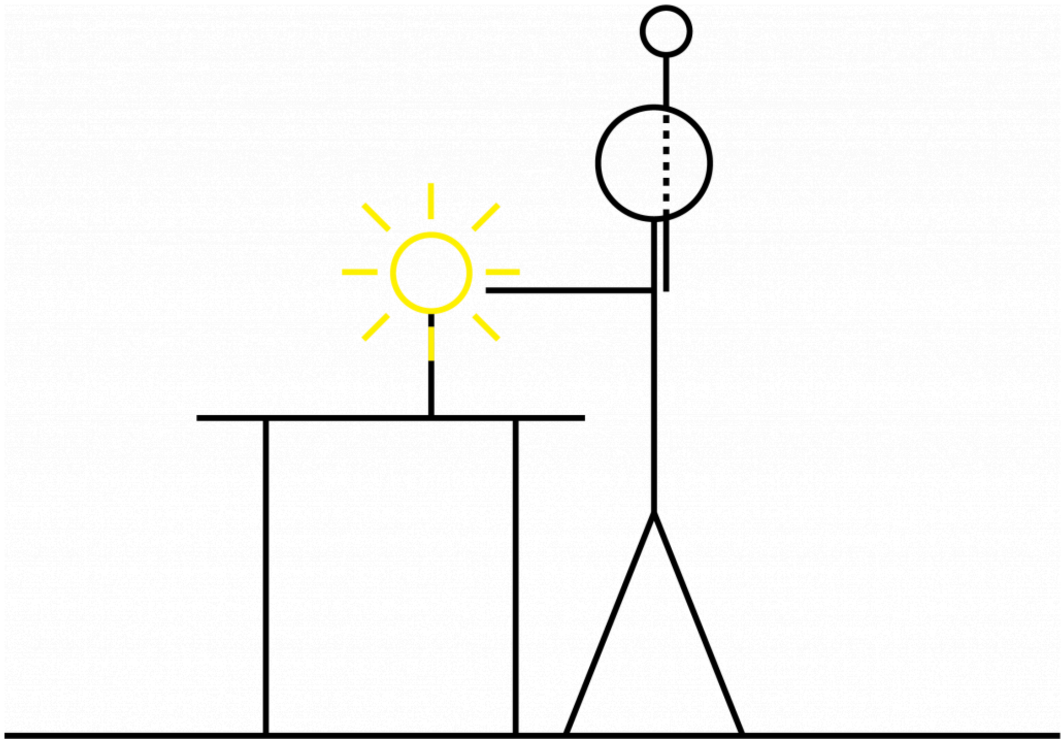


FIG. 5.39 Student holding arms at a 90 degree right angle while holding out ball in one hand and touching lamp with the other hand.

- How should the ball look when you turn on the lamp if the ball looks like a quarter moon?
- Turn on the light.
- What do you see?
- How can you move so the ball looks half lit when holding your arms at a right angle?
- What can you infer about the arrangement of the Sun, Earth, and Moon if you have to move far away from the lamp in order to see a half lit ball when your arms are forming a right angle when pointing at the lamp and holding out the ball?

Question 5.28 What are the relative sizes of the Sun and the Moon?

- If the Sun is very far away and the Moon is close by but they look about the same size in the sky, what are their relative sizes?
    - Hold your thumb up and compare it to a round wall clock or some other object that looks roughly the same size as your thumb when viewed from a distance.

- Then walk close to the wall clock or other object and compare its size with your thumb.
- What can you infer about the relative sizes of the Sun and the Moon?

3. Example of student work discussing the arrangement and relative sizes of the Sun, and Moon.

The moon is close to the earth and the sun is far away. *To model evidence of this statement we took a basketball in our right hand and held it out to the right side and took our left arm and held it out in front of us, creating a 90 degree angle. We started with a darkened room and a lamp directly in front of us, representing the sun, the basketball representing the moon and ourselves representing the Earth. We started about an arm's length from the "sun" and knew from previous observation that if the sun and moon are 90 degrees apart that the "moon" should be half lit representing a quarter moon. However, the ball looked more than half lit when held equidistant from the lamp with arms at 90 degrees. So in order to accomplish this visual we had to walk backwards until only half of the "moon" was lit, which ended up being about halfway across the room. Based on the visual we had just given ourselves with this representation, we could then infer that the sun is far away from the moon and the earth is closer to the moon.*

The moon is small and the sun is very large. *When looking at the sun and moon in the sky it is very hard to tell which is bigger and which is smaller, or if they might be the same size. Based on the previous example, we inferred that the sun was far away from the earth and moon, so we recreated this same scenario in the classroom to demonstrate why we see what we see in the sky. Everyone was to look up at the clock in the classroom and hold their thumb up so it looked like they were visually next to each other. Then we were told to back up until our thumb and the clock appeared to be the same size, so everyone backed up and was almost all the way on the other side of the room before their thumb appeared to be the same size as the clock. We saw how far we were from it and then were told to walk up close to the clock and see how large the clock was as we got closer. It seemed huge at a short distance! With this simulation we have some information that allows us to infer why the sun may seem the same size, because it is so far away, but in reality is very large compared to the moon and earth.*

Physics student, Fall 2014

Question 5.29 How does the view of the phases of the Moon from Earth compare with the view from above the solar system?

Equipment: For each student: Use both sides of a folded 8.5×11 sheet of paper.

As shown in Fig. 5.40, fold the sheet in half lengthwise; next fold in half again, but top to bottom; finally fold in half one more time top to bottom. Then open the sheet to provide the multiple-box format for Table V.6 as shown in Fig. 5.41.

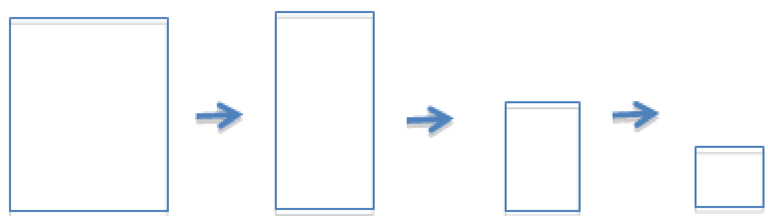


FIG. 5.40 *Creating the boxes for Table V.6 by folding a sheet of paper in half three times.*

- Open the sheet. As indicated in Fig. 5.41, in the left column, sketch a phase of the Moon as seen from Earth. In the right column, sketch that phase of the Moon as would be seen from above the solar system.
- Observed view from Earth:
  - Near the bottom of each box, draw a line to represent the horizon and label the cardinal directions.
  - Place a stick figure (without arms) on the horizon.
  - Center a small round circle at the top of a box to represent the Sun at noon.
  - For each phase, add arms with one pointing at the Sun and the other pointing at the appropriate angle for the Moon for each phase.
  - Sketch the Moon with about the same diameter of the circle representing the Sun and with the appropriate shape for each phase.
- Inferred view from above the solar system:
  - Sketch a large curve at the top of the box to represent part of a large Sun.

- Sketch a small circle near the bottom of the box to represent the Earth.
- For each phase, sketch a smaller circle (about ¼ size of Earth) to represent the Moon; place this smaller circle near the circle representing the Earth, so that this Moon forms the appropriate angle with respect to the Earth and Sun for that phase.

TABLE V.6 Comparison of Views from Earth and Space	
View from Earth New moon	View from above solar system New moon
Sun Waxing crescent	Sun Waxing crescent
Sun First quarter	Sun First quarter
Sun Waxing gibbous	Sun Waxing gibbous

FIG. 5.41 *Format for comparing observed view from Earth with inferred view from above the solar system.*

- On the reverse side, sketch full, waning gibbous, third quarter, and waning crescent phases as seen from the Earth and from above the solar system.

- What determines the size and shape of the lit portion of the phase of the Moon we see?

Complete entries in Table V.7. Then write a summary of what you have learned before reading an example of student work about how the phases of the Moon would look when viewed from above the solar system.

TABLE V.7 Additional insights about the phases of the moon

TABLE V.7 Additional insights about the phases of the moon			
Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
		What we see depends upon our perspective.	
		What we see from Earth is the portion of the lit side that is visible from Earth given the relative positions of the Sun, Earth, and Moon as the Moon revolves around the Earth.	

4. Example of student work about views of the Moon from Earth and above the solar system.

> ***What we see depends upon our perspective.*** *The table below* (*Figs.* 5.42 *and* 5.43) *presents how each phase of the moon is viewed from Earth, and the view of the solar system from above during that phase.*

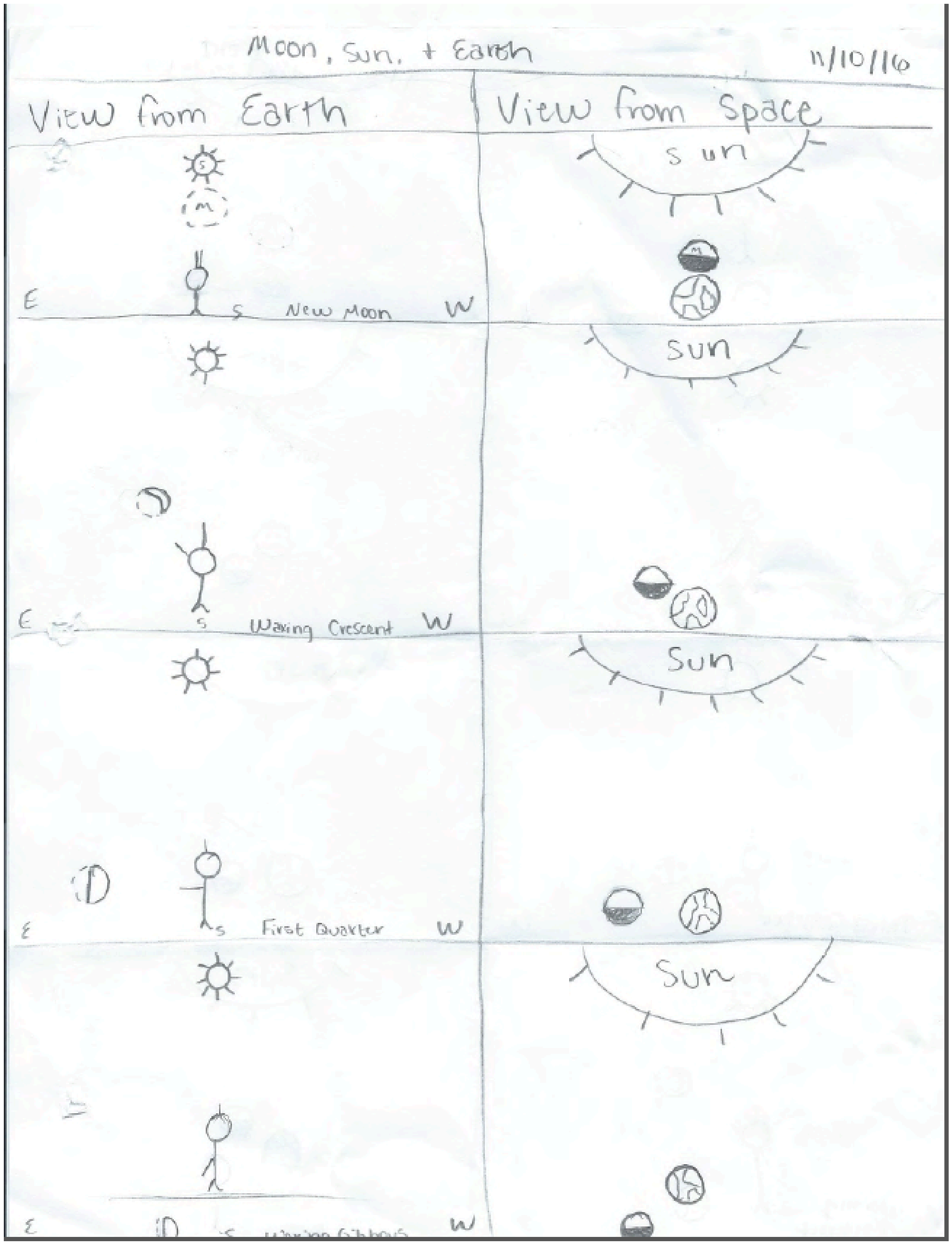


FIG. 5.42 Student table presenting observed views of waxing phases from Earth and inferred views from space.

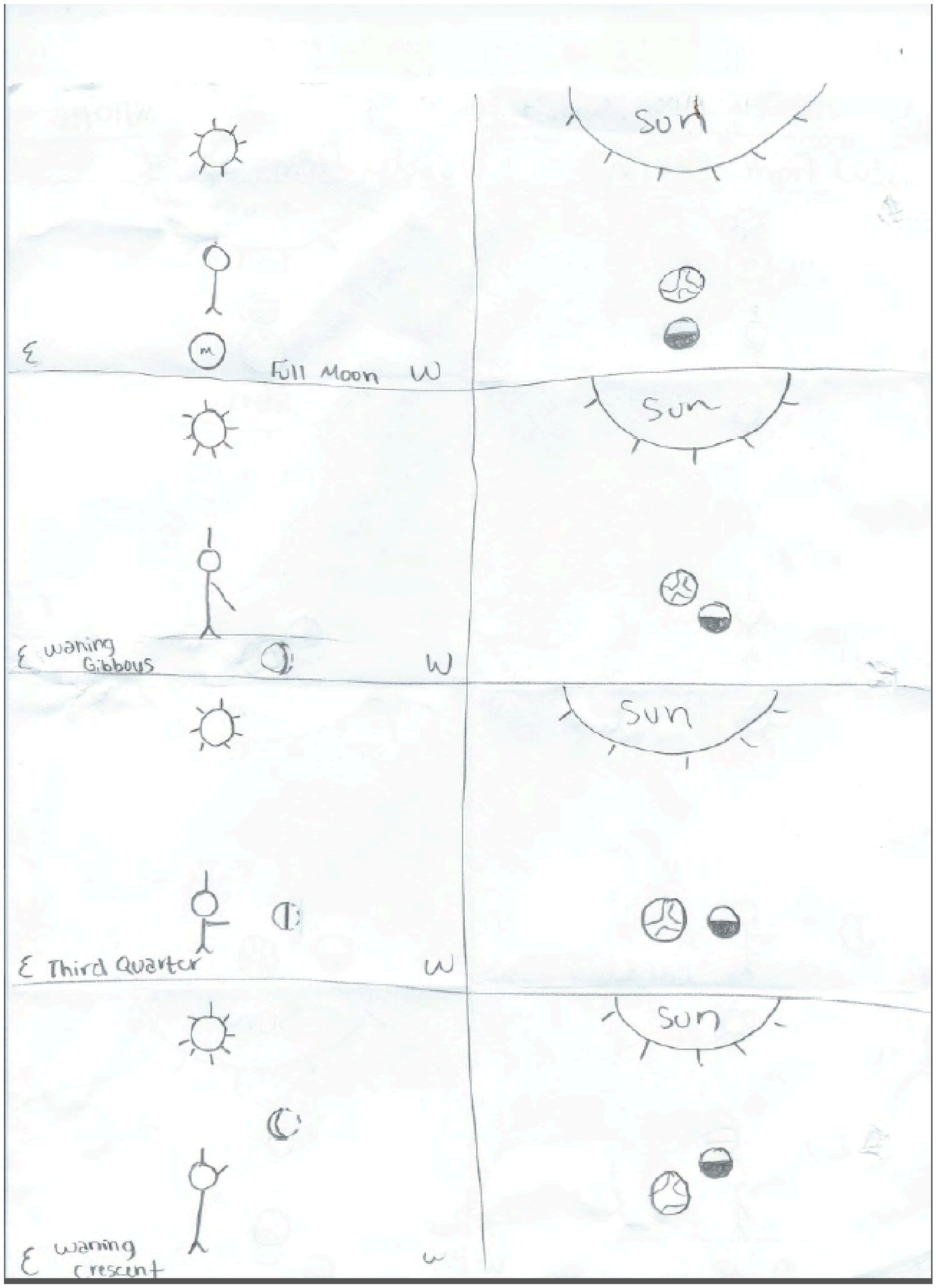


FIG. 5.43 Student table presenting observed views of waning phases from Earth and inferred views from space.

Physics student, Fall 2016

5. Nuances about viewing the phases of the Moon from above the solar system

The right columns of Figs. 5.42 and 5.43 show inferred views from above the solar system as the Moon revolves around the Earth. For the Moon, the side facing toward the Sun is always fully it. This is shown as half-lit in Figs. 5.42 and 5.43 because this is a view from above a fully lit sphere facing the Sun. The same would be the case for the Earth as well. The circle representing the Earth in Figs. 5.42 and 5.43 also should be shown as fully lit sphere facing the Sun (which looks half lit from above).

In the right columns of Figs. 5.42 and 5.43, the side of the Moon facing away from the Sun is not lit. This represents that the shaded side of a phase of the Moon is caused by the Moon's shadow on itself. It is not the shadow of the Earth. This is similar to the shadow on the back side of a barrier placed between a lamp and a screen, as in Question 1.6 and Fig. 1.8 in Unit 1. The same would be the case for the Earth as well. The circle representing the Earth in the right columns of Figs. 5.42 and 5.43 also should be dark for the side facing away from the Sun.

In the right columns of Figs. 5.42 and 5.43, the relative sizes of the circles representing the Earth and Moon should show the Moon about ¼ the size of the Earth. This is an assertion by the instructor rather than a comparison resulting from an observation. The placement of the Moon should be a consistent distance close to the Earth and both Earth and Moon should be far from the Sun. The student has positioned the Moon correctly for the various phases and has been consistent in showing the Moon's lit face toward the Sun and the dark side away from the Sun.

In the left columns of Figs. 5.42 and 5.43, the student has shown the size of the Sun and the Moon as roughly equal, as they appear from Earth. The shapes of the phases and angles formed by pointing at the Sun and Moon are basically correct. The phases that are not visible at noon are shown at the correct angle below the horizon.

Fig. 5.44 shows another way to illustrate what the phases of the moon would look like from above the solar system as well as on Earth.

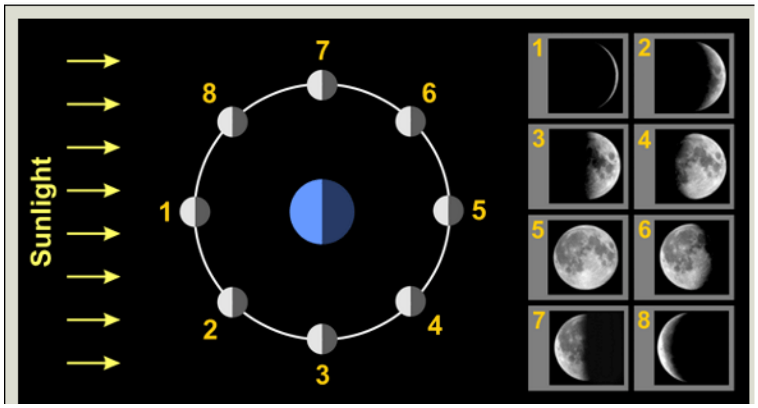


FIG. 5.44 Inferred Moon orbit from above the solar system with adjacent table showing observed phases on Earth. *http://astro.unl.edu/naap/lps/lunarPage2.html Image reproduced from the Astronomy Education website at the University of Nebraska-Lincoln. (http://astro.unl.edu).*

Sunlight is shown as coming from so far away that the rays traveling toward the Earth and Moon are parallel. The positions of the Moon in its revolution around the Earth are numbered, starting with new Moon. The views of the phases as seen from the northern hemisphere on Earth are shown separately in the adjacent table. This is helpful because the first quarter moon at position #3 is shown appropriately lit on the same side as the incoming sunlight, on the left as seen from above the solar system. This phase (#3) also is shown appropriately lit on the right in the table showing the phases as seen from the northern hemisphere on Earth.

In contrast, many diagrams of the Moon's phases combine the views from Earth and from above the solar system into one diagram as in Fig. 5.45. In such diagrams, the moons representing the Moon in orbit are all lit the same way, facing the Sun. The moons representing waning phases as seen from Earth, however, are lit facing away from the Sun. Such combined diagrams can be very confusing for students who are just learning that the Sun is always on the same side as the lit side of the Moon.

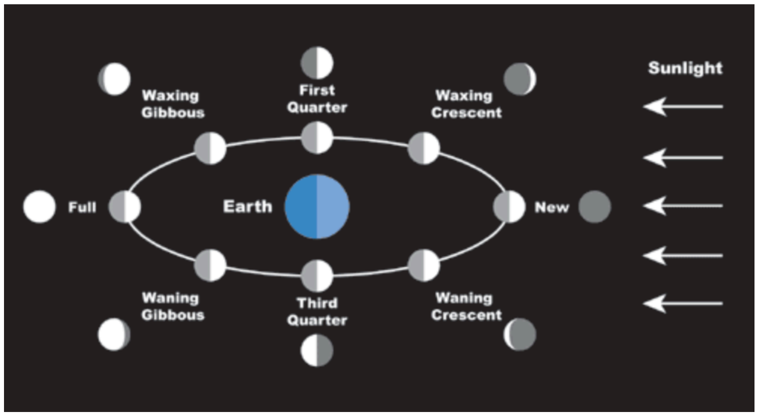


FIG. 5.45 Combined diagram of the Moon's phases viewed from Earth and from above the solar system. https://spaceplace.nasa.gov/review/dr-marc-earth/moon-phases.html

Figure 5.46 shows a diagram that illustrates how much of the lit side of the Moon can be seen from Earth and distinguishes between the dark side and the far side of the Moon.

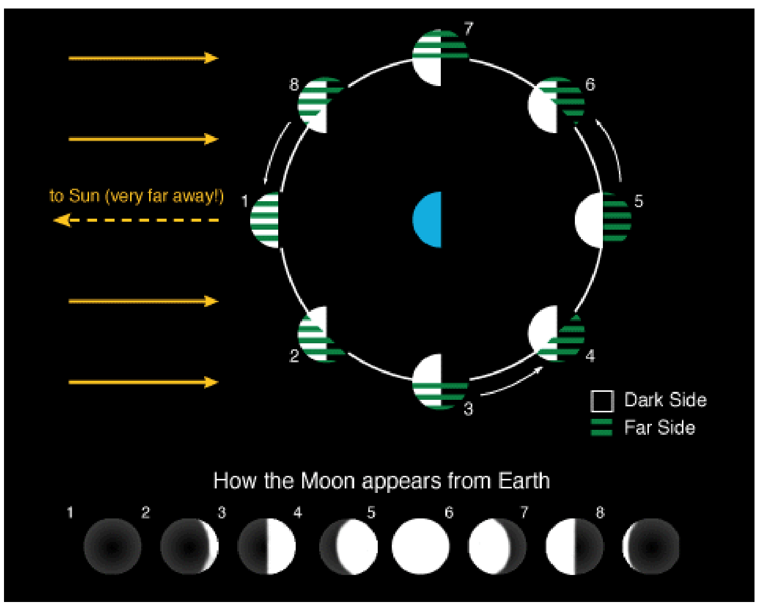


FIG. 5.46 Observed view of phases of the moon from Earth and inferred view from above the solar system that illustrates how much of the lit side of the Moon can be seen from Earth. https://starchild.gsfc.nasa.gov/docs/StarChild/questions/phases.html

The *dark side of the Moon* is the half of the moon that is *not facing the Sun* and is in the Moon's own shadow; as the Moon revolves around the Earth, the dark side is always dark.

The *front side of the Moon* is the half of the moon that *is facing the Sun* and is always lit; as the Moon revolves around the Earth, the front side is always lit.

The *far side of the Moon* is the half of the moon that *is facing away from the Earth* and is represented by the green stripes.

The *near side of the Moon* is the half of the moon that *is facing the Earth*, which is what we "see" from Earth:

- In the new moon position (#1), for example, the near side of the Moon is the same as the dark side of the Moon and is completely dark, which is why we cannot see the new moon in the sky even when the sky is clear. It looks like the Moon should be casting a shadow on the Earth, which it does during a solar eclipse. Usually, however, the Moon is a little above or below the direct line of sight and the Moon's shadow misses the Earth.
- In the waxing crescent phase (#2), the near side of the Moon is partially lit and what we see from Earth is that partially lit side, which looks like a crescent.
- In the 1st quarter phase (#3), the near side of the Moon is half lit and that's what we see from Earth.
- In the waxing gibbous phase (#4), the near side of the Moon is mostly lit, on the right side as seen from the northern hemisphere, on the left side as seen from the southern hemisphere.
- In the full phase (#5), the near side of the Moon is the same as the front side of the Moon and is fully lit as seen everywhere from Earth. The Earth looks like it is in the way and should be casting a shadow on the Moon, which it does during a lunar eclipse. Usually, however, the Moon is a little above or below the Earth's shadow and not eclipsed.
- The waning phases are similar, with the near side facing the Earth now showing less and less of the lit side facing the Sun.

Envisioning what one would see from the perspective of standing on the Earth can be confusing when looking at such diagrams. If you envision yourself standing on the top half of the blue Earth (in the northern hemisphere) and looking outward from the Earth toward position #3 in the circle (which is lit on the left), for example, you would see the Moon half lit on the right as shown for phase #3 in the row below. If you envision yourself standing on the bottom half of the blue earth (in the southern hemisphere) and looking toward position #3, you would see the Moon half lit on the left as shown in the the circle.

Such diagrams reflect choices made by the artists who drew them. The artists drawing Figures 5.44 and 5.46, for example, drew rays from the Sun coming from the left whereas the artist for Figure 5.45 drew rays coming from the right. Figure 5.46 shows an Earth and moons of the same size whereas both Fig. 5.44 and Fig. 5.45 show moons about half the size of the Earth. The appropriate proportion would be a moon about 1/4 the diameter of an Earth. In addition, the artists drawing Figures 5.44 and 5.46 drew from the perspective of looking down from above the solar system with the Moon revolving around the Earth in a circular orbit whereas the artist drawing Figure 5.45 drew from the perspective of looking from the side so that the Moon's almost circular orbit looks like an elongated ellipse. You can see this effect of a circular object looking like an elongated eclipse by looking down on a circular lid and then moving the lid up until you are looking directly at it from the side.

Question 5.30 Does the Moon revolve around the Earth in the clockwise or counter-clockwise direction?

- Compare the representations of the Moon's revolution around the Earth in Figs. 5.29, 5.30, 5.32, 5.42 – 5.46. Are they consistent? If so, do they represent the Moon as revolving clockwise or counter-clockwise around the Earth?
- Suppose you are teaching students in Australia and choose to develop an explanation for the changing phases of the moon as discussed in section V.A.3 above. The students would need to move a ball around their heads so that the waxing phases look lit on the left and the waning phases look lit on the right. How should they move their balls? Clockwise or counter-clockwise?

G. Considering what happens when the Sun, Earth, and Moon are arranged in a line.

Question 5.31 What causes lunar and solar eclipses?

Equipment: Use a lamp without a shade in a dark room and a ball on a stick to model eclipses.

- How can you hold a ball to model a lunar eclipse?
  - Stand away from the lamp. Hold the ball in the waxing gibbous Moon position. Move the ball into the full Moon position and on into the waning gibbous position so that the ball moves into and through the shadow of your head (representing the Earth).
  - Use the central idea developed in Question 1.5 in Unit 1 to draw a ray diagram that illustrates the arrangement of the Sun, Moon, and Earth that causes a lunar eclipse. Indicate the *umbra* and *penumbra* parts of the Earth's shadow. The *umbra* is the dark central shadow formed by the Earth blocking light from all areas of the Sun. *Penumbra* refers to the lighter shadow formed on either side of the umbra by the Earth blocking light from only one side of the Sun.
- How can you hold a ball to model a solar eclipse?
  - Stand away from the lamp. Hold the ball in the waning crescent Moon position. Move the ball into the new Moon position and then into the waxing crescent position so that the shadow of the ball falls on a particular place on the "Earth" (your eyes in your head).
  - Use the central idea developed in Question 1.5 in Unit 1 to draw a ray diagram that illustrates the arrangement of the Sun, Moon, and Earth that causes a solar eclipse.
- Check https://www.timeanddate.com/eclipse/next-lunar-eclipse.html and https://www.timeanddate.com/eclipse/next-solar-eclipse.html to see when the

next eclipses are and whether any are within viewing distance for you.

- Select an upcoming total lunar eclipse. Click on the areas that will be seeing totality. What is the typical length of time that people will be able to see the entire Moon eclipsed? Is the area on Earth where totality is visible wide or narrow?

- Select an upcoming total solar eclipse. Click on areas that will be seeing totality. What is the typical length of time that people will be able to see the entire Sun eclipsed? Is the area on Earth where totality is visible wide or narrow? **If you are able to see a solar eclipse be sure to obtain and use appropriate safety protection for your eyes**.
- How are solar and lunar eclipses similar? How are they different?

The reason that eclipses do not happen every month is that the Moon's orbit is tilted about 5° as shown in Fig. 5.47.

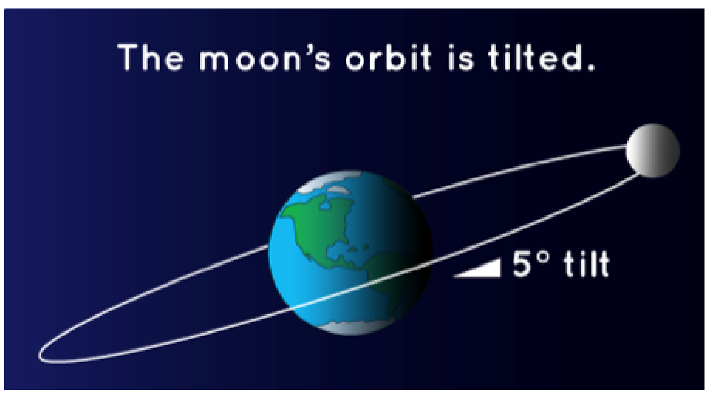


FIG. 5.47 Tilted orbit of the Moon around the Earth.
https://spaceplace.nasa.gov/eclipses/en/

Complete entries in Table V.8. Then write a summary of what you have learned before reading an example of student work about the causes of solar and lunar eclipses.

TABLE V.8 Explaining eclipses of the Sun and Moon

TABLE V.8 Explaining eclipses of the Sun and Moon

Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-an-eclipse-58		Eclipses occur when the Moon is precisely in line with the Earth and the Sun.	

1. *Example of student work about the causes of lunar and solar eclipses*

Eclipses occur when the Moon is precisely in line with the Earth and the Sun. *Below (Figs. 5.48 and 5.49) I have inserted both a sketch of a lunar eclipse and a solar eclipse. We recently had a lunar eclipse back in September. In my sketch you can see that this is when the Sun, Moon and Earth are directly in front of each other, basically in a straight line. The Earth is between the Moon and the Sun; this is the Earth blocking the light rays from the Sun getting to the Moon. This is what created what people say was the "Blood Moon". The moon was dark, but still had a slight outline of its shape. It was crazy to be able to see that, it was awesome!*

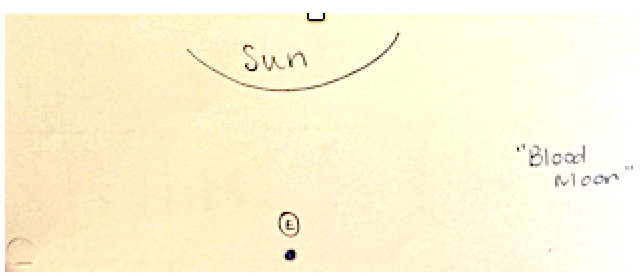


FIG. 5.48 *Student diagram for a lunar eclipse.*

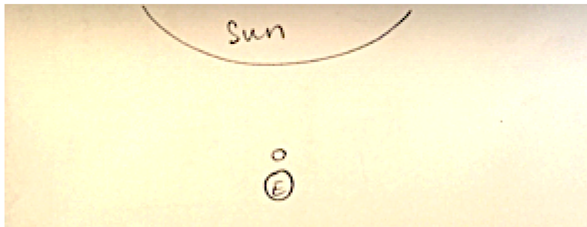


FIG. 5.49 Student diagram for a solar eclipse.

> *I was lucky enough to be able to see that in my lifetime and will actually get to see a solar eclipse as well. There is a prediction that this is going to be visible from Corvallis in August of 2017. A solar eclipse is when the Moon is between the Sun and the Earth. There is going to be a portion of the Earth that is going to see this at this time. This is because the Moon is blocking the Sun in that specific spot. This is crazy to think about because the last one happened back in 1991 when I was not even born yet.*
>
> Physics student, Fall 2014

H. Exploring Internet resources about the Moon with a friend or family member

Question 5.32 What Internet resources are available for teaching and learning about the Moon?

- Put "phases of the moon" in your computer browser. View at least four websites that present a diagram and explanation about the phases of the moon. Select the diagram and explanation you like the best. Why do you like this one best?
- Invite a friend or family member to explore this website with you. If possible, invite someone of the age you want to teach. Then write a reflection upon your conversation:
  - What does your friend/family member already know about the phases of the moon?
  - Describe what your learner asked, said, did and found.

- What aspects of the website seemed to help this learner learn about the phases of the moon?
- What aspects of the website, if any, seemed to hinder learning?
- What have you learned about science learning and teaching from this experience?

1. Example of student work about engaging a friend or family member in learning about the phases of the Moon

> *For this assignment, I asked my family friend who is a 6th grade student about the moon. When I asked her what she already knew about the moon, she said things like "there are different shapes of the moon" and "I see it at night." We looked at the website https://www.timeanddate.com/calendar/aboutmoonphases.html . I liked this site because it not only had a picture of all the moon phases which she seemed to somewhat know about, but also summaries for each phase as well as some pictures that show where the moon, sun and earth are at a certain phase.*
>
> *G asked me why the moon spins in a circle around the earth. This was a hard question for me to answer because I can't explain why it revolves in a circle, I can just explain what is happening as it revolves. I find that often times, my learners are asking me questions that I have trouble answering.*
>
> *An aspect of the website that seemed to really help us learn was the variety of pictures that included the moon, sun and earth for different phases, This helped me to show and explain that at different phases the moon is in different places. However, there was lots of writing on the website. While this was helpful for me, this seemed to hinder G's learning, as she didn't have a desire to read it and it made the website appear more difficult/boring.*
>
> *In regards to science learning and teaching. I have learned through this that there are going to be times where my students stump me. I am not always going to know all the answers, but that is okay, and it is part of science.*
>
> Physics student, Winter 2018

This is another example of the nature of science, that as one learns more and shares that knowledge with others, new questions often arise. Question 5.48 addresses the question that emerged during this conversation, what keeps the Moon revolving around the Earth in its orbit?

I. Pausing to review before taking the next step

Before undertaking the next step in an extended exploration, it can be helpful to review the understandings developed so far.

1. Reviewing two explanatory models for day and night

Equipment: Use a fist and your body to demonstrate the fixed Earth, REVOLVING Sun model for day and night (see IV.A. Question 5.22)

- What is the evidence supporting this explanatory model for day and night?

Equipment: Use a lamp without a shade and your body to demonstrate the fixed Sun, ROTATING Earth model for day and night (See IV.B, Question 5.22)

- What is the evidence supporting this explanatory model for day and night?
- How are these models useful?

2. Reviewing an explanatory model for the phases of the Moon

- Where is the Sun with respect to the phase of the Moon when both are visible in the sky?
- What are the phases of the moon observed?
- How are these phases related to the angle formed by pointing one arm at the Sun and the other arm at the Moon?

Equipment: Use a lamp without a shade, a ball on a stick, and your head to replicate here on Earth the phases of the Moon observed in the sky. (See V, C, Question 5.23)

- What is the logic by which one can infer that the phases of the Moon are caused by the revolution of the Moon around the Earth?

- What causes lunar and solar eclipses?

Daily observations indicate that the Sun seems to rise in the east, move in an arc across the sky and set in the west. The Moon seems to move in the same way, rising in the east, moving in an arc across the sky, and setting in the west. These observations suggest that the Sun and the Moon revolve daily around the Earth. An alternative model, hard to envision, is that the Earth is rotating on its axis daily, that we, living on the surface of the Earth, are spinning on by the Sun and Moon rather than that the Sun and Moon are revolving around us on a fixed Earth.

On-going observations of the Moon indicate that the lit shape of the Moon changes in a regular way, increasing from crescent to half lit to more than half lit to full and then decreasing from more than half lit to half lit to crescent to not being visible even when the sky is clear. The Moon sometimes is visible during the day as well as at night. Sometimes the Moon is lit on the right and sometimes on the left but when both the Sun and the Moon are visible in the sky, the Sun is always on the same side of the Moon that is lit.

The angle formed by pointing one arm at the Sun and one arm at the Moon changes, from acute to right, to obtuse, to straight as the lit portion of the Moon increases on the right at our location and back from straight to obtuse to right to acute as the lit portion of the Moon decreases on the left at our location. Patterns identified in systematic observations of the relation between the lit portion of the Moon (its phase) and this angle are useful in predicting when each phase of the Moon will be rising, transiting, and setting. Such systematic observations lead to paradoxes, however, such as that sometimes the Moon seems to chase the Sun across the sky but sometimes the Sun seems to chase the Moon. Also the Moon seems to move from east to west, like the Sun, over several hours but in the opposite direction from west to east over several days.

If both the Sun and the Moon are visible in the sky and one holds up a ball near the Moon, one can see the Sun shining on the ball in the same way that the Sun is shining on the Moon. It is important NOT to look directly at the Sun in order to avoid damaging one's eyes! The shape of the lit portion of the ball matches the shape of the lit portion of the Moon. The shape of the dark part of the ball matches the shape of the missing portion of the circular shape of a full Moon. The shadow forming the dark part of the ball is the ball's own shadow as the front of the ball is blocking light from falling on the back of the ball. This suggests that the missing portion of the Moon is not visible because it is in the Moon's own shadow, the front of the Moon blocking light from falling on the back of the Moon. The Earth's shadow is not involved at all, although many people explain the Moon's changing phases this way, probably because they associate objects with casting shadows on nearby surfaces rather than with objects blocking light from falling on the backs of the objects themselves.

To move the ball in a way that replicates the changing phases of the Moon one simply moves the ball around one's head while taking care not to block the light falling on a "full" ball and to hold the ball in such a way that it does not block light falling directly in one's eyes in the "new" ball position. This replication here on Earth of what one sees in the sky suggests that the cause of the changing phases of the Moon is that the Moon is revolving around the Earth, not daily, but rather during the many days that the phases are changing, in about a month.

The claim that the phases of the Moon are caused by the Moon revolving around the Earth during about a month is supported by its power in explaining two paradoxes. The Moon seems to be chasing the Sun daily across the sky in the waxing phases, when seen by those of us on a daily rotating Earth, as the Moon is revolving around the Earth through angles 0° to 180°. The Sun daily seems to be chasing the Moon when the Moon is continuing to revolve around the Earth through angles 180° to 360° (or from 180° back to 0 depending upon how one labels the angles). The Moon appears to be moving east to west over several hours because the Earth is rotating past it as the Earth rotates on its axis. The Moon appears to be moving west to east over several days because the Moon actually IS moving as it revolves around the Earth.

Eclipses occur when the Moon, Earth, and Sun are directly lined up in the full Moon (lunar eclipse) and new Moon (solar eclipse) positions. Eclipses do not occur every month because the Moon's orbit is inclined about 5 degrees so usually the Moon is little above or a little below the direct line of sight from the Sun.

The practices involved in developing these understandings included questioning, observing, discussing, predicting, modeling, and interpreting findings. Of particular importance was identifying patterns, seeking ways to link cause and effect, and employing systems thinking.

VI. Developing Additional Central Ideas Based on Evidence about the Sun, Earth, and Stars

This section focuses upon observing seasonal differences in patterns of stars that are visible at night, tracking details about the Sun's apparent daily motion, and noticing seasonal differences in regional climates. Interpreting these observations will be helpful in developing an explanatory model for the Earth's annual motion around the Sun as well as for explaining why the Earth has seasons,

A. Noticing seasonal patterns in the night sky

People who live where there are few lights at night typically are very familiar with patterns of stars that are visible in the night sky and with ways in which these change with the seasons. People who live in cities typically are unaware of such patterns and their changes because of the many artificial lights that brighten the night sky. Some star patterns may be visible, however, if you look up on a clear night. During this course, try to do this frequently!

Question 5.33 What seasonal patterns are evident in the constellations of stars visible at night?

- Discuss with your group members any patterns of stars that you have noticed.
- On a clear night go outside and look up! Enjoy what you can see and create your own patterns among the visible stars.
- If interested in what others have envisioned when viewing the stars, go to a website such as https://www.windows2universe.org/the_universe/Constellations/constnavi.html or http://www.astronomy.com/observing/astro-for-kids/2008/03/learn-the-

constellations where you can read about the circumpolar constellations, those which are visible all year long, and about constellations only visible during different seasons (spring, summer, fall, winter) in the northern and southern hemispheres.

- To access an interactive map of the sky that can display what you might see on a clear night in your location, go to https://www.skyandtelescope.com/observing/interactive-sky-chart/. Click to open, enter your zipcode, year, month, day, and hour. To access names of bright stars, click the display option *Star Names*. To see traditional constellations, click on *Constellation lines* and later *Constellation names*.

Some constellations are visible in both the northern and southern hemispheres although the southern hemisphere constellations may look upside down from those shown below. Stars within a constellation look as if they are near by one another as seen from Earth; however, they likely are very distant from one another in space. In 1922, the International Astronomical Union defined 88 official constellations, (https://www.iau.org/public/themes/constellations/). Many of their names were derived from Greek and Roman mythology as shown in the star chart for the northern hemisphere in Fig. 5.50. For a similar star chart for the southern hemisphere see: https://maas.museum/app/uploads/sites/6/2016/03/starmapApril2016.pdf.

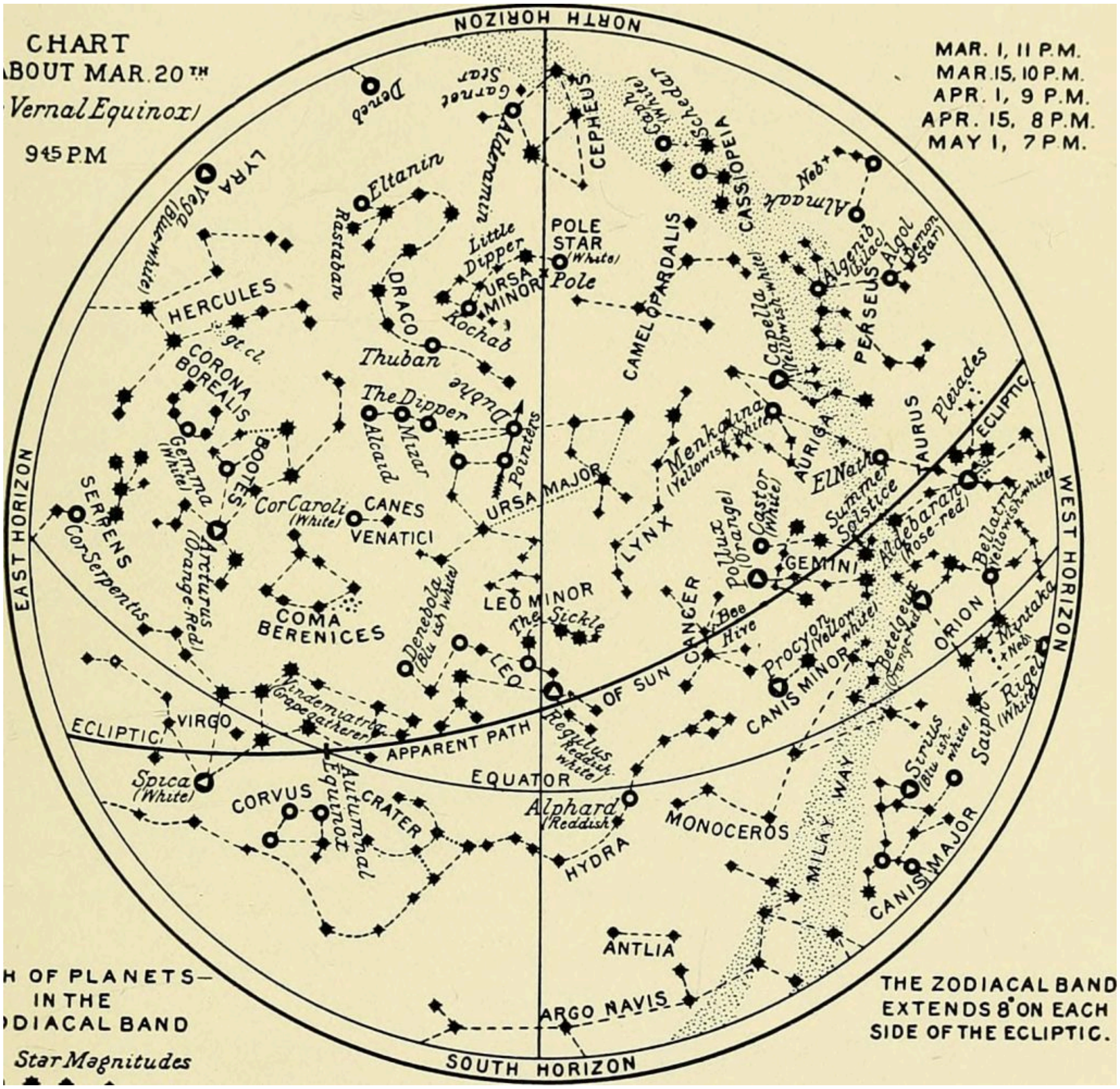


Fig. 5.50 Star chart for spring skies in the northern hemisphere. From The Call of the Stars by John R. Kippax (G. P. Putnam's Sons, New York, 2010), p. 58. [*https://www.flickr.com/photos/internetarchivebookimages/14783530782*](https://www.flickr.com/photos/internetarchivebookimages/14783530782)

People of many cultures have seen a wide variety of patterns in the stars. The Ojibwe People of Canada and northern United States, for example, envisioned constellations based upon their own stories as shown in the Ojibwe Sky Star Map at https://web.stcloudstate.edu/aslee/OJIBWEMAP/home.html. This star map shows Ojibwe constellations superimposed on those described in Greek and Roman myths.

- Different constellations are high in the night sky during different seasons of the year.

During spring in the northern hemisphere or autumn in the southern hemisphere, for example, look for stars that seem to form a backwards question mark as shown in Fig. 5.51. These stars were seen as outlining the head and mane of Leo, a constellation representing a vicious lion fought by Hercules according to Greek and Roman mythology. The brightest star, Regulus, has the Latin name for king. Another bright star, Denebola, has an Arabic name for "lion's tail" (see: https://africancosmosdiary.wordpress.com/tag/constellations/). Many cultures interpreted the changing patterns of stars high in the sky in terms of seasonal patterns in climate. Seeing the constellation Mishi Bizhiw, a mountain lion , high in the sky, for example, warned Ojibwe travelers not to trust thin ice on lakes as they moved from winter camp (See information about Mishi Bizhiw at https://web.stcloudstate.edu/aslee/OJIBWEMAP/OjibweConstellationGuide.pdf).

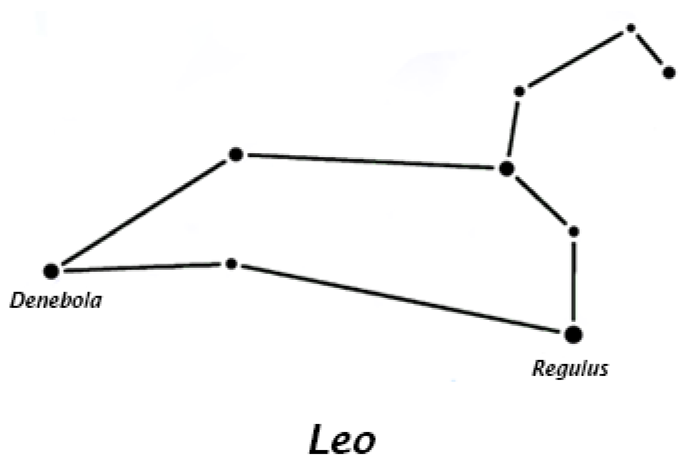


Fig. 5.51 The constellation Leo the Lion associated with Greek and Roman mythology. Modified from star map created by Torsten Bronger. *https://commons.wikimedia.org/wiki/File:Leo_constellation_map.png* [CC 3.0]

- During summer in the northern hemisphere or winter in the southern hemisphere, look for stars high in the sky that seem to form a half circle near stars that seem to outline a human figure as shown in Fig. 5.52. In Greek and Roman mythology, Corona Borealis was a northern crown and Hercules was a hero. In 2013, the biggest super cluster of galaxies in the universe, the Hercules-Corona Borealis Great Wall, was discovered in the direction of these two constellations (see https://www.space.com/33553-biggest-thing-universe.html). The Ojibwe community saw this half circular star pattern as representing Madoodiswan, a sweat lodge, with a person nearby, Noondeshin Bemaadizid, a bather exhausted from the experience but renewed in strength and spirit. (See: https://web.stcloudstate.edu/aslee/OJIBWEMAP/OjibweConstellationGuide.pdf).

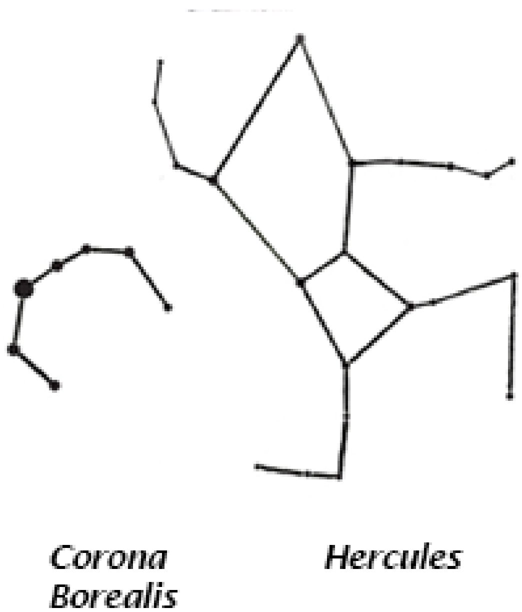


Fig. 5.52 The constellations Corona Borealis and Hercules associated with Greek and Roman mythology. Star patterns modified from https://www.iau.org/public/images/detail/crb/ and https://www.iau.org/public/images/detail/her/; IAU and Sky and Telescope [CC:4.0].

- During fall in the northern hemisphere or spring in the southern hemisphere, look for stars that seem to form a square near stars that seem to outline a flying bird as shown in Fig. 5.53. In Greek and Roman mythology, Pegasus, was a winged horse and Cygnus, a swan. Telescopes looking in this direction have detected planets orbiting stars outside our solar system (See: https://exoplanets.nasa.gov/resources/231/hd-209458b/). In Ojibwe mythology, Mooz was a moose, appreciated for providing food, clothing, and shelter. Ajiijaak was a crane, leading people to stay strong. (See: https://web.stcloudstate.edu/aslee/OJIBWEMAP/OjibweConstellationGuide.pdf).

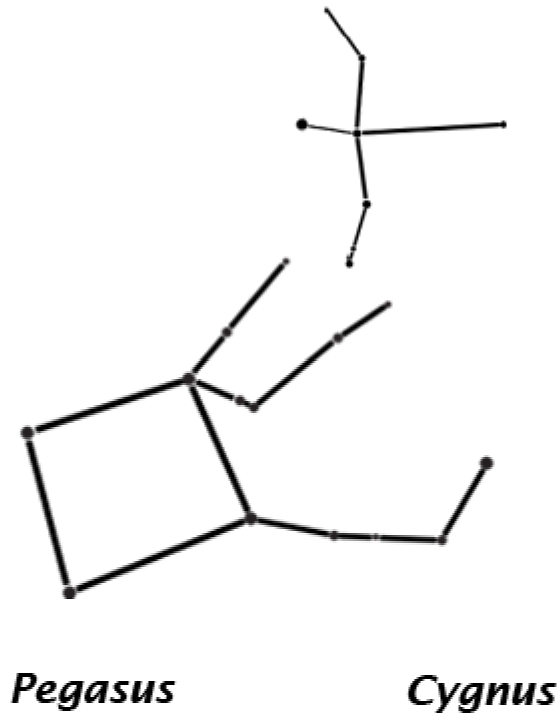


Fig. 5.53 The constellations Pegasus, the flying horse, and Cygnus, the swan, associated with Greek and Roman mythology. Star patterns modified from https://www.iau.org/public/images/detail/peg/ and https://www.iau.org/public/images/detail/cyg/; IAU and Sky and Telescope [CC 4.0]

- During winter in the northern hemisphere or summer in the southern hemisphere, look for stars that seem to form a human figure with a belt as shown in Fig. 5.54. Orion was a great hunter in Greek mythology. Some stories envisioned Orion as followed by one of his dogs, Canis Minor, as he was raising a club and holding up a shield to fight Taurus, a charging bull (See: http://www.ianridpath.com/startales/orion.htm). Below the belt is M42, the Orion Nebula, where stars are being formed (https://www.nasa.gov/feature/goddard/2017/messier-42-the-orion-nebula). The Ojibwe community also envisioned a human-like figure, Biboonkeonini, the Wintermaker, with stars for shoulders and knees as well as three stars for a belt and long arms stretching to a bright star on either side (see: https://web.stcloudstate.edu/aslee/OJIBWEMAP/OjibweConstellationGuide.pdf).

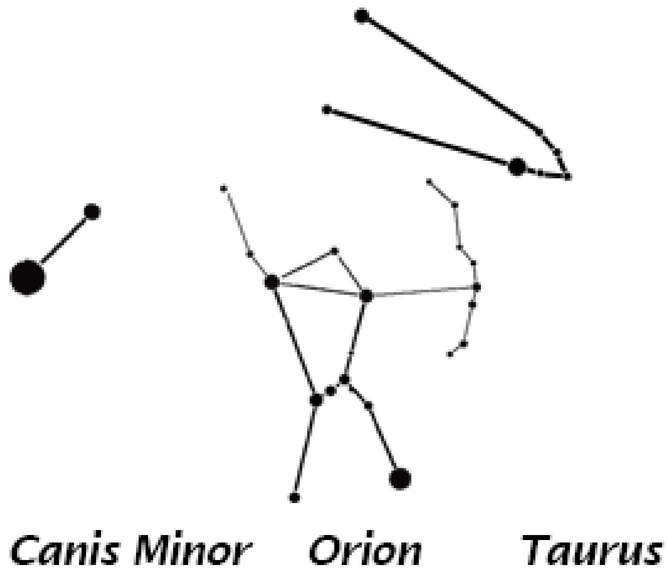


Fig. 5.54 The constellations Canis Minor, Orion, and Taurus associated with Greek mythology. Star patterns modified from https://www.iau.org/public/images/detail/ori/, https://www.iau.org/public/images/detail/cmi/ and https://www.iau.org/public/images/detail/tau/; IAU *and Sky and Telescope* [CC 4.0]

- Summarize the changes that occur in the constellations visible in the sky during a year. Complete entries in Table V.9. Then write a summary of what you have learned about seasonal differences in the stars visible at night.

TABLE V.9 Developing central ideas about seasonal differences in visible stars

TABLE V.9 Developing central ideas about seasonal differences in visible stars			
Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
		Like the Sun and the Moon, the stars seem to be revolving around the Earth each night	constellation
		Some constellations of stars are seasonal, seeming to rise in the east and set in the west like the Sun and Moon but are only visible during part of the year	
		Some constellations of stars are always visible in one hemisphere but not in the other.	northern hemisphere southern hemisphere
		Some constellations are visible in both the northern and southern hemispheres depending upon where one is	

B. Noticing seasonal patterns in sunlight and shadows

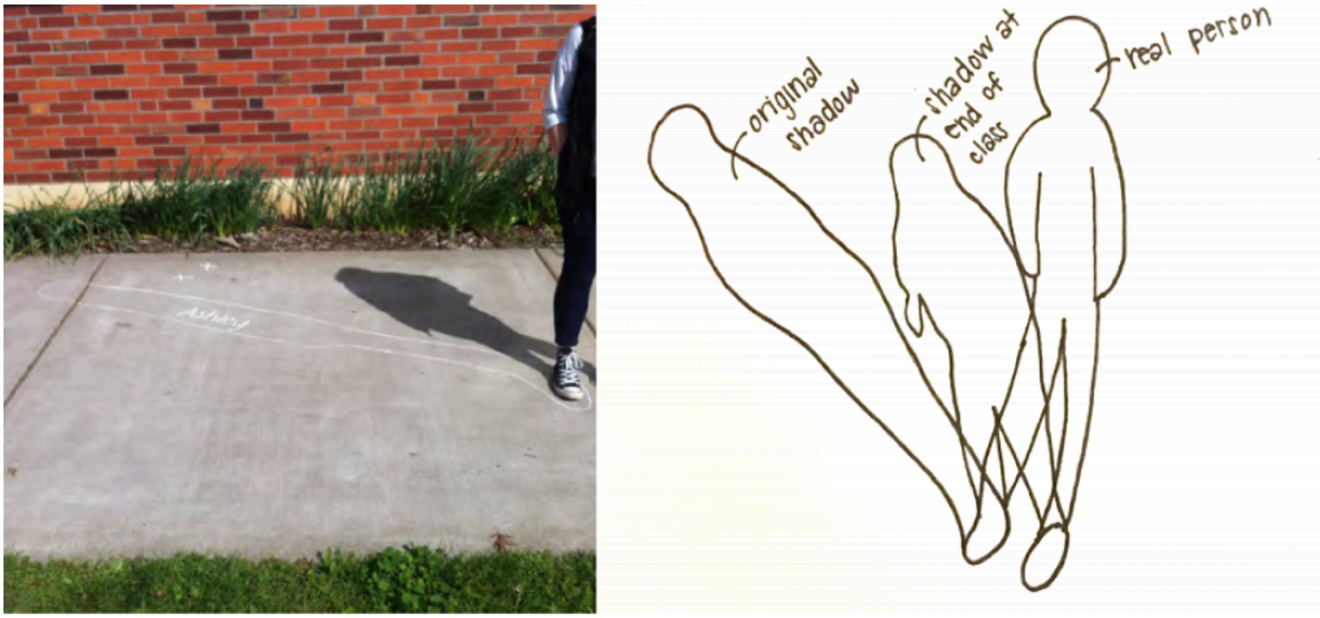
In addition to seasonal differences in some of the stars visible overhead at night, there are large seasonal differences during the day in the lengths of shadows on the ground as well as in the Sun's apparent motion across the sky.

Question 5.34 What seasonal patterns are evident in how the Sun seems to move across the sky?

1. Interpreting changes in the Sun's maximum angular altitude α

Section III.B. Question 5.8 explored how the Sun seems to move across the sky by observing the shadows cast by a gnomon (person, post, paperclip, or nail) perpendicular to the ground as shown in Figs. 5.9 and 5.13 (repeated below).

- What do you wonder about such shadows?



FIGs. 5.9 and 5.13 (repeated). Sketching a group member's shadow on pavement near beginning and end of class.

Some aspects to consider include:

- How do shadows change in size and orientation during morning, noon, and afternoon on a sunny day?
- In what directions do the shadows point?
- When during the day are shadows longest? When are shadows the shortest?
- What happens during the year? How do shadows change in size and orientation throughout the day during different times of year?
- How does the length of the shortest shadow during the day change with the seasons?
- What is the connection between how long a shadow is and how high the Sun seems to be in the sky?

Now consider how the Sun seems to be moving. DO NOT LOOK DIRECTLY AT THE SUN!

- What do you wonder about the Sun's apparent daily journey across the sky?

Here are some aspects to consider:

- How does the Sun's highest altitude α seem to be changing over a week? Over several weeks? Several months?
- Does the Sun's apparent maximum angular altitude α seem to be getting higher? Lower?
- Is the Sun ever directly overhead?

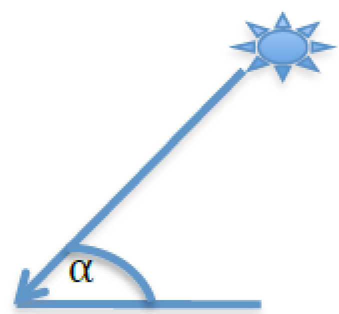


FIG. 5.55 Angular altitude α of the Sun in the sky.

The angular altitude of the Sun, angle α (alpha), can be estimated by measuring the height of a gnomon H and the length of its shadow L, drawing a careful ray diagram and measuring the angle α with a protractor or calculating the tangent H/L, and identifying the angle for which that is the tangent as shown in Fig. 5.10 (repeated).

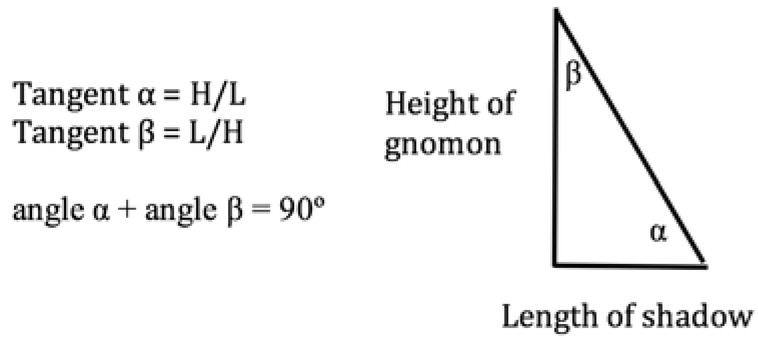


FIG. 5.10 (repeated). Right triangle formed by gnomon, its shadow, and rays from the Sun.

- Complete entries in Table V.10. Then write a summary of what you have learned about seasonal differences in the lengths of shortest shadows during the day.

TABLE V.10 Developing central ideas about seasonal differences in the lengths of the shortest shadows during a day

TABLE V.10 Developing central ideas about seasonal differences in the lengths of the shortest shadows during a day			
Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
		The shortest length of a shadow cast by a gnomon occurs when the Sun is at its apparent maximum angular altitude	gnomon angular altitude
		The Sun's apparent angular altitude α (alpha) is formed by the rays of the Sun and a gnomon's shadow. Angle α can be estimated by measuring the height of the gnomon H, and length of the shadow L, drawing a careful ray diagram, and measuring α with a protractor or using a calculator or trig table to find the angle for which the tangent is equal to H/L.	protractor tangent

		The angle β (beta) is formed by the rays of the Sun and a gnomon. This angle can be estimated by measuring β on a careful ray diagram with a protractor or estimated by finding the angle for which the tangent is (L/H).	

2. *Interpreting data obtained from Internet resources*

- What differences have you noticed in what the Sun seems to be doing during the different seasons of the year. During this course, for example:
  - Where has the Sun seemed to rise? (north of east? directly east? south of east?)
  - What has been the apparent daily maximum height of the Sun above the horizon? (high, medium, low?)
  - Where has the Sun seemed to set? (north of west? directly west? south of west?)
  - What is the duration of daylight compared to darkness? (longer time period? about the same time period? shorter time period?
- Use the Internet or other source of information to identify the current dates in your location for the:
  - spring equinox (equal number of hours of sunlight and darkness)
  - summer solstice (longest number of hours of sunlight and shortest number of hours of darkness
  - autumn equinox (equal numbers of hours of sunlight and darkness)
  - winter solstice (shortest number of hours of daylight and longest number of hours of darkness)

- To consider seasonal effects at your location, go to https://www.timeanddate.com/sun/ , enter a place or city in the search window, and explore predictions of what happens on the spring equinox, summer solstice, fall equinox, and winter solstice at your location:
  - Where does the Sun seem to rise (north of east? east? south of east?) at this

- location on the spring equinox? summer solstice? autumn equinox? winter solstice?
  - What is the maximum altitude of the Sun in the sky for this location on these dates?
  - Where does the Sun seem to set (north of west? west? south of west?) at this location on these dates?
  - What is the duration of daylight for this location on these dates?
  - Create a table to report this information.
- Summarize these seasonal effects for your location for the Sun's apparent:
  - rising and setting times
  - maximum height of the Sun's arc across the sky
  - duration above the horizon

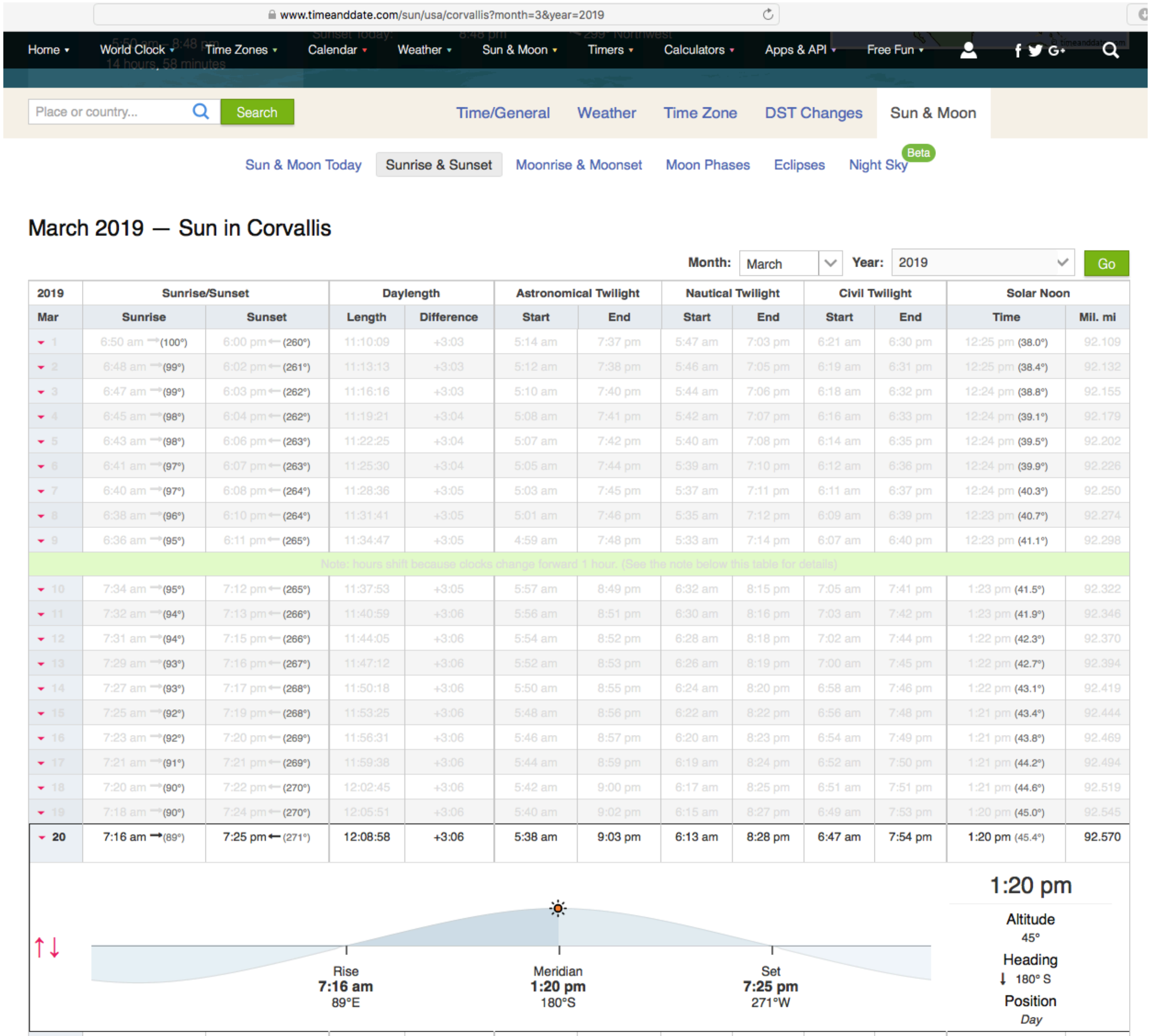
3. Example of interpreting Internet data about changes in the Sun's apparent daily motion

At https://www.timeanddate.com/sun/, enter Corvallis, Oregon, for example, in the search window for place or country, click on the Sunrise & Sunset button, change the month to March and current year, click on Go and click on a box in the row highlighted for the date of the equinox. A report appears as shown in Fig. 5.56. The green band indicates the start of daylight saving time at this location.

The report below predicts that on this spring equinox in Corvallis, the Sun would appear to:

- rise at 7:16 am, Pacific daylight saving time
- rise almost directly east (specifically 89° east of north)
- be highest in the sky at 1:20 pm time, Pacific daylight saving time
- be at a maximum altitude of 45° above the horizon
- set at 7:25 pm, Pacific daylight saving time
- set almost directly west (specifically 271° west of north)

and that the duration of daylight would be about 12 hours.



March 2019 — Sun in Corvallis

Month: March Year: 2019 Go

2019	Sunrise/Sunset		Daylength		Astronomical Twilight		Nautical Twilight		Civil Twilight		Solar Noon	
Mar	Sunrise	Sunset	Length	Difference	Start	End	Start	End	Start	End	Time	Mil. mi
1	6:50 am → (100°)	6:00 pm ← (260°)	11:10:09	+3:03	5:14 am	7:37 pm	5:47 am	7:03 pm	6:21 am	6:30 pm	12:25 pm (38.0°)	92.109
2	6:48 am → (99°)	6:02 pm ← (261°)	11:13:13	+3:03	5:12 am	7:38 pm	5:46 am	7:05 pm	6:19 am	6:31 pm	12:25 pm (38.4°)	92.132
3	6:47 am → (99°)	6:03 pm ← (262°)	11:16:16	+3:03	5:10 am	7:40 pm	5:44 am	7:06 pm	6:18 am	6:32 pm	12:24 pm (38.8°)	92.155
4	6:45 am → (98°)	6:04 pm ← (262°)	11:19:21	+3:04	5:08 am	7:41 pm	5:42 am	7:07 pm	6:16 am	6:33 pm	12:24 pm (39.1°)	92.179
5	6:43 am → (98°)	6:06 pm ← (263°)	11:22:25	+3:04	5:07 am	7:42 pm	5:40 am	7:08 pm	6:14 am	6:35 pm	12:24 pm (39.5°)	92.202
6	6:41 am → (97°)	6:07 pm ← (263°)	11:25:30	+3:04	5:05 am	7:44 pm	5:39 am	7:10 pm	6:12 am	6:36 pm	12:24 pm (39.9°)	92.226
7	6:40 am → (97°)	6:08 pm ← (264°)	11:28:36	+3:05	5:03 am	7:45 pm	5:37 am	7:11 pm	6:11 am	6:37 pm	12:24 pm (40.3°)	92.250
8	6:38 am → (96°)	6:10 pm ← (264°)	11:31:41	+3:05	5:01 am	7:46 pm	5:35 am	7:12 pm	6:09 am	6:39 pm	12:23 pm (40.7°)	92.274
9	6:36 am → (95°)	6:11 pm ← (265°)	11:34:47	+3:05	4:59 am	7:48 pm	5:33 am	7:14 pm	6:07 am	6:40 pm	12:23 pm (41.1°)	92.298
Note: hours shift because clocks change forward 1 hour. (See the note below this table for details)												
10	7:34 am → (95°)	7:12 pm ← (265°)	11:37:53	+3:05	5:57 am	8:49 pm	6:32 am	8:15 pm	7:05 am	7:41 pm	1:23 pm (41.5°)	92.322
11	7:32 am → (94°)	7:13 pm ← (266°)	11:40:59	+3:06	5:56 am	8:51 pm	6:30 am	8:16 pm	7:03 am	7:42 pm	1:23 pm (41.9°)	92.346
12	7:31 am → (94°)	7:15 pm ← (266°)	11:44:05	+3:06	5:54 am	8:52 pm	6:28 am	8:18 pm	7:02 am	7:44 pm	1:22 pm (42.3°)	92.370
13	7:29 am → (93°)	7:16 pm ← (267°)	11:47:12	+3:06	5:52 am	8:53 pm	6:26 am	8:19 pm	7:00 am	7:45 pm	1:22 pm (42.7°)	92.394
14	7:27 am → (93°)	7:17 pm ← (268°)	11:50:18	+3:06	5:50 am	8:55 pm	6:24 am	8:20 pm	6:58 am	7:46 pm	1:22 pm (43.1°)	92.419
15	7:25 am → (92°)	7:19 pm ← (268°)	11:53:25	+3:06	5:48 am	8:56 pm	6:22 am	8:22 pm	6:56 am	7:48 pm	1:21 pm (43.4°)	92.444
16	7:23 am → (92°)	7:20 pm ← (269°)	11:56:31	+3:06	5:46 am	8:57 pm	6:20 am	8:23 pm	6:54 am	7:49 pm	1:21 pm (43.8°)	92.469
17	7:21 am → (91°)	7:21 pm ← (269°)	11:59:38	+3:06	5:44 am	8:59 pm	6:19 am	8:24 pm	6:52 am	7:50 pm	1:21 pm (44.2°)	92.494
18	7:20 am → (90°)	7:22 pm ← (270°)	12:02:45	+3:06	5:42 am	9:00 pm	6:17 am	8:25 pm	6:51 am	7:51 pm	1:21 pm (44.6°)	92.519
19	7:18 am → (90°)	7:24 pm ← (270°)	12:05:51	+3:06	5:40 am	9:02 pm	6:15 am	8:27 pm	6:49 am	7:53 pm	1:20 pm (45.0°)	92.545
20	7:16 am → (89°)	7:25 pm ← (271°)	12:08:58	+3:06	5:38 am	9:03 pm	6:13 am	8:28 pm	6:47 am	7:54 pm	1:20 pm (45.4°)	92.570

FIG. 5.56 Predictions for rising, transiting, and setting for the Sun on a March equinox, in Corvallis. https://www.timeanddate.com/sun/usa/corvallis?month=3&year=2019

As shown in Fig. 5.57, predictions for these events on a June solstice in Corvallis, Oregon are for the Sun to appear to:

- rise at a much earlier time, at 5.28 am, Pacific daylight saving time
- rise north of east (55° NE)
- be at a much higher maximum altitude in the sky (69°) at about the same time (1.14 pm, Pacific daylight saving time)
- set much later, at 9:01 pm, Pacific daylight saving time
- set north of west (305° NW)

and that the duration of daylight would be much longer, about 15 ½ hours.

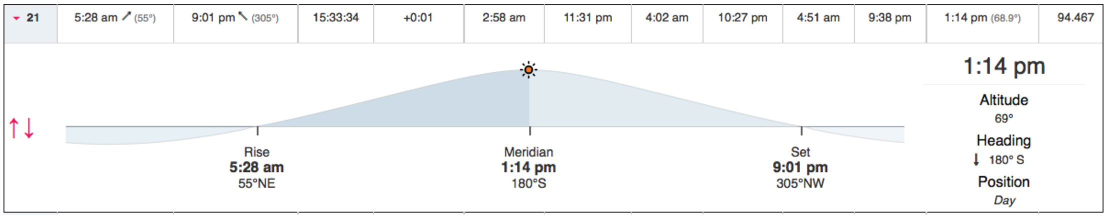


FIG. 5.57 Predictions for rising, transiting, and setting for the Sun on a June solstice in Corvallis. https://www.timeanddate.com/sun/usa/corvallis?month=6&year=2019

As shown in Fig. 5.58, predictions for these events on a September equinox in Corvallis, Oregon are similar to the March equinox. The Sun appears to:

- rise at about the same time, at 7:01 am Pacific daylight time,
- be almost directly east (89° E),
- be at about the same maximum altitude in the sky (45°) at about the same time (1.05 pm Pacific daylight time),
- set at about the same time , at 7:08 pm Pacific daylight time),
- set directly west (270° W)

and that the duration of daylight would be about 12 hours.

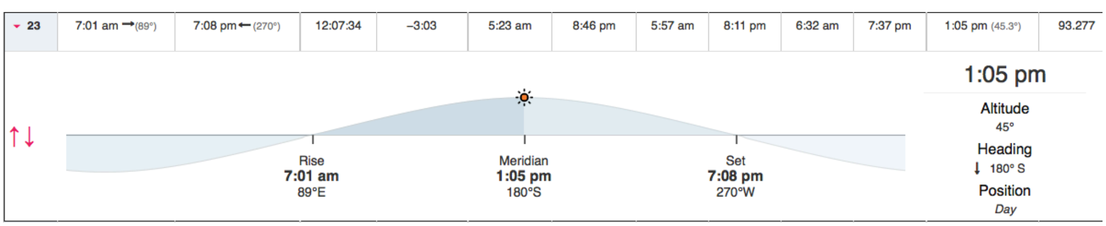


FIG. 5.58 Prediction for rising, transiting, and setting for the Sun on a September equinox. https://www.timeanddate.com/sun/usa/corvallis?month=9&year=2019

As shown in Fig. 5.59, predictions for these events on a December solstice in Corvallis, Oregon are for the Sun to appear to:

- rise at a much later time, at 7:46 am Pacific standard time, (equivalent to 8:46 am, Pacific daylight saving time)
- rise south of east (123° ESE),
- have a much lower maximum altitude in the sky (22°) at about the same time, 12:11 pm, Pacific standard time, (equivalent to 1:11 pm Pacific daylight saving time),
- set much earlier, 4:35 pm, (equivalent to 5:35 pm Pacific daylight saving time),
- set south of west (237° WSW),

and that the duration of daylight would be much shorter, about 8 3/4 hours.

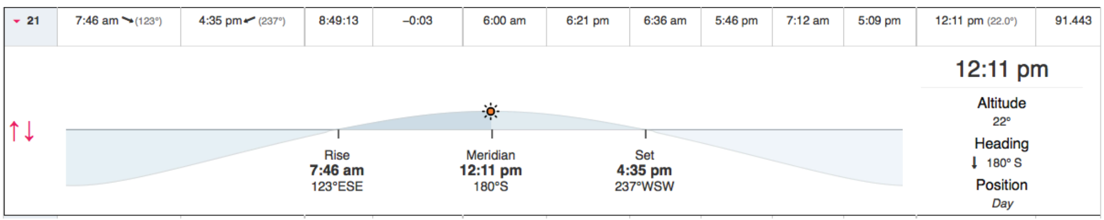


FIG. 5.59 Predictions for rising, transiting, and setting for the Sun on a December solstice. https://www.timeanddate.com/sun/usa/corvallis?month=12&year=2019

The shaded portions of Figs. 5.56-5.59 demonstrate the large differences between the solstices in the duration of daylight and the maximum altitude of the Sun at this location. The information provided in this website is summarized in Table V.11.

Table V.11 Solar data for Corvallis, Oregon during equinoxes and solstices

Table V.11 Solar data for Corvallis, Oregon during equinoxes and solstices							
Date in 2019	Sun rise	Direction	Transit	Maximum angular altitude	Sun set	Direction	Duration of daylight
March 20 spring equinox	7:16 am PDT	89° E of N	1:20 pm PDT	45°	7:25 pm PDT	271° W of N	12 hours
June 21 summer solstice	5:28 am PDT	55° N of E	1:20 pm PDT	69°	9:01 pm PDT	305° N of W	15.5 hours
Sept 23 autumn equinox	7:01 am PDT	89° E	1:05 pm PDT	45°	7:08 pm PDT	270° W	12 hours
Dec 21 Winter solstice	7:46 am PDT	123° S or E	12:11 pm PST (like 1:11 pm PDT)	22°	4:35 pm PST (like 5:35 pm PDT	237° S of W	8.75 hours

The data provided in Figs. 5.56 – Fig. 5.59 and Table V.11 indicate that at our location, the Sun's maximum altitude α (alpha) at the summer solstice is about 69°, but only about 22° at the winter solstice, and in between these, about 45°, at the spring and autumn equinoxes. What this means is that the shortest shadows during a day also change in length, being shortest at the summer solstice and longest at the winter solstice as shown in Fig. 5.60.

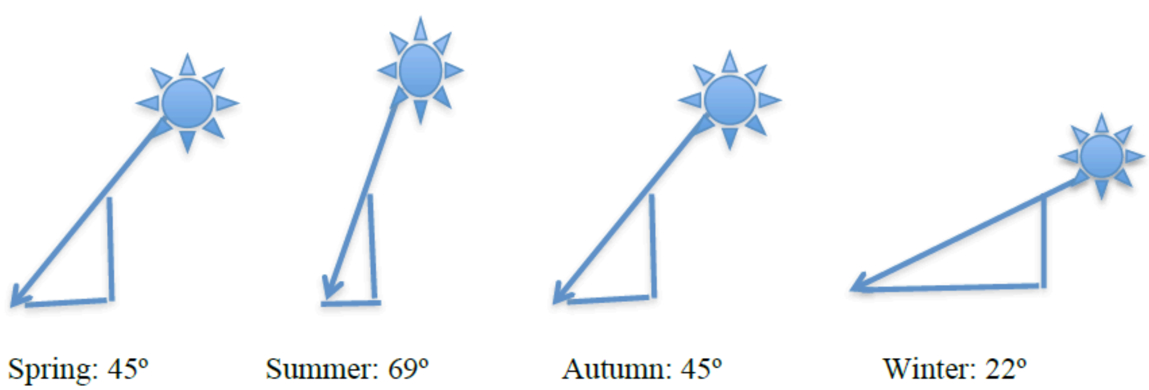


FIG. 5.60 Differences in maximum angular altitude α of the Sun and lengths of shortest shadows during the seasons.

The data in Table V.11 also indicate that at our location:

- The Sun rises well North of East and sets well North of West at the summer solstice but rises well South of East and sets well South of West at the winter solstice, and in between these, rises in the East and sets in the West at the spring and autumn equinoxes.
- The Sun is above the horizon for the most hours (15.5) at the summer solstice and the fewest hours at the winter solstice (8.75), and in between these, above the horizon the same number of hours (12) as below the horizon at the spring and autumn equinoxes.
- During summer, the Sun's maximum altitude is higher, the Sun's rays shine down more directly through the atmosphere, and the duration of daylight is longer than during winter.

4. Cultural examples of noticing changes in the Sun's maximum angular altitude α

Ancient peoples erected monuments oriented to the solstices such as at Maeshowe, built by Neolithic farmers about 5000 years ago on the Island of Orkney in Scotland. This burial *cairn* is a large mound made of stone, with a long low entrance passageway that is oriented so that sunlight shines through it into the inner chamber only during a few days before and after the winter solstice. (http://www.orkneyjar.com/history/maeshowe/solstice.htm, http://www.orkneyjar.com/history/maeshowe/index.html, http://www.maeshowe.co.uk).

As shown in Fig. 5.61, ancient peoples also constructed large upright stone monuments oriented toward the Sun and Moon, such as the Calanais Standing Stones on the Island of Lewis, also in Scotland (https://stonesofwonder.com/callanis.htm).

Fig. 5.61 Calanais Standing Stones, Isle of Lewis, Scotland. https://commons.wikimedia.org/wiki/File:Calanais_Standing_Stones_20090610_01.jpg CC 3.0

These sites predate Stonehenge in England, which also has large upright stones positioned with astronomical significance (https://www.english-heritage.org.uk/visit/places/stonehenge/history-and-stories/history/significance/). New instruments and techniques have led to new information about this area (https://www.smithsonianmag.com/history/what-lies-beneath-Stonehenge-180952437/). Recent droughts have led to new discoveries in Ireland of the remains of ancient *henges*, circular structures that have become visible in fields photographed from above by drones (https://www.smithsonianmag.com/smart-news/drought-reveals-giant-4500-year-old-irish-henge-180969650/).

Several ancient henges in North America have been excavated in part of the Cahokia Mounds State Historic Site located in Collinsville, Illinois. Built about 900-1100 A,D, these henges were made with red cedar posts about 15-20 inches in diameter and about 20 feet high. Some aligned with the rising Sun during solstices and equinoxes. See the description of WoodHenge at https://cahokiamounds.org/explore/#tab-id-r.

Modern people have chosen to celebrate astronomical solar equinoxes and solstices in similar ways. In a project led by astronomer Judith Young, the University of Massachusetts at Amherst has constructed a modern standing stone circle (See: http://www.umass.edu/sunwheel/pages/whatis.html) and http://www.umass.edu/sunwheel/images/sunwheel/paper.html

The Southern Colorado Astronomical Society has created a standing stone circle near Spanish Peaks in a project led by Russ Erganbright, a retired engineer. They have carefully sited each stone to illustrate where the Sun will rise and set during equinoxes and solstices. (See https://www.skyandtelescope.com/sky-and-telescope-magazine/beyond-the-printed-page/beyond-the-printed-page-a-modern-standing-stone-calendar/)

As shown in Fig. 5.62, Keppel Henge is a standing stone circle in a garden in Ontario, Canada that was developed by Steve Irvine and Bill Loney.

Fig.5.62 Keppel Henge, a standing stone circle in Ontario, Canada. http://www.steveirvine.com/henge4.html. Photograph copyright Steve Irvine, 2019.

Keppel Henge includes a North Star Stone with a notch through which a nearby Pointer Stone points at Polaris, the North Star. As shown in Fig. 5.63, the stars appear to move around Polaris during this photograph made with a one hour exposure.

FIG. 5.63 The apparent movement of stars around Polaris during one hour. *http://www.steveirvine.com/henge4.html* *Photograph copyright Steve Irvine, 2019.*

As shown in Fig. 5.64, Steve Irvine used a pinhole camera to photograph the apparent path of the Sun over a six-month period at the Keppel Henge site. This photograph shows the changing height of the arc that the Sun made as it appeared to move across the sky. The pinhole camera was a coffee can with a pinhole on one side, attached to the trunk of a tree.

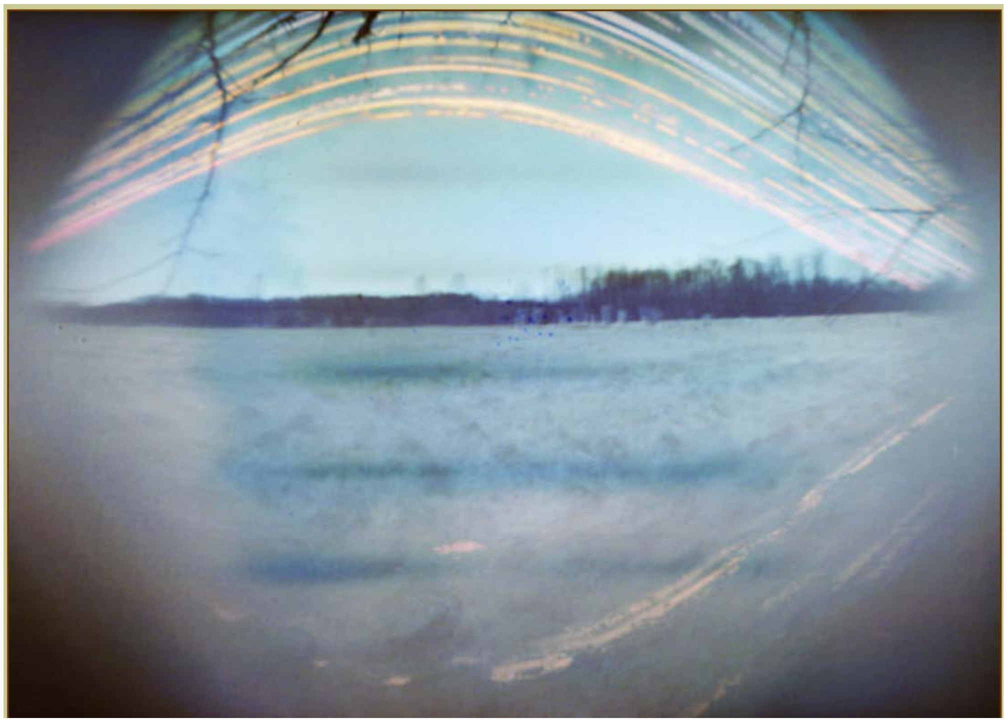


FIG. 5.64 *The apparent daily path of the Sun across the sky from the winter to summer solstices as photographed with a pinhole camera at Keppel Henge, Ontario, Canada.* http://www.steveirvine.com/henge_solargraph.html *Photograph copyright Steve Irvine, 2019.*

For additional images of the Sun, Moon, and stars from this location, see http://www.steveirvine.com/astro/index.html

C. Interpreting connections between seasonal differences in the Sun's apparent angular altitude and regional climates

Question 5.35 What is the connection between seasonal differences in the Sun's apparent angular altitude and regional climates?

- To consider monthly differences in climate in the US, click on your state and nearest town or city in https://www.usclimatedata.com.
- Describe seasonal differences in:

- average monthly temperature
- average monthly precipitation

As shown in Fig. 5.65, for example, a graph represents the average monthly high and low temperatures as well as monthly average rainfall for Corvallis, Oregon.

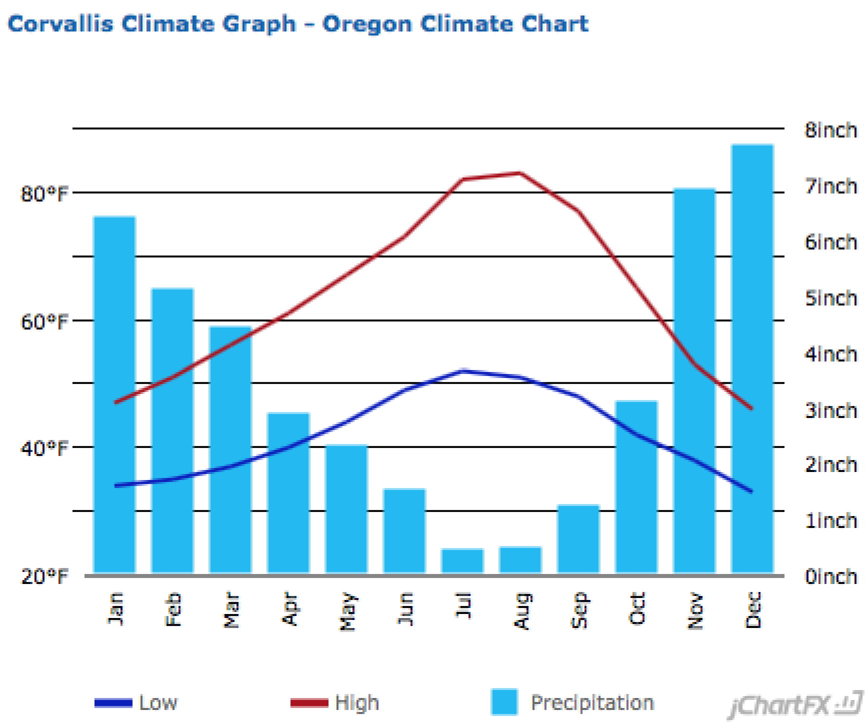


FIG. 5.65 Average monthly temperature and precipitation for Corvallis, Oregon. https://www.usclimatedata.com/climate/corvallis/oregon/united-states/usor0076

In summary, during summer in our location the Sun rises north of east and sets north of west during the spring and summer; rises directly east and sets directly west, during the equinoxes; and rises south of east and sets south of west, during autumn and winter. The Sun appears to rise earlier in the morning, to travel in a higher arc across the sky, and to set later in the evening in the summer than in the winter. The Sun's maximum angular altitude is about 69° on the summer solstice, 45° on the equinoxes, and 22° on the winter solstice.

During summer the Sun is above the horizon for more hours and seems to travel in a higher arc across the sky so that its rays shine more directly down through the atmosphere. Therefore, more energy from the Sun reaches the surface for a longer time period during the summer compared to the amount of energy from the Sun reaching the surface during winter. Our summers are warm and dry; our winters cool and wet. This climate is typical for our region, the Pacific Northwest in the US.

For some world wide climate information, go to https://www.climate.gov/maps-data/dataset/monthly-climatic-data-world-data-tables.

- Summarize the seasonal changes that occur in your location for:
    - when and where the Sun appears to rise
    - how high the Sun appears to go in its arc across the sky
    - when and where the Sun appears to set
    - how long the Sun is above the horizon
    - the average monthly temperature
    - the average monthly precipitation

Complete entries in Table V.12. Then write a summary of what you have learned about connections between seasonal differences in the details of the Sun's apparent daily motion and in the typical temperature and precipitation experienced in your region on the Earth.

TABLE V.12 Developing central ideas about seasonal differences in the details of the Sun's apparent daily motion and in regional climates

TABLE V.12 Developing central ideas about seasonal differences in the details of the Sun's apparent daily motion and in regional climates			
Sketch of set up	Evidence	Central Ideas	Relevant Vocabulary
		The Sun seems to rise north of east (spring, summer), directly east (spring and autumn equinoxes), and south of east (autumn and winter) in the northern hemisphere	
		The Sun's apparent highest maximum angular altitude (angle α) in the sky occurs at the summer solstice; the Sun's lowest maximum angular altitude α occurs during the winter solstice.	
		The Sun seems to set north of west (spring, summer), directly west (spring and autumn equinoxes), and south of west (autumn and winter) in the northern hemisphere	

		During spring and summer, the Sun is visible above the horizon for a longer duration (more than 12 hours) than not visible below the horizon; On the spring and autumn equinoxes, the Sun is visible above the horizon for the same duration, 12 hours, as not visible below the horizon; During autumn and winter, the sun is visible above the horizon for a shorter duration (less than 12 hours) than not visible below the horizon.	
		During summer, the Sun's maximum altitude is higher, the Sun's rays shine down more directly through the atmosphere, and the duration of daylight is longer than during winter.	

VII. Using Central Ideas Based on Evidence to Develop Two Explanatory Models for Seasonal Patterns in the Constellations Visible at Night

This section uses evidence of seasonal differences in developing two explanatory models for seasonal patterns in the constellations visible at night.

Question 5.36 Why are there seasonal patterns in the constellations visible at night?

Just as there were geocentric and heliocentric models to explain day and night, people have developed two explanatory models for the seasonal patterns of the visible stars.

A. Using a geocentric model to explain the seasonal patterns of constellations visible at night

Using a fixed Earth, revolving Sun model, many ancient astronomers considered the Sun, planets, and stars to be revolving daily around a stationary Earth. They envisioned these entities as being located on nesting *celestial spheres* centered on the Earth and spinning daily on their axes. The Sun also appeared to move annually with respect to the stars along a path on its celestial sphere known as the *ecliptic* as shown in Fig. 5.66.

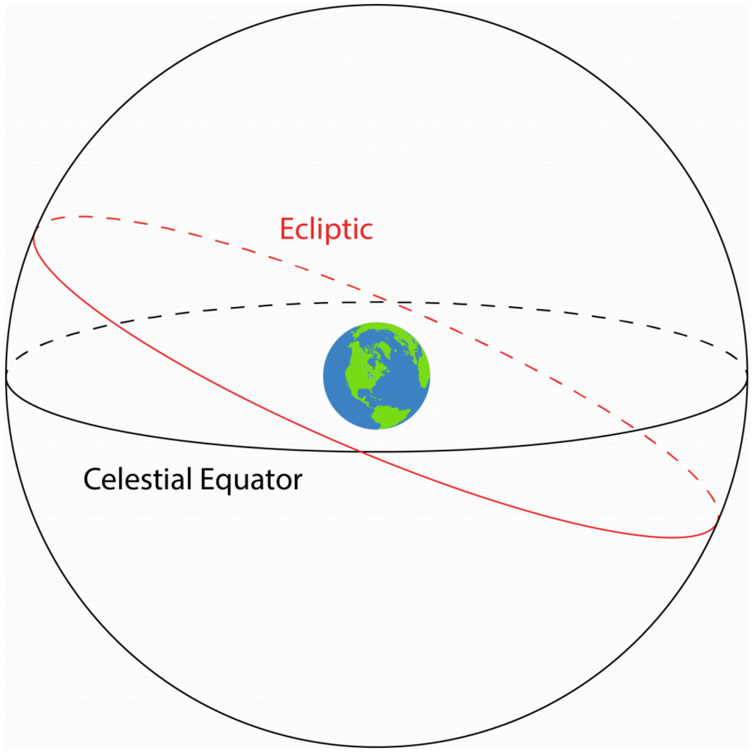


Fig. 5.66 Model of celestial sphere centered on the Earth.

Because the Sun was so bright, it would outshine the stars near where it was on the ecliptic. Therefore, people on Earth would see different stars at different times of year, those opposite the Sun in its annual path on the ecliptic around the Earth. These ancient astronomers envisioned the Sun's path along the ecliptic as tipped at an angle to the celestial sphere's equator. In this geocentric model, the constellations appeared on an inclined band on the ecliptic of a celestial sphere encircling the Earth as shown in Fig. 5.67. The band was known as the *Zodiac* as shown in this illustration published in a book by Regiomontanus about Ptolemy's *Almagest* in 1496. (http://abyss.uoregon.edu/~js/glossary/ptolemy.html).

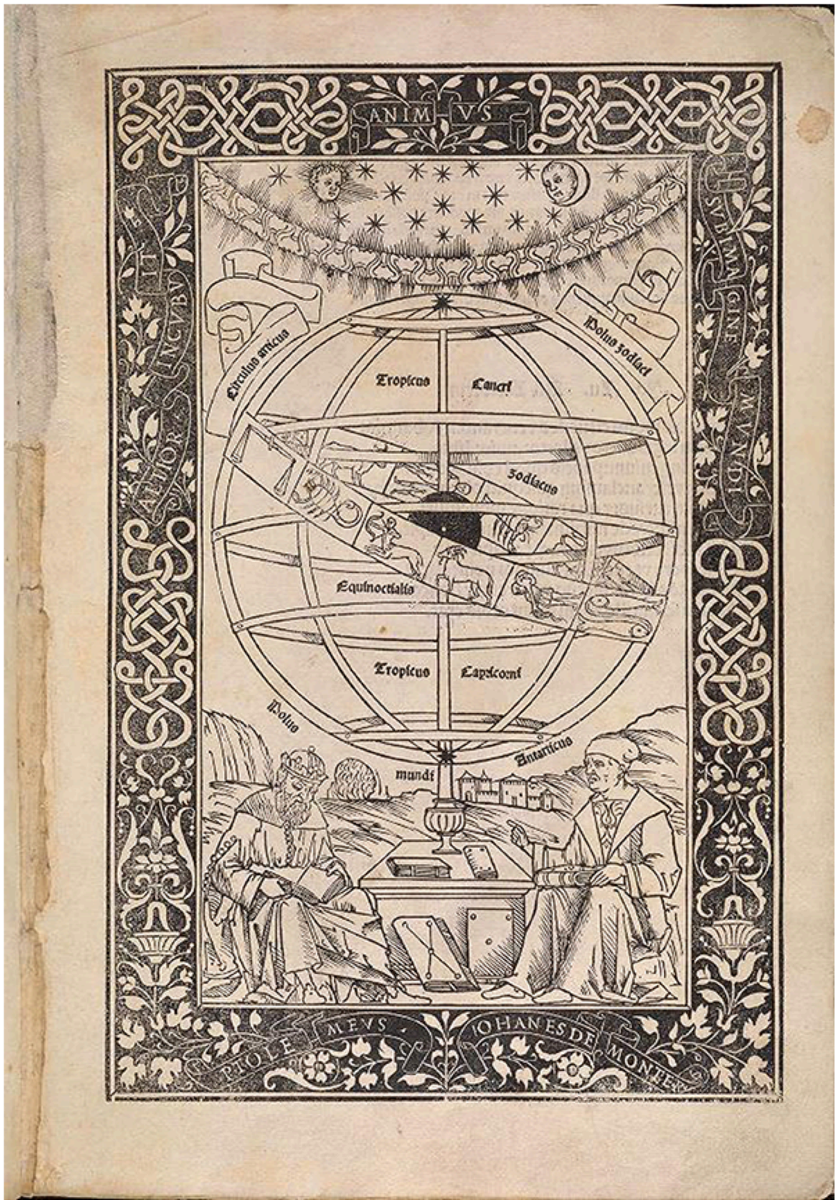


FIG. 5.67 Illustration of the zodiac on a celestial sphere in Epitome of the Almagest, 1496. [*https://library.si.edu/digital-library/book/epytomaioannisd00regi*](https://library.si.edu/digital-library/book/epytomaioannisd00regi) *(page 7) Dibner Library of the History of Science and Technology, Smithsonian Libraries.*

B. Using a heliocentric model to explain the seasonal patterns of the constellations visible at night

As suggested by Copernicus in 1543 and Galileo in 1632, an alternative explanatory model is that the Sun is not moving but it is the Earth that is revolving around the Sun. Demonstrate this heliocentric model as follows:

> Equipment: Use a lamp without a shade, masking tape, 4 pieces of chart paper, marker, and circular lid for each small group or student:
>
> Place a lamp without a shade in the middle of a dark room. Use masking tape to tape the cord to the floor to avoid having anyone trip over it. On each of four large pieces of chart paper, draw a constellation to represent one of the seasons such as those shown in Figs. 50-54. On each wall of the room, tape a constellation representing spring, summer, fall or winter night skies. Start by placing the constellation representing summer on the wall that is in the north direction if you live in the northern hemisphere or in the south direction if you live in the southern hemisphere.

- Everyone stand in a circle around the lamp. How would you each model "midday"?
- Next all model a rotating Earth by rotating in place, counter-clockwise if you live in the northern hemisphere, clockwise if you live in the southern hemisphere.
- How would you each model "midnight"?
- What constellation do you each see represented on the wall you are facing?
  What constellations do colleagues see when facing other walls?
- What constellation represents what is seen during each season?
  - What constellation is on the wall modeling what someone may see at midnight during spring?
  - during summer?
  - during autumn?
  - during winter?
- If you live in the northern hemisphere, keep rotating while revolving around the lamp in a counter-clockwise direction.
  If you live in the southern hemisphere, keep rotating while revolving around the lamp in a clockwise direction.
- Stop in the midnight position occasionally and report what constellation you see on the wall you are facing.
- Describe how this demonstrates a heliocentric model of the Earth's annual motion with respect to the Sun.
- Sketch the circular path you and your classmates are following around the lamp

    - as if you are looking down on this activity from above the lamp
    - as if you are looking at this activity from the side, as if you are looking in on it from a window
- Check the shape of your drawings by looking at a circular lid
    - from above
    - from the side

Resources in books and on the Internet frequently differ in the perspective assumed in drawings of the Earth's orbit. As shown on the left in Fig. 5.68, drawings from a perspective of looking down on the solar system from above show an almost circular orbit. As shown on the right in Fig. 5.68, drawings from a perspective looking at the orbit from the side show an exaggerated elliptical shape.

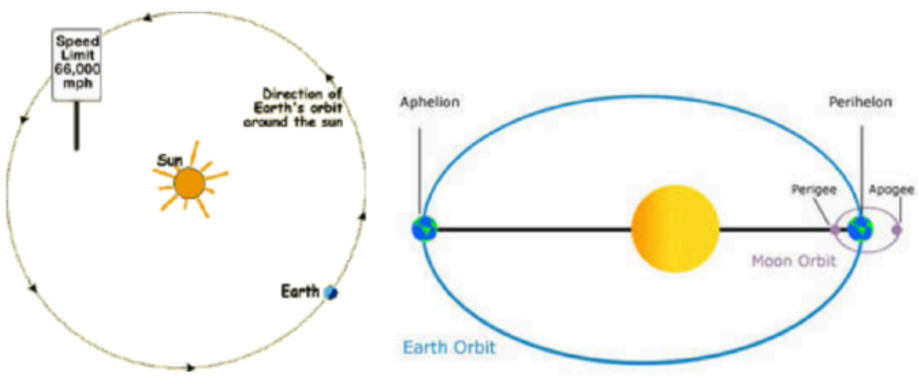


FIG. 5.68 *Drawings of the orbit of the Earth around the Sun from two perspectives*
https://spaceplace.nasa.gov/launch-windows/en/
https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-orbit-58.html

VIII. Using Central Ideas Based on Evidence to Develop an Explanatory Model for the Earth's Seasons

A. Explaining the Earth's seasons with a heliocentric model

Question 5.37 Why is it hot in the summer and cold in the winter?

An additional aspect of this heliocentric model is to envision the Earth as tilted on its axis. The tilt of the Earth's axis of rotation has profound implications for variations in climate as the Earth revolves in its orbit around the Sun as shown in Fig. 5.69.

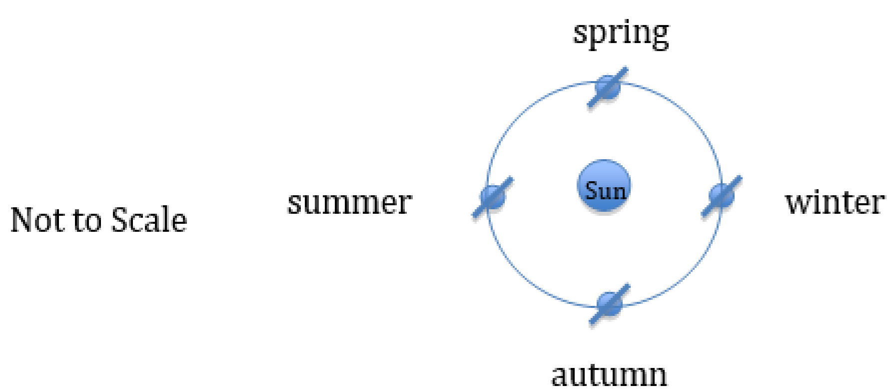


FIG. 5.69 Model of the Earth envisioned as tilted on its axis while revolving counter-clockwise around the Sun, with seasons identified for the northern hemisphere.

Note that the tilt is envisioned as always being in the same direction throughout the Earth's annual trip around the Sun:

In the northern hemisphere, as shown in Fig. 5.69 for example, the Earth is envisioned as moving in a counter-clockwise direction around the Sun with the tilt is always in the same direction, toward the north star, Polaris. In spring, the tilt is toward Polaris but opposite to the counter-clockwise direction of motion around the Sun. In summer, the tilt is still toward Polaris and now toward the Sun but perpendicular to the counter-clockwise direction of motion. In autumn, the tilt is still toward Polaris but also in the counter-clockwise direction of motion around the Sun. In winter the tilt is still toward Polaris but away from the Sun, perpendicular to the counter-clockwise direction of motion.

To model the revolution of the tilted rotating Earth around the Sun :

> Equipment: Use a lamp without a shade, masking tape, four constellations drawn on chart paper, and a globe representing the Earth. Place the lamp without a shade in the middle of the room, with its cord taped to the floor. Tape the four constellations representing spring, summer, fall, and winter to the appropriate walls.

- Which wall is in the north direction? east? south? west?
- Have someone hold the globe. Toward which wall should this person always tilt the axis of the globe?
- Which season is being represented by where this person is standing with respect to the lamp, the tilted globe, and the designated wall?
    - Tilt backwards along the path around the lamp but toward the designated wall for spring
    - Tilt both toward the designated wall and the lamp for summer
    - Tilt forward along the path around the lamp and toward the designated wall for autumn
    - Tilt away from the lamp but toward the designated wall for winter
- Have the person holding the globe keep the globe rotating on its axis and tilted toward the designated wall while walking around the lamp
- Where should the person be standing to represent:
    - the spring equinox?
    - the summer solstice?
    - the autumn equinox?
    - the winter solstice?

  as the person walks around the lamp, while keeping the rotating globe's axis tilted toward the designated wall?

Now everyone model the tilted rotating Earth revolving around the Sun:

- Tilt in the direction of the designated wall.
- Practice modeling the Earth's daily rotation while tilted in this direction.
- Which season are you modeling?

    - Where are you with respect to the lamp and the constellations on the walls?
    - Are you:
    - tilted toward the designated wall but tilted backwards along the path around the lamp as you move forwards ? (spring)
    - tilted toward both the designated wall and the lamp? (summer)
    - tilted toward the designated wall and forward along the path around the lamp ? (autumn)
    - tilted toward the designated wall but away from the lamp but? (winter)
- Now put the rotating and revolving motions together. As you revolve around the lamp, keep your body tilted toward the designated wall while rotating on that axis.
- What is the connection between this model of a tilted rotating Earth revolving around the Sun and the evidence of changes in the Sun's maximum angular altitude α and the tilt's effect on seasonal changes in the climate?
- Draw two diagrams, one representing a tilted Earth revolving around the Sun in an almost circular orbit and the other representing a lamp and students modeling the reasons for the Earth's seasons.

The data reported in section VI.B.3 indicate that during summer the Sun is above the horizon for more hours and seems to travel in a higher arc across the sky so that its rays shine more directly down through the atmosphere. Therefore, more energy from the Sun reaches the surface for a longer time period during the summer compared to the amount of energy from the Sun reaching the surface during winter.

In summary:

- The Sun is higher in the sky when the Earth is in a position in its orbit where its axis is tilted toward the Sun during the summer solstice.
- The Sun is lower in the sky when the Earth is in a position in its orbit on the other side of the Sun, where the Earth's axis is tilted away from the Sun during the winter solstice.
- During spring and autumn equinoxes, the Earth's tilt is parallel to the direction of travel and the tilt does not affect the number of hours that the Sun is above or below the horizon.

- Note that the Earth's axis of rotation always tilts in the same direction, in the northern hemisphere, for example, always toward Polaris, the North Star. What changes is where the Earth is in its orbit around the Sun.

Many people associate being warm with being close to a heat source and being cold with being far away from a heat source. Thus it may seem reasonable to associate summer with being closer to the Sun and winter with being farther away. This is not the case here, however. The Sun is about 100,000,000 miles away. The diameter of the Earth is only about 10,000 miles. The fractional difference in being on one side (tilted toward) or the other side (tilted away) from the Sun is only 10,000/100,000,000 = 1/10,000. This is not enough to make a difference.

The northern and southern hemispheres are effectively the SAME distance from the Sun; yet the southern hemisphere experiences winter while the northern hemisphere is experiencing summer; the southern hemisphere experiences summer while the northern hemisphere is experiencing winter. The difference is caused by where the Earth is in its orbit around the Sun and how this position affects the direction of the tilt of Earth's axis of rotation with respect to the Sun, not by a very minor difference in distance from the Sun.

Fig 5.69 assumes that the Earth's orbit around the Sun is circular. The orbit is, however, slightly elliptical. This means that the northern hemisphere is actually slightly closer to the Sun in January than in July, the opposite of what one might expect.

- Complete entries in Table V.13. Then write a summary of what you have learned about developing an explanatory model for the Earth's seasons.

TABLE V.13 Developing an explanatory model for the Earth's seasons

TABLE V.13 Developing an explanatory model for the Earth's seasons

URL or Sketch	Evidence	Central Ideas	Relevan Vocabu
		The Earth revolves around the Sun in one year. The orbit is nearly circular.	revolve orbit cons

http://sciencenetlinks.com/science-news/science-updates/tilted-earth/		The Earth's axis is tilted at about 23.4 degrees to the plane of the orbit	axis plane o
https://www.illustrativemathematics.org/content-standards/tasks/1140		As viewed from the northern hemisphere, the Earth rotates counterclockwise about an axis tilted about 23.4 degrees to the plane of the Earth's orbit while Earth revolves counterclockwise around the Sun	rotates revolve coun se clock
https://spaceplace.nasa.gov/seasons/en/ http://www.todayifoundout.com/index.php/2011/12/the-earth-is-hottest-when-it-is-furthest-from-the-sun-on-its-orbit-not-when-it-is-closest/		A hemisphere tilts toward the Sun but perpendicular to the Earth's orbit, during the summer solstice	Hemisp solstice
https://spaceplace.nasa.gov/seasons/en/		A hemisphere tilts along the Earth's orbit, either in the opposite or same direction of motion, during the spring and autumn equinoxes	equino

https://spaceplace.nasa.gov/seasons/en/		A hemisphere tilts away from the Sun, perpendicular to the Earth's orbit, during the winter solstice	

IX. Estimating the Tilt of the Earth

How curious are you about the tilt of the Earth? This section provides a detailed account of geometric arguments that underlie a surprisingly simple way to estimate the tilt of the Earth's axis. The only equipment you need would be a post and a way to measure its height and the length of its shortest shadow during equinoxes and solstices. If you enjoy puzzling through such geometrical arguments, read on. If not, perhaps skim this briefly to see what is here and then go on to the next section.

A. Developing and using mathematical representations to estimate the tilt of the Earth's axis

Ancient peoples noticed seasonal changes in the lengths of shadows as well as in the Sun's apparent path across the sky, particularly during equinoxes and solstices. A Greek astronomer, Eratosthenes (276-195 BC), for example, estimated the magnitude of the tilt by using such observations and his knowledge of geometry.

Question 5.38 How can one estimate the tilt of the Earth's axis of rotation?

This section develops a geometrical approach to estimating the tilt of the Earth's axis of rotation. This approach is surprisingly simple:

- Measure the maximum angular altitude of the Sun, angle α (alpha), at a given location during a solstice and during an equinox; then subtract one angle from the other.
- Or measure the maximum angular altitude of the Sun, angle α (alpha), at a given location during both solstices; then subtract the angle during the winter solstice from the angle during the summer solstice and divide by two.
- Or substitute (90° − the latitude of the gnomon) for the maximum angular altitude of the sun at an equinox and use this along with the maximum altitude of the Sun at one of the solstices as indicated in the box below.

Estimating those angles involves simply using a protractor, consulting data sources such as the tables presented in Figs. 5.56-5.59, or measuring the height of the gnomon (a post) and the length of its shadow at solar noon, dividing one by the other to find the angle's tangent, and identifying the angle with a calculator or trigonometry table.

1. Envisioning the tilt of the Earth's axis of rotation

The tilt of the Earth's axis is known as its *obliquity* and is represented by angle ε (the Greek letter epsilon). As shown in Fig. 5.70, the tilt is the angle ε between the Earth's axis of rotation, which is represented by the large dashed line from the North Pole to the South Pole, and the vertical axis, which is represented by the small dashed vertical line. The vertical axis is perpendicular to the plane of the Earth's orbit around the Sun. This discussion assumes the Earth is spherical. The small dashed horizontal line represents the projection of the orbital plane on this cross section of a spherical Earth.

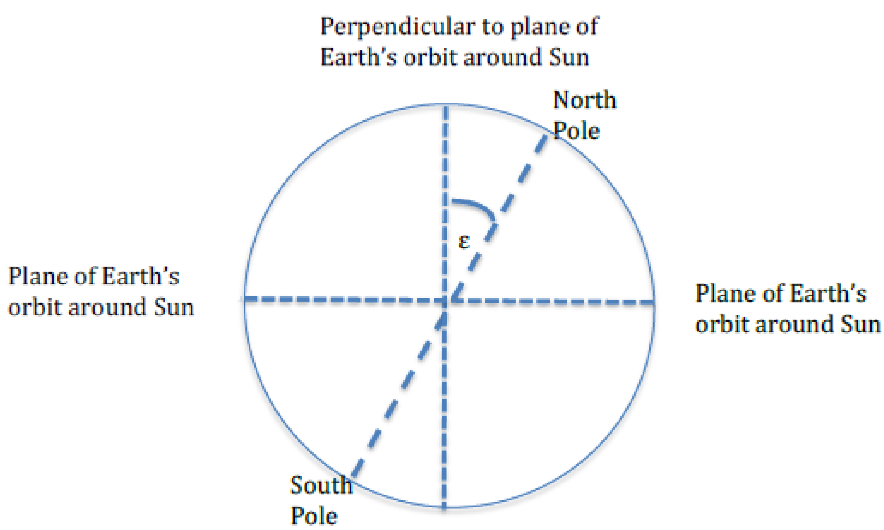


FIG. 5.70 Tilt of the Earth's axis of rotation with respect to the vertical to the plane of its orbit.

2. Estimating the tilt of the Earth's axis of rotation

How can you find out what the maximum angular angle of the Sun is at your location during a solstice or equinox?

To estimate the maximum angular angle of the Sun by observing a gnomon's shadow, provide for each group: a vertical post (a gnomon) in a flat sunny area, chalk, straight stick, protractor, and if needed a meter stick and trigonometry table or calculator with trig functions. Or use measurements of the maximum angular altitude of the Sun for the equinoxes and solstices at your location as reported in tables such as those shown in Figs. 5.56 – 5.59.

- Find a vertical post such as a fence post whose height you can measure and whose shadow is visible on flat ground during the middle of a sunny day. Or create such a gnomon by positioning a straight stick vertically in a flat sunny area.
- Mark the tip of the gnomon's shadow on the ground frequently during the middle of the day. Local solar noon occurs at the moment of the gnomon's shortest shadow.

The maximum angular altitude of the Sun, angle α(alpha), varies as shown in Fig. 5.71.

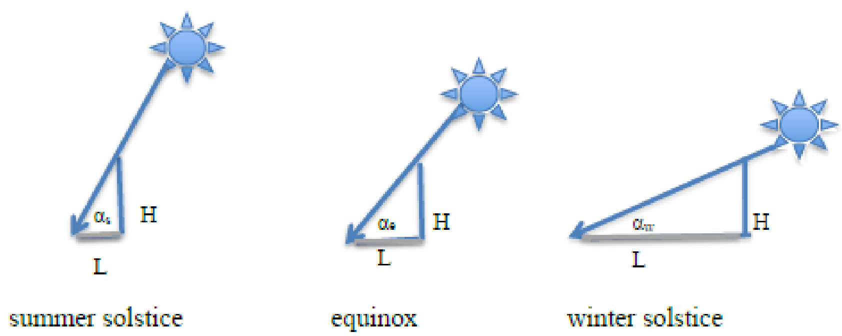


FIG. 5.71 Maximum angular altitudes of the Sun formed by a gnomon's shadows and rays of light from the Sun during the solstices and equinoxes.

There are many ways to obtain values for the maximum angular altitude of the Sun, angle α (alpha), during the solstices and equinoxes at a particular location:

- Estimate the maximum angular altitude of the Sun, angle α, directly by placing a straight stick, representing a light ray, from the top of the gnomon to the tip of the shadow at local noon (time of shortest shadow) and use a protractor to estimate the angle α formed by the stick and the gnomon's shadow.
- Or measure the height of the gnomon, H, and the length of its shadow, L, at solar noon. Then:

- Draw a careful ray diagram: First draw a line of length H representing the gnomon perpendicular to a line of length L representing the shadow. Next draw a straight line representing a light ray traveling from the tip of the line representing the gnomon to the end of the line representing the shadow. Then use a protractor to estimate the angle α formed by the lines representing the light ray and the shadow on the ground.
- Or calculate the tangent of angle α:

$$\text{Tangent of } \alpha = \frac{\text{height of the gnomon}}{\text{length of shortest shadow at solar noon}} = \frac{H}{L}.$$

- Then with a trigonometry table or calculator with trigonometry functions (arctan, sometimes written as $\tan^{-1}$), identify the angle α for which H/L is the tangent.

- Or one can calculate angle α_e at an equinox if one knows the latitude, angle ϕ (phi), of the location of the gnomon. Angle α_e at solar noon during an equinox is related to the *latitude* of the location of the gnomon as stated here and derived under #4 below.

Maximum angular altitude of the Sun during an equinox, angle α_e = 90° – angle ϕ

- Find a location's latitude in a data base or if in the northern hemisphere, estimate the latitude φ by using a protractor to estimate the angular altitude of the star Polaris on a clear night. Polaris is close to where the Earth's axis of rotation points in the northern sky. (A star does not appear near where the Earth's axis points in the southern sky; this option for estimating a location's latitude is not available there.) Substitute (90° – the latitude φ of the gnomon) for the maximum angular altitude of the sun at an equinox and use this along with the maximum altitude of the Sun at one of the solstices as indicated in the box below

- Another way to find the maximum angular angle of the Sun during the solstices and equinox is to use data for your location as predicted in tables such as in Figs. 5.56-5.59.

- Once you have estimates for the maximum angular altitude of the Sun, angle α, as discussed above:
    - Estimate the tilt of the Earth's axis, angle ε (epsilon), in at least one of the ways below:

Tilt of the Earth's axis, angle ε:

ε = angle α_s at summer solstice – angle α_e at equinox

Tilt of the Earth's axis, angle ε:

ε = angle α_e at equinox – angle α_w at winter solstice

Tilt of the Earth's axis, angle ε:

ε =
{\Large \frac{\text{angle} \, \alpha_s \text{at summer solstice } - \, \alpha _w \, \text{at winter solstice}}{2}}

These mathematical relationships can be envisioned as shown in Fig. 5.72. Detailed derivations are presented in sections #5, #7, and #8 below.

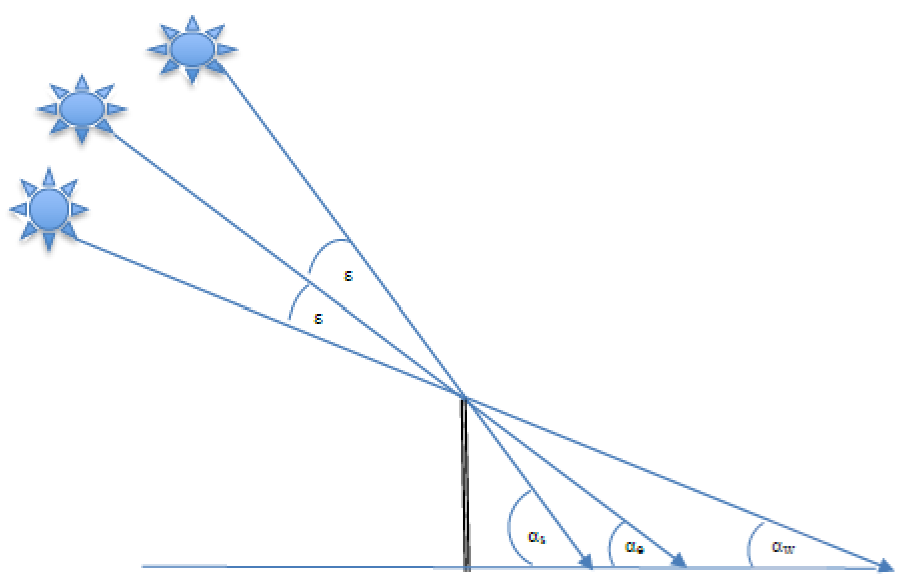


FIG. 5.72 Geometrical relationships among the tilt of the Earth ε and the maximum angular altitude of the Sun at the summer solstice, α_s, equinox, α_e, and winter solstice, α_w.

At our location, for example, as noted in the tables presented in Figs. 5.56 – 5.59:

angle α_s at the summer solstice in Corvallis = about 69 °

angle α_e at an equinox in Corvallis = about 45 °

angle α_w at the winter solstice in Corvallis = about 22 °

Tilt of the Earth's axis, ε:

ε = angle α_s at summer solstice – angle α_e at equinox

= about 69° – about 45 °

= about 24 °

Tilt of the Earth's axis, ε:

ε = angle α_e at equinox – angle α_w at winter equinox

= about 45° – about 22 °

= about 23 °

Tilt of the Earth's axis, ε:

$$\varepsilon = \frac{\text{angle}\,\alpha_s\ \text{at summer solstice} - \alpha_w\ \text{at winter solstice}}{2}$$

= (about 69° – about 22 °)/2

= about 47 °/2

= about 23.5°

The currently accepted value for the tilt of the Earth, called its *obliquity*, is 23.4° (https://www.timeanddate.com/astronomy/axial-tilt-obliquity.html)

An example middle school science lesson plan exploring this relationship is provided in http://www.umass.edu/sunwheel/pages/lesson5.html (this refers to: http://www.umass.edu/sunwheel/pages/lesson1.html)

Deriving the relationship that the tilt ε equals the difference between two angles depends upon a series of geometrical arguments that are presented next.

3. Nuances in developing and using mathematical representations to estimate the tilt of the Earth's axis of rotation

According to the heliocentric model, a nearly spherical Earth is revolving around the Sun each year in a nearly circular orbit that forms a plane. Diagrams representing the revolution of the Earth around the Sun can be confusing, however, because of the differing perspectives from which they are drawn.

As shown in Fig. 5.73, the perspective of a diagram of the Earth's orbit around the

Sun can be from above, looking down on a nearly circular orbit, or from the side, where the nearly circular orbit appears to be elliptical. Both of these diagrams are drawn from the perspective of the northern hemisphere where small arrows indicate the Earth to be orbiting counter-clockwise.

The diagrams in Fig. 5.73 differ, however, in how they portray a tilted axis, either tilted to the left or to the right. The direction of the tilt is consistent, however, either always toward the left or always toward the right. The statement "the axis tilts toward the Sun during summer and away from the Sun during winter" does not mean that the Earth's axis is tilting back and forth. What is changing instead is where the Earth is in its orbit with respect to the Sun.

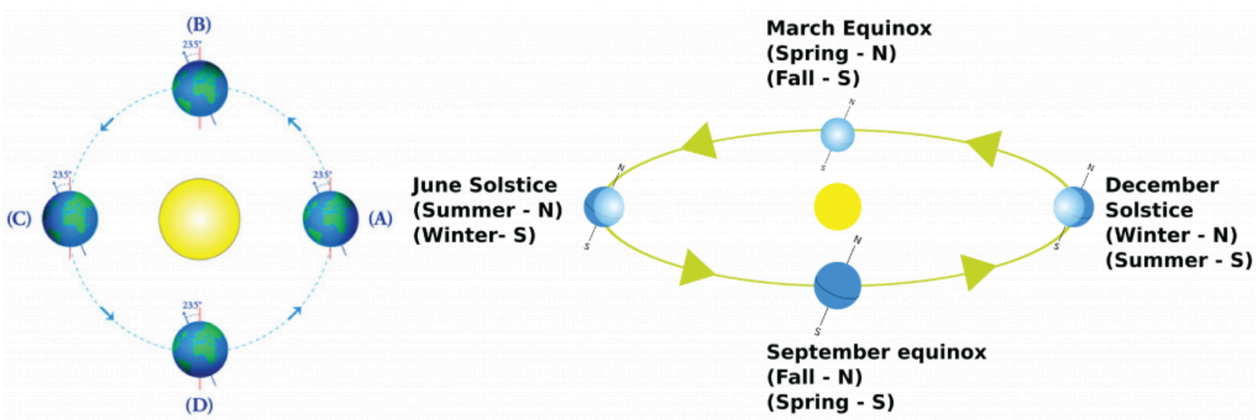


FIG. 5.73 Left: Earth in its orbit around the Sun as viewed from above, with tilt to the left. Right: Earth in its orbit around the Sun as viewed from the side, with tilt to the right.
https://www.illustrativemathematics.org/content-standards/tasks/1140 (CC BY-NC-SA 4.0)
https://commons.wikimedia.org/wiki/File:Orbital_relations_of_the_Solstice,_Equinox_%26_Intervening_Seasons.svg (CC0 1.0)

The artist drew a circular orbit in the diagram on the left, from the perspective of a viewer looking down from above the solar system. The position for summer (A) is on the right, with the North Pole shown tilted toward the left, toward the Sun. The position for winter (C) is on the left, with the North Pole still tilted toward the left, but away from the Sun.

The artist drew an apparently elliptical orbit in the diagram on the right, from the perspective of looking from the side, outside of the position labeled for fall. The position for summer is on the left, with the North Pole shown tilted toward the Sun on the right. The position for winter is on the right, with the North Pole tilted toward the right, away from the Sun.

The perspective shown on the right is the perspective adopted in the solstice diagrams below. In the diagram for the summer solstice in the northern hemisphere, light rays come from the Sun on the right. In the diagram for the winter solstice in the northern hemisphere, light rays come from the Sun on the left.

From this perspective, however, the Sun's rays during an equinox would be coming into or out of the plane of the paper and difficult to show in a diagram. Therefore, the perspective chosen for a diagram for an equinox is at right angles to those for the solstices.

4. Estimating latitude and maximum angular altitude of the Sun during an equinox

Question 5.39 Why does a location's latitude, angle ϕ = 90° – angle α_e?

Fig. 5.74 is a cross section of a spherical Earth during the spring equinox, with the Sun's rays coming from the right. The tilt of the Earth's axis would be into or out of the plane of the paper and not visible from this perspective. Fig. 5.74 is not to scale. During an equinox, the Sun would appear to rise directly east, set directly west and be above the horizon for 12 hours everywhere on Earth (spring: March 19, 20, or 21 and autumn: September 22, 23, or 24).

A gnomon of height H is placed at a location with *latitude* ϕ (phi). Latitude tells how far above the equator a location is. The gnomon's latitude, angle ϕ, is the angle formed by a line to the center of the Earth from this location and a line from a point on the equator to the center of the Earth,

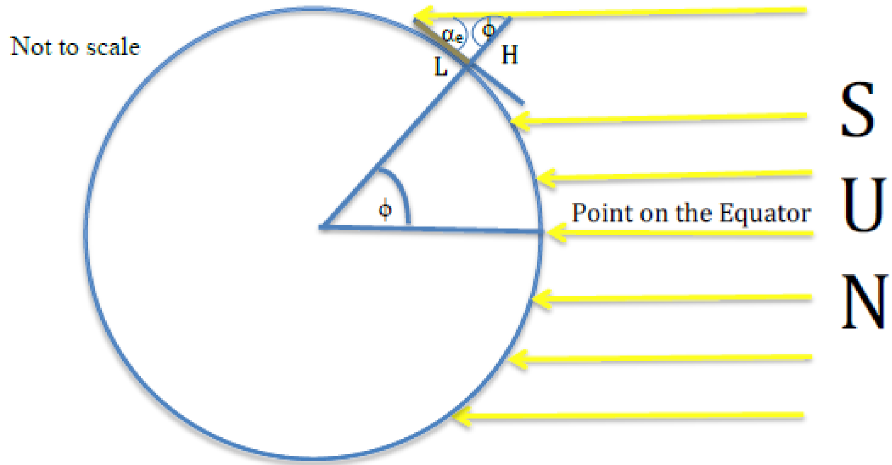


Fig. 5.74 Diagram representing the Sun's rays shining on the Earth during the spring equinox.

The gnomon casts a shadow of length L on the flat ground; the shadow is represented by the left part of the line perpendicular to the gnomon and tangent to the circle representing a spherical Earth. Rays of light from the Sun make an angle α_e with the ground. Angle α_e is the maximum angular altitude of the Sun during an equinox and its tangent is H/L at solar noon when L is the gnomon's shortest shadow.

The rays of light from the Sun are coming from so far away that they are considered to be parallel. Therefore, the angle formed by the rays of light and the gnomon is equal to the latitude, angle ϕ, because alternate interior angles formed by a transversal are equal when the transversal cuts two parallel lines. (See: https://www.mathopenref.com/anglesalternateinterior.html) The tangent of angle ϕ is L/H at solar noon.

The rays of light, gnomon, and shadow form a right triangle. The angles in a right triangle sum to 90°. Therefore: angel α_e+ angle ϕ = 90° and

A location's latitude, angle ϕ = 90° – angle α_e where α_e is the maximum angular altitude of the Sun during an equinox

This equation will be helpful below in estimating the tilt of the Earth's axis during the summer and winter solstices at the same location. Note also that at a latitude of angle ϕ = 0 degrees, at the equator, angle α_e will equal ninety degrees. This means the Sun will be directly overhead and there will be no shadows at solar noon during an equinox at the equator.

At our location in Corvallis, Oregon, the height of a gnomon and its shortest shadow on an equinox are about equal in length and the angular altitude of the Sun is about 45°, the value provided in the tables shown in Figs. 5.56 and 5.58. The actual latitude for Corvallis is 44.5646°.

5. Deriving the tilt of the Earth in terms of the difference between the maximum angular altitudes of the Sun during the summer solstice, α_s, and equinox, α_e

Question 5.40 Why does the tilt, angle ε = angle α_s at summer solstice – angle α_e at equinox?

Representing the tilted Earth during a solstice is quite complicated and therefore developed here in a series of steps. In Fig. 5.75, the perspective is from the side and the Earth's orbital plane is represented as perpendicular to the plane of the paper, with a spherical Earth emerging from the paper.

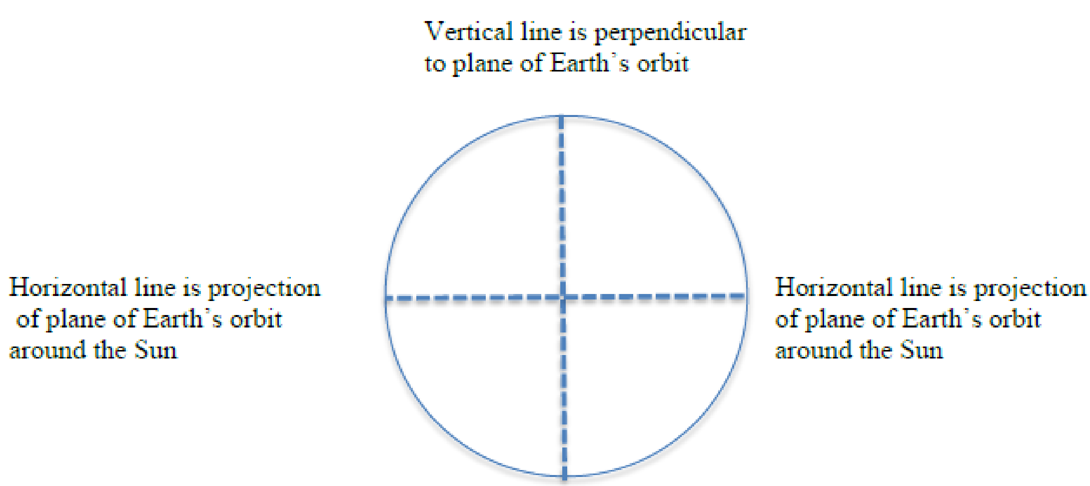


FIG 5.75 Cross-section of orbiting Earth with horizontal line representing projection of the plane of the Earth's orbit around the Sun.

A cross-section of the spherical Earth is represented by a circle that has horizontal and vertical axes at right angles. The dashed horizontal line represents a horizontal axis through the middle of the sphere. This is a projection of a plane that represents the plane of the Earth's orbit around the Sun. Envision a spherical Earth emerging from the plane of the paper.

The dashed vertical line represents a vertical axis through the middle of the Earth that is perpendicular to the plane of the Earth's orbit around the Sun.

Next consider that the spherical Earth also has axes tilted by an angle ε (epsilon) as in Fig. 5.76. The top of the tilted vertical axis represents the North Pole of the Earth and the bottom of the tilted vertical axis represents the South Pole of the Earth. Both ends of the tilted horizontal axis represent points on the Earth's equator.

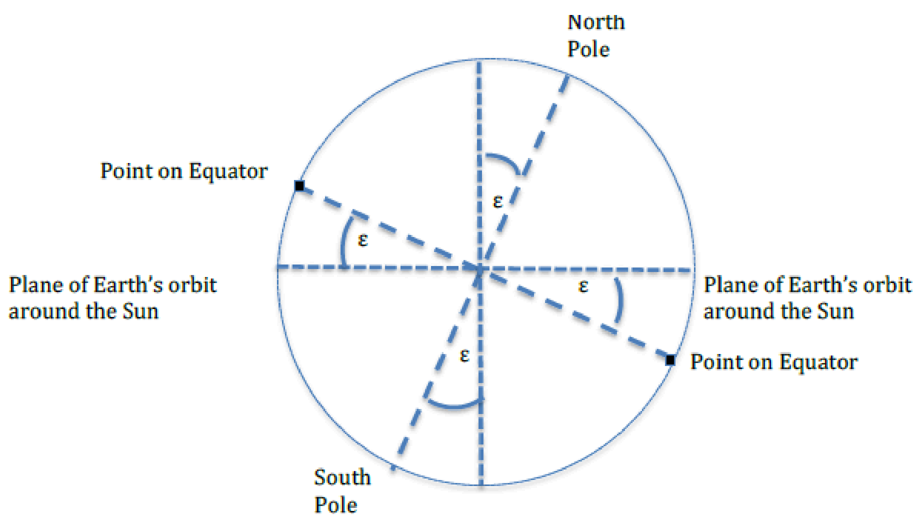


Fig. 5.76 Cross-section of a spherical Earth whose axis of rotation is tilted at angle ε (epsilon) with respect to the vertical to the plane of the Earth's orbit around the Sun.

Fig. 5.76 represents a cross-section through the center of a spherical Earth, rather than an attempt to represent the sphere in three-dimensions.

The dashed North/South pole line represents an axis through the center of the Earth. Envision the Earth rotating daily about this axis.

The dashed tilted horizontal axis represents the projection of the equator through the center of the rotating Earth.

The angle ε (epsilon) is the Earth's *obliquity* or tilt of the Earth's axis of rotation with respect to the vertical axis perpendicular to the plane of its orbit around the Sun.

The short dashed horizontal axis represents the projection of the plane of the Earth's orbit around the Sun.

The short dashed vertical axis represents a vertical axis perpendicular to the plane of the Earth's orbit around the Sun

Then consider a point that is at an angle ϕ (phi) between the Equator and the North Pole. As shown in Fig. 5.77, the angle ϕ (phi) represents the *latitude* of the point. The latitude ϕ (phi) of the point is the angle formed by a line from the point to the center of the Earth (red) and the line from a point at the Earth's equator to the center of the Earth (red). Points on the equator are considered to be at latitude of ϕ = 0. Fig. 5.77 is not drawn to scale.

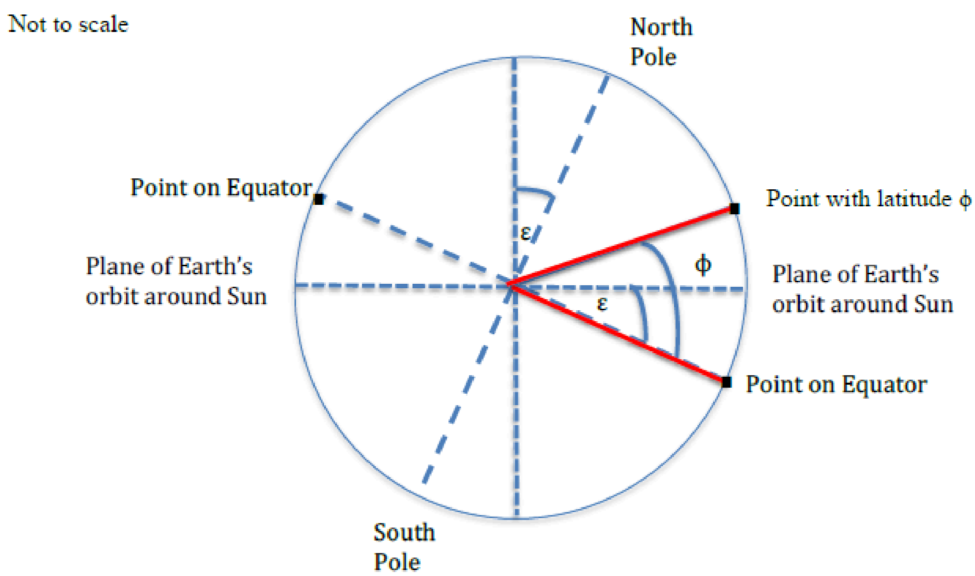


FIG. 5.77 Angle [latex]\phi[/latex] (phi) represents the latitude of a point with respect to a point on the equator.

During the summer solstice (June 19, 20 or 21) in the northern hemisphere, the Earth's tilted axis is pointing directly toward the Sun. During the summer solstice, the Sun rises the most north of east, moves highest across the sky, sets the most north of west, and is above the horizon for the most hours.

In Fig. 5.78, the yellow arrows represent light rays from the Sun, which is so far away that the incoming rays are essentially parallel. A gnomon at latitude ϕ has its shortest shadow at solar noon on the summer solstice. The shadow is represented by the gray half of the line representing the ground perpendicular to the gnomon.

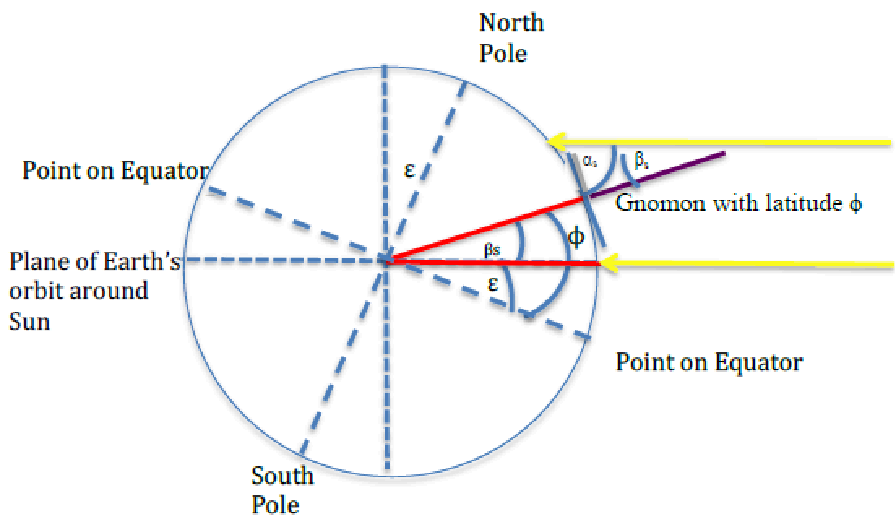


FIG. 5.78 Rays from the Sun and the gnomon create its shortest shadow at noon during the summer solstice in the northern hemisphere.

Angle α_S, angle alpha during the summer solstice, is the maximum angular altitude of the Sun. This angle is formed by the shadow and rays from the Sun at solar noon on the summer solstice.

Angle β_S, angle beta during the summer solstice, is formed by the gnomon and rays from the Sun at solar noon on the solstice.

Angle α_S + angle β_S = 90° because the gnomon forms a right angle with the flat area on which the shadow falls.

Therefore, angle β_S = 90° − angle α_S

The angle β_S formed by the gnomon and the light rays is congruent with the angle β_S formed by the red line to the center of the Earth from the point and the red line representing the horizontal axis. These angles are congruent because they are alternate interior angles formed by a transversal cutting across two parallel lines.

As shown in Fig. 5.77, angle ϕ = angle β_S+ angle ε

Solving for angle ε:

The tilt of the Earth, angle ε = angle ϕ − angle β_S

Both of these angles can be rewritten in terms of other angles:

The latitude of the gnomon, angle ϕ, is related to the maximum angular altitude of the Sun at the equinox as shown earlier in #4:

angle ϕ + angle α_e = 90° so angle ϕ = 90° − angle α_e

Angle $\beta_s$forms a right triangle with angle α_s:

angle α_s + angle β_s= 90° so angle β_s = 90° − angle α_s

If the tilt of the Earth, angle ε = angle ϕ − angle β_s

Then: angle ε = (90° − angle α_e) − (90° − angle α_s)

= 90° − angle α_e− 90° + angle α_s

The tilt of the Earth, angle ε = angle α_s − angle α_e

As claimed above in #2, the angular tilt of the Earth, angle ε, can be estimated simply by measuring the height of a gnomon (person, post, upright stick…) and its shadow at solar noon during the summer solstice and during the equinox, dividing the height of the gnomon by the length of the shadow (H/L) for each observation, finding the angles for which these numbers are the tangents, and subtracting the maximum angular altitude of the Sun in the sky at the equinox from the maximum angular altitude of the Sun in the sky at the summer solstice.

6. Discussing the effect of the tilt of the Earth at several latitudes

Question 5.41 What are the Tropic of Cancer, Arctic Circle, and Antarctic Circle?

The tilt of the Earth's axis of rotation causes unusual effects at several latitudes known as the Tropic of Cancer near the equator, the Arctic Circle near the North Pole, and the Antarctic Circle near the South Pole.

As shown in Fig. 5.79, at latitude ϕ equal to angle ε above the equator at solar noon on the summer solstice in the northern hemisphere, sunlight shines directly down on a gnomon (a person, post, upright stick…) that casts no shadow. A long red dashed line in Fig. 5.79 represents a projection of the Tropic of Cancer, a line around the Earth at this latitude of about 23.4°, the most northern latitude at which the Sun is ever directly overhead, where α_s= 90°. The Tropic of Cancer was named about 2000 years ago when the Sun was perceived as being in the constellation with the Latin name for crab (https://www.space.com/16970-cancer-constellation.html) in its annual path along the zodiac in the geocentric model of the Sun revolving around the Earth. The word *tropic* is derived from a Greek word for *turn*. After the summer solstice, the Sun appears to turn back toward the south in where it appears to rise and set.

The Arctic Circle is the lowest latitude at which the Sun never seems to set during the summer solstice in the northern hemisphere, where $\alpha_S = 0°$. As shown in Fig. 5.79, this occurs at a latitude of an angle ε below the North Pole, about 66.5° above the equator. A short red line with thin dashes represents the projection of the Arctic Circle on this cross section through the middle of a spherical Earth.

At this same time (June 19, 20, or 21) but known as the winter solstice in the southern hemisphere, no sunlight reaches the South Pole or areas within the latitude of an angle ε above the South Pole, about 66.5° below the equator. A line around the Earth at this latitude, about -66.5°, is known as the Antarctic Circle. A short red line with thick dashes represents the projection of the Antarctic Circle on this cross section through the middle of a spherical Earth in Fig. 5.79.

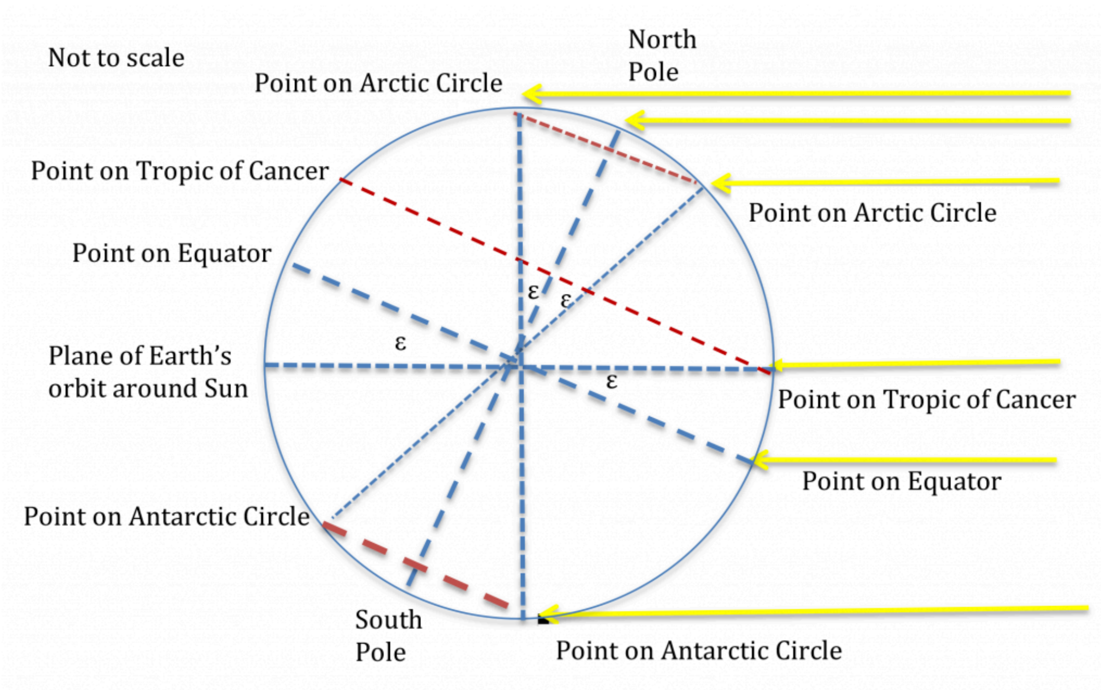


FIG. 5.79 Tropic of Cancer, Arctic Circle and Antarctic Circle during the June solstice.

The diagrams in Figs. 5.74 and 5.79 can be puzzling in that both include a point at which light rays shine directly on a gnomon at solar noon so that the gnomon does not cast a shadow. Fig. 5.74 identifies this as a point on the equator. Fig. 5.79 identifies this as a point at a latitude angle ε above the equator, on the Tropic of Cancer. Both points appear as if they lie half-way between the top and bottom of a circle representing a cross section of a spherical Earth, a circle divided by a horizontal line representing the projection of the equator in Fig. 5.74 and a circle divided by a horizontal line representing the projection of the plane of the Earth's orbit around the Sun in Fig. 5.79.

The key to understanding this puzzle is to recognize that these diagrams are drawn from two different perspectives that represent different positions in the Earth's orbit around the Sun. Fig. 5.74 represents the Earth in a position at an equinox. Fig. 5.79 represents the Earth in a position at a solstice. It can be difficult to envision the difference between these 3-dimensional perspectives as represented on these 2-dimensional diagrams.

Fig. 5.74 represents an equinox, when the Earth's tilt is not evident in a cross section through the middle of a spherical Earth emerging from the paper. The tilted axis is pointing along the direction of travel, into or out of the plane of the paper, and only represented by a dot in the center of the circle. Fig. 5.79 represents the summer solstice in the northern hemisphere; the tilted axis is pointing perpendicular to the direction of travel and visible as the inclined axis of rotation in a cross section of a spherical Earth emerging from the plane of the paper.

7. Deriving the tilt of the Earth in terms of the difference between the maximum angular altitudes of the Sun during an equinox, α_e, and during the winter solstice, α_w

Question 5.42 Why does the tilt, angle ε = angle α_e at equinox – angle α_w at winter solstice?

During the winter solstice in the northern hemisphere (December 20, 21, or 22), when the Earth's axis of rotation points away from the Sun, the Earth is on the other side of the Sun from its position during the June solstice shown above in Fig. 5.78. The light rays from the Sun come in parallel from the opposite direction, as shown below in Fig. 5.80. During the winter solstice at this location in the northern hemisphere, the Sun rises the most south of east, moves the lowest across the sky, sets the most south of west, and is above the horizon for less than 12 hours.

Envision a gnomon placed perpendicular to the surface, at a location whose latitude is angle ϕ. In this case the Sun is at its smallest maximum angular altitude at this latitude and the gnomon casts a long shadow as shown in the gray line on the right part of the tangent to the surface of the Earth at the gnomon's location as shown in Fig. 5.80. This figure is not to scale.

The angle β_W (angle beta during the winter solstice) is formed between the ray from the Sun and the gnomon. This angle is equal to the angle β_W formed by a line from the point to the center of the Earth and the horizontal axis because they are alternate interior angles formed by a transversal line intersecting with two parallel lines.

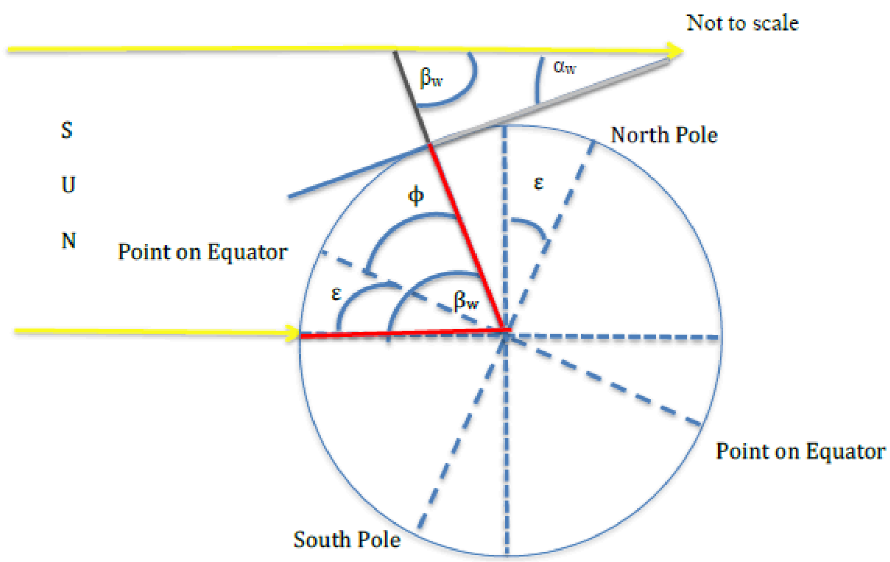


FIG. 5.80 Diagram for the winter solstice at latitude [latex]\phi[/latex] in the northern hemisphere.

w

angle ε = angle β_W – angle ϕ

Both of these angles can be rewritten in terms of other angles:

Angle $\beta_W$forms a right triangle with angle α_W:

angle α_W + angle β_W = 90°;

Therefore: angle β_W = 90° – angle α_W

The latitude of the gnomon, angle ϕ, is related to the maximum angular altitude of the

Sun at the equinox as shown earlier in #4: angle ϕ + angle α_e = 90° so angle ϕ = 90° – angle α_e

If the tilt of the Earth, angle ε = angle β_W – angle ϕ

Then: angle ε = (90° – angle α_W) – (90° – angle α_W)

= 90° – angle α_W– 90° + angle α_e

The tilt of the Earth, angle ε = angle α_e– angle α_W

As claimed above in #2, the angular tilt of the Earth can be estimated simply by measuring the height of a gnomon (person, post, upright stick…) and its shadow at solar noon during the winter solstice and during the equinox, dividing the height of the gnomon by the length of the shadow (H/L) for each observation, finding the angles for which these numbers are the tangents, and subtracting the maximum angular altitude of the Sun in the sky at the winter solstice from the maximum angular altitude of the Sun in the sky at the equinox.

8. Developing and using a mathematical representation to estimate the Earth's tilt if a location's latitude is not known

Question 5.43 Why does the tilt, angle ε = $\frac{\textbf{angle}\,\alpha_s - \textbf{angle}\,\alpha_w}{2}$***?***

Although a location's latitude is well known now, ancient astronomers did not need this information if they were able to measure the maximum angular altitude of the Sun, angle α, during both the summer and winter solstices at the same location.

Add the equations from summer and winter solstices:

From #5 above: angle ε = angle α_e– angle α_W

From #7 above: angle ε = angle α_S– angle α_e

Add: 2 (angle ε) = angle α_e– angle α_W + angle α_S– angle α_e

$$\text{angle}\,\epsilon = (\frac{\text{angle}\,\alpha_s - \text{angle}\,\alpha_w}{2})$$

as claimed in #2. It is possible to estimate the tilt of the Earth, angle ε (epsilon), by measuring the maximum angular altitude of the Sun (angle alpha, α) during the summer and winter solstices at a particular location, subtracting the maximum angular altitude of the Sun during the summer solstice, angle α_S, from the maximum angular altitude during the winter solstice, angle α_W, and dividing by 2. One does not need to know the latitude of one's location! This may be the method that the ancient Greek astronomer Eratosthenes used to estimate the tilt.

9. Discussing additional effects of the tilt of the Earth's axis on several latitudes

Question 5.44 What happens at the Tropic of Capricorn, Antarctic Circle, and Arctic Circle?

As shown in Fig. 5.81, at solar noon on the summer solstice in the southern hemisphere (December 20, 21, or 22), sunlight shines directly down on a gnomon (a person, post, upright stick…) that casts no shadow at a latitude that is an angle ε below the equator. A long red dashed line in Fig. 5.81 represents a projection of the Tropic of Capricorn, a line around the Earth at this latitude of about − 23.4°. This is the farthest south of the equator that the Sun is ever directly overhead.

The Tropic of Capricorn was named about 2000 years ago when the Sun was perceived as being in the constellation with the Latin name for goat horn (https://www.thoughtco.com/tropic-of-cancer-tropic-of-capricorn-3976951) in its annual path along the zodiac in the geocentric model of the Sun revolving around the Earth.

The lowest latitude at which the Sun never seems to set during the summer solstice in the southern hemisphere is called the Antarctic Circle. As shown in Fig. 5.81, this occurs at a latitude of an angle ε above the South Pole (about 66.5° below the equator). A short red line with thick dashes represents the projection of the Antarctic Circle on this cross section through the middle of a spherical Earth.

At this same time but known as the winter solstice in the northern hemisphere, no sunlight reaches the North Pole or areas within the latitude of an angle ε below the North Pole (about 66° above the equator). A line around the Earth at this latitude is known as the Arctic Circle. A short red line with thin dashes represents the projection of the Arctic Circle on this cross section through the middle of a spherical Earth in Fig. 5.81.

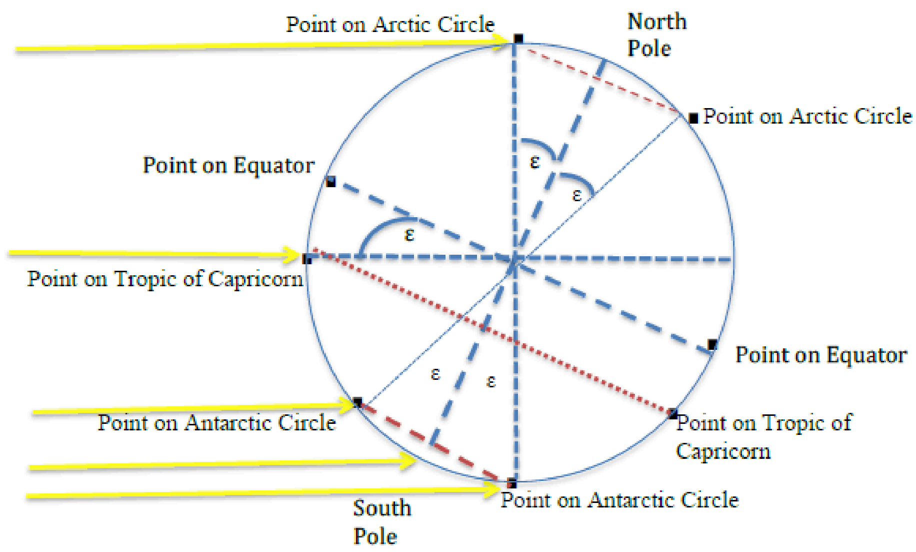


FIG. 5.81 Tropic of Capricorn, Antarctic Circle and the Arctic Circle during the December solstice.

X. Developing and Using Mathematical Representations to Estimate an Intriguing Quantity

This section explores ways to visualize what happens as the Moon revolves around the Earth while the Earth is revolving around the Sun. Acting out such simultaneous motions can help make visible something surprising about what is happening. Drawing diagrams and developing mathematical representations can help answer intriguing questions that emerge from such visual representations of the simultaneous motions of the Moon and Earth.

A. Visualizing relationships among the Sun, Earth, and Moon through actions

Question 5.45 How are the motions of the Moon revolving around the Earth related to the motions of the Earth revolving around the Sun?

1. Acting out the simultaneous motions of the Earth and the Moon

Equipment: Use the setup for modeling the Earth revolving around the Sun: put a lamp without a shade in the middle of the room, with cord taped to the floor to avoid students tripping over the cord. If possible, do this activity just before the Moon will be in its third quarter phase. It also can be adapted for use near the Moon's first quarter phase.

- Stand in pairs around the lamp representing the Sun. One person in each pair plays the role of the Earth. The other person in each pair plays the role of the Moon.
- Review the meanings of **revolving** and **rotating**.

- With the lamp turned off, rehearse how to act out the motion of the Earth during **one week**:
    - About how far will the person representing an observer on Earth be moving in an orbit around the lamp?
    - In what direction will the person representing “Earth” be revolving?
    - In what direction with the person representing “Earth” be rotating?
    - How many times will the person representing“Earth” be rotating to represent one week?

- With the lamp turned off, rehearse how to act out the motion of the Moon during **one week**:
    - Where should the person playing the role of a full Moon stand with respect to the lamp and to the person representing an observer on Earth ?
    - To where should the person representing a full Moon move to represent the third quarter Moon position?
    - How will this person move to continue facing the person playing the role of an observer on Earth?
- Turn on the lamp. Sing or count *day* 1, *day* 2, *day* 3, *day* 4, *day* 5, *day* 6, *day* 7 while the person representing an observer on Earth and the person representing the Moon model the simultaneous motions of the Moon revolving around the Earth while the Earth revolves around the Sun while rotating on its axis during one week between the Moon’s full and third quarter phases.
- If you see a third quarter Moon, where are you and everyone else on Earth heading next?

2. Nuances in acting out the simultaneous motions of the Moon and the Earth

This kinesthetic activity engages participants in using their own motions to demonstrate what is happening. In particular, this activity can help distinguish more clearly between the specific meanings of *revolving*, in which one object orbits another object, and *rotating*, in which an object spins on its own axis.

The Earth does not move very far during one week compared to its total orbit around the Sun. There are about 52 weeks in one year, so the distance that the person playing the role of the Earth should move would be about 1/52 of the circumference of a circular orbit around the lamp. This is not very far – about a meter if the participants are moving in a circle about 10 meters away from the lamp. (Circumference/52 = $2\pi R/52$ = 2*3*10 m/52 = a little over 1 meter.)

It is important to model accurately the direction of revolution and rotation. In the northern hemisphere, the person representing the Earth should **revolve** *counterclockwise* around the lamp while **rotating** seven times *counterclockwise* in order to model the Earth's motion during one week of seven days.

To start in the full Moon position, the person playing the role of the Moon should stand facing the person playing the role of the Earth in a line with the lamp as shown in Fig. 5.82.

FIG. 5.82 Initial arrangements for students modeling the simultaneous motions of the Moon and Earth.

As shown in Fig.5.83, when moving to the third quarter phase, the person playing the role of the Moon should move *counterclockwise* around the "Earth" until forming a right angle with the "Earth" and the lamp. The "Moon" should continue facing the "Earth" by also doing a quarter of a rotation while revolving

FIG. 5.83 Final arrangement in the northern hemisphere for students modeling the simultaneous motions of the Moon and Earth.

At the end of modeling the simultaneous motions of the Moon and the Earth between full moon and third quarter moon phases, the "Moon" person should be standing directly in the "Earth" person's direction of travel around the lamp. The participants will have acted out a surprising finding:

When looking at a third quarter Moon, one is looking at the

“place in space” where everyone on the Earth will soon “be” as the Earth revolves in its orbit around the Sun!

Acting out these simultaneous motions of the Earth and Moon can enhance students understanding of the difference between revolving and rotating motions as well as of the phenomena being modeled. Some students may remember the observations by a child visiting the southern hemisphere (Figs. 5.36 and 5.37) and wonder about what direction students in the opposite hemisphere would be revolving and rotating. Depending upon the time available and the level of understanding evident in class, exploring this issue may be feasible, particularly with a small group of students who like to pursue details that deepen their understandings.

The Sun and Moon appear to rise in the east and set in the west in both hemispheres. What is different is the direction one is looking when one sees the Moon, which is orbiting roughly in the plane of the equator (see Fig. 5.47).

In the northern hemisphere, the Sun and Moon appear mostly in the southern sky. When one looks south, east is on the left and west is on the right; therefore, both the Sun and Moon appear to move across the sky from left (east) to right (west) in the *clockwise* direction, as shown by the observation reported earlier in Fig. 5.8. In this case, the term *clockwise* reflects a geocentric model, with the Sun appearing to revolve daily around the Earth in a *left to right*, *clockwise* motion across the sky. Acting out the simultaneous motions of the Earth and Moon reflects a heliocentric model, however, with the lamp representing a fixed Sun and with the “Moon” revolving a quarter turn around the “Earth” and the “Earth” rotating seven times on an axis and revolving a short distance around the lamp, all in a *counterclockwise* direction.

In the southern hemisphere, the person representing the Earth should **revolve** *clockwise* around the lamp while **rotating** seven times *clockwise* to model the Earth’s motion during one week of seven days. To start in the full Moon position, the person playing the role of the Moon should stand facing the person playing the role of the Earth in a line with the lamp as in Fig. 5.82

When modeling moving to the third quarter phase, the person playing the role of the Moon should move *clockwise* around the “Earth” until forming a right angle to the lamp. The “Moon” should continue facing the “Earth” by also doing a quarter of a rotation while revolving.

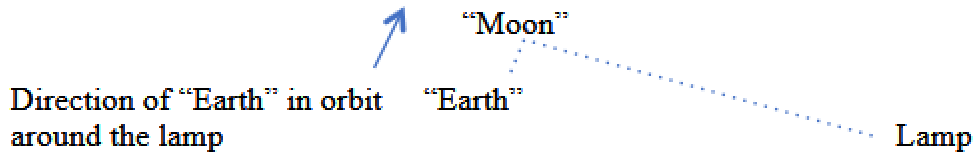


FIG. 5.84 Final arrangement in the southern hemisphere for students modeling the simultaneous motions of the Moon and Earth.

At the end of modeling the simultaneous motions of the Moon and the Earth between full moon and third quarter moon phases, the "Moon" person should be standing directly in the "Earth" person's direction of travel around the lamp. The participants will have acted out the surprising finding that when looking at a third quarter Moon, one is looking at the "place in space" where everyone on the Earth will soon "be" as the Earth revolves in its orbit around the Sun!

In the southern hemisphere, the Sun and Moon mostly appear in the northern sky. When one is looking north, east is on the right and west on the left; both the Sun and Moon appear to move across the sky from right (east) to left (west) in a *counterclockwise* direction. In this case, the term *counterclockwise* reflects a geocentric model, with the Sun appearing to revolve daily around the Earth in a *right to left* motion across the sky. Acting out the simultaneous motions of the Earth and Moon reflects a heliocentric model, however, with the lamp representing a fixed Sun and with the "Moon" revolving a quarter turn around the "Earth" and the "Earth" rotating seven times on an axis and revolving a short distance around the lamp, all in *clockwise* direction.

B. Visualizing by drawing a diagram and thinking conceptually about the situation

Question 5.46 When you see a third quarter Moon, you are looking at the "place in space" where you and everyone else on Earth will soon "be"! How soon will you get "there"?

- If you are looking at a third quarter Moon, how soon do you think you and everyone else on Earth will “be” at the “place is space” where a third quarter moon “is” now?

- Compare your estimate with those by your group members: are their estimates of the time required in minutes? hours? days? weeks? months?
- With your group members consider how you might calculate a numerical estimate:
  - What can you draw to help visualize this situation?
  - What are some central ideas that might be helpful in developing an equation with which to calculate an estimate of the time required for this ‘trip’?
  - What quantities might be relevant to include in such an equation? What numerical values might be helpful to know?
  - How can you use these insights to develop an equation and calculate an estimate?

1. Drawing a diagram that represents the situation and considering relevant central ideas

The following handout can guide development of a numerical estimate:

Where Are All of Us on Earth Heading Next?

Early one morning you see a third quarter moon.

Sketch a stick figure pointing one arm at the Sun and one arm at a 3rd quarter moon.

About what time is this? (Sketch below is for someone in the northern hemisphere)

____

East S West

- What if you were able to look down on a third quarter moon from above the solar system?
  - Sketch the Earth in its orbit around the Sun.
  - Sketch the Moon in the third quarter position in its orbit around the Earth.

- Where are all of us on Earth heading next?
- When will we get there?
- Make an estimate based on your intuition

To make an estimate numerically:

- What do you know about the physics of this situation?
- What concepts, for example, are useful in describing motions?
  - How are the distance traveled (Δ x) and the duration of a trip (Δt) related?

Use Δ (Greek letter delta) to represent "change in":

  - Δx is the change in position or distance traveled;
  - Δt is the change in clock-reading or duration of the trip.
- What two assumptions would be helpful to make in this situation?
  - About the Earth's orbit?
  - About the Earth's speed in its orbit?

- What is the key relationship in this situation?

- Why is this equality justified?
- How can this equality be stated mathematically in words? In symbols?
- What is the equation (in symbols) for the unknown?

Δt =

- What numerical values do we know or are told?

Round numerical values to ease calculation when making an estimate:
Δx = average distance between Earth and Moon = 238,000 miles = about 250,000 miles
ΔT = duration of one trip of Earth around Sun = one year = 365.25 days = about 400 days
R = distance from Earth to Sun = 93,000,000 miles = about 100,000,000 miles

Circumference of orbit = 2πR = distance Earth would travel in a circular orbit around the Sun

- How much time (Δt) would it take for the Earth to move in a circular orbit around the Sun from where the Earth is "now" to where the third quarter moon is "now"?

Δt =

- Is this a reasonable answer? Explain why.

2. Example of student work about the simultaneous motions of the Earth and Moon

As shown in FIG. 5.85, a student drew a sketch from the perspective of someone in the northern hemisphere who is looking south to see the Moon, with east on the left and west on the right. A third quarter moon is shown high in the sky with the Sun rising in the east at about 6 am. Two arrows represent the person forming a right angle by pointing one arm at the Sun and the other arm at the Moon, which is approximately half lit on the left.

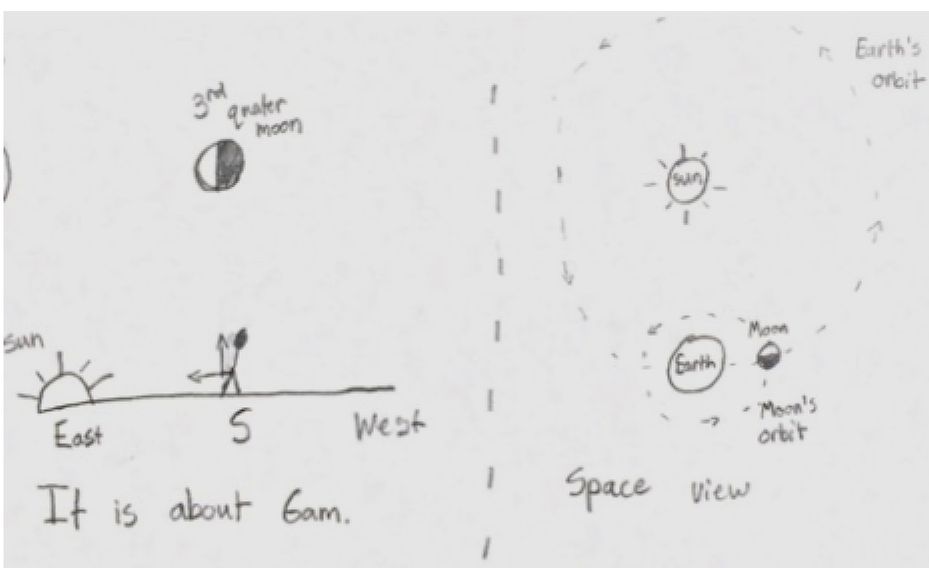


FIG. 5.85 Student sketches of view of 3rd quarter Moon from Earth and from space.

As shown on the right of Fig. 5.85, this student also drew a sketch of an inferred view from space from the perspective of looking down on the solar system from above. Dashes and arrows indicate the Earth revolving counterclockwise in its orbit around the Sun and the Moon revolving counterclockwise in its orbit around the Earth. The Moon, approximately half lit on the side facing the Sun, is shown in the 3rd quarter position, to the right of the Earth and located directly in the Earth's orbit. If the Earth continues revolving counterclockwise around the Sun as shown, how soon will the Earth "be" in the "place in space" where the Moon "is" now? The student wrote:

> *The Earth will be headed to the point where the 3rd quarter moon is currently in…space. The Earth has a counterclockwise rotation* (although true, the appropriate word should be "revolution" here) *meaning it is moving right. To achieve the appearance of the third quarter moon, the moon has to be forming a 90-degree angle with Earth in respect to the sun. The moon must also be on the right side of the Earth as the left side of the moon appears lit by light from the sun.*
>
> *A key concept needed to figure out how soon we will get there is the relationship between position, motion, and speed. If one knows their position, then they know the distance traveled and the amount of time it took to travel that distance. Knowing this it is possible to figure out how fast one got to that position or the speed they traveled…*
>
> *The key relationship is the assumption that the speed of the time it takes to make one full orbit around the sun is the same speed it takes to travel from the earth's current position to the position of the 3rd quarter moon.*
>
> *The speeds can be set equal because* (of the assumption that) *the earth travels a constant speed when traveling its* (assumed circular) *orbit around the sun. The smaller journey is merely a section of that larger journey, but maintains that constant speed.*
>
> *This relationship between the speeds leads to the equality that the distance of earth's orbit over the time it takes to complete earth's full orbit is equal to the distance to the 3rd quarter moon over the time it takes to reach the position of the 3rd quarter moon.*
>
> (Edits added in parentheses)

As shown in FIG. 5.86, this student wrote, in both words and symbols, the mathematics described above based on the assumption that the Earth is moving with constant speed in a circular orbit so that the speed for the total trip around the Sun is equal to the speed of the small trip from where the Earth "is" to where the third quarter Moon "is" now:

$$\text{Total Trip Speed} = \text{Speed of Small Trip}$$

The student stated this key relationship both in words and symbols:

\begin{split}{\text{In words:}}\\\\\frac{\text{Distance of Earth's orbit}}{\text{Time of Earth's orbit}} & = \frac{\text{Distance to the 3rd quarter moon}}{\text{Time to the 3rd quarter moon}} \\\\{\text{In symbols:}}\\\\ \frac{2 \pi R}{\Delta T} & = \frac{\Delta x}{Δt}\end{split}

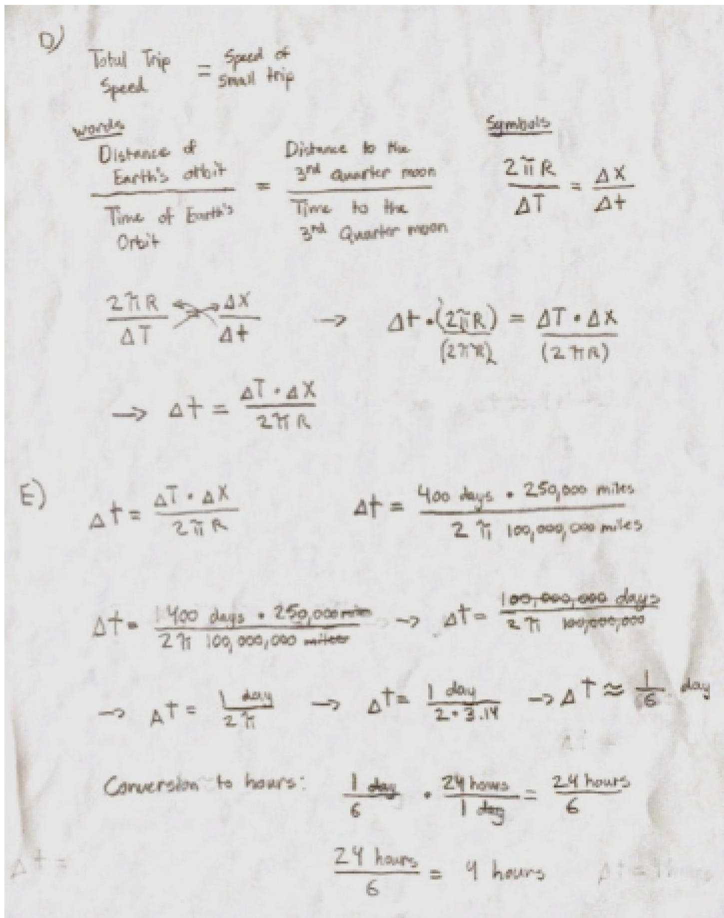


FIG. 5.86 Student's estimate of time needed for the Earth to move to the "place in space" where a third quarter Moon "is" now.

The total distance traveled around the Earth's assumed-to-be circular orbit would be its circumference, 2πR; Δx represents the small distance traveled, the distance from where the Earth is and the "place in space" where the Moon is "now."

The student used "Time of Earth's orbit" to refer to the duration of the whole trip around the Sun and "Time to the 3rd Quarter moon" to refer to the duration of the short trip. This general language use of the word "time" can be separated into two distinct ideas: "duration" to refer to how long a trip lasts and "clock-reading" to refer to a particular instant, such as when a trip started or ended. In this case, "duration" is the meaning intended. The student used a capital T, ΔT, to refer to the duration of the entire trip around the Sun and a lower case t, Δt, to refer to the duration of the short trip from where the Earth "is" to where the Moon "is" now.

Next the student solved this equation for the duration (Δt) for the small trip and substituted the estimated values provided. These had been rounded to make the calculation easy without needing a calculator:

$$\Delta t = \frac{\Delta T \bullet \Delta x}{2\pi R}$$

$$\Delta t = \frac{400 days \bullet 250,00 \text{ miles}}{2\,\pi 100,000,000 \text{ miles}}$$

Then the student reduced this equation to: Δt = \frac{1 day}{2\pi} = \frac{1 day}{2*3} = \frac{1 day}{6}

and converted this to hours: $\Delta t = \frac{24 \text{ hours}}{6} = 4 \text{ hours}$

to obtain an estimate of about 4 hours for the time for the Earth to move from where the Earth "is" to the "place in space" where the third quarter Moon "is" now.

Finally, as shown in Fig. 5.87, the student reflected upon the reasonableness of this answer:

> *I believe this answer is reasonable because when creating another equality which puts parts over wholes, it is equal. The equality is the distance to the 3rd quarter moon over the distance of earth's rotation* (should be *revolution) equal to amount of time it takes to reach the 3rd quarter moon over the amount of time it takes to complete the earth's orbit around the sun. When all the values are substituted in as they were for the original problem the values are equal to each other as shown below.*

(Edit added in parentheses)

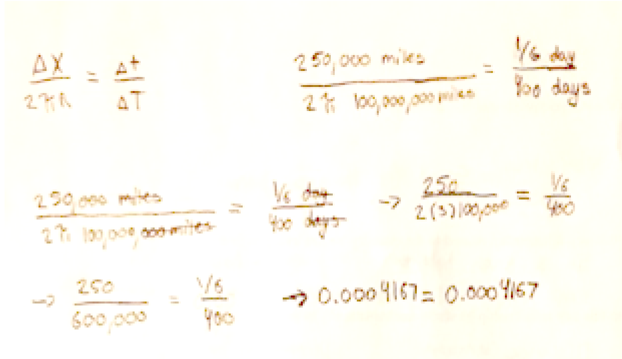


FIG. 5.87 Student's check on the reasonableness of the calculated answer.

Physics Student, Winter 2018

Another student made sense of this answer in another way conceptually, by figuring out how far the Earth travels around the Sun in an hour and dividing that into the distance between the Earth and the Moon. This is similar to finding out how much time a 300 mile trip will take if one is traveling on a freeway at 60 miles/hour: (300 miles)/(60 mile/hour) = 5 hours.

> *I also did this problem using the distance the earth travels in a year, which is 584 million miles, and divided by 365 days to find out how far the earth travels in a day, I then divided this number by 24 to find out how far it travels in a hour. With this number I divided 238,900 miles, which is the distance to the moon, by the distance the earth travels in an hour to determine how many hours it takes the earth to move into the position of the moon. It was found that the earth takes about 4 hours to travel the distance to the moon.*

This student apparently used some of the provided information, that the Earth is 93,000,000 miles from the Sun, as well as the assumption of a circular orbit, to estimate the total distance traveled around the Sun, 2πR, as 584,000,000 miles in one year of 365 days. The student next divided these numbers to find the distance traveled in one day, 584,000,000 miles/365 days = 1,600,109 miles/day (wow!) and divided by 24 hours to find the Earth's orbital speed as 66,671 miles/hour. Then the student divided this number into the distance traveled from the Earth to the Moon: 238,900 miles/(66,671 miles/hour) = 3.58 hours. So about 4 hours is a reasonable answer, given the rounded numbers used.

Another way is to look up useful information on the Internet, such as the speed of the Earth in its orbit (https://astrosociety.org/edu/publications/tnl/71/howfast.html says

66,000 miles/hour), calculate how far the Earth would go at this speed in four hours, and compare that to the given average distance from the Earth to the Moon (238,000 miles).

(66,000 miles/hour)(4 hours) = 265,000 miles. This is high compared to the given average distance from the Earth to the Moon but close, given the rounded numbers provided.

An additional way would be to figure out how many of the short distances (from Earth to Moon) fit into the total distance around the Sun:

$$\frac{\text{Total distance around the Sun}}{\text{Distance from Earth to Moon}} = \frac{2\pi R}{\Delta x}$$

Multiply this by the time obtained (Δt) and see if one gets a "year"

$$\frac{(2\pi R)(\Delta t)}{\Delta x} = \Delta T \, \text{(works symbolically if)} \frac{2\pi R}{\Delta T} = \frac{\Delta x}{\Delta t} \text{is solved for} \ \Delta T$$

Using the rounded values provided:

$$\frac{2\pi(100,000,000\,\text{miles})}{250,000\,\text{miles}} \text{(about 4 hours)} = (2\pi\ 400)(4\ \text{hours}) = 9600\ \text{hours}$$

1 year = (about 400 days) (24 hours/day) = 9600 hours

3. Nuances about working on this question

Another student drew the following sketches on the handout as shown in Fig. 5.88:

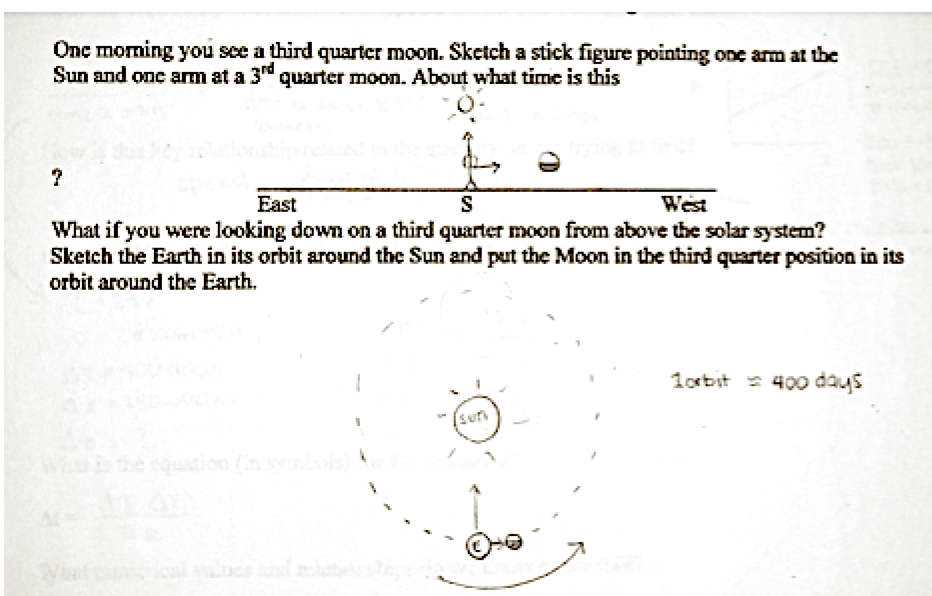


FIG. 5.88 *Another student's sketches for a third quarter moon as seen from Earth and space.*

Although the problem statement included the phrase "one morning," this student drew the Sun in the "noon" position with a setting third quarter Moon. "Noon" was the position suggested earlier for the Sun in the tables shown in Fig. 5.42 and 5.43 that present views of the phases of the moon as seen from Earth and from Space. The student also drew the view from space in the same way as shown in that table. The two views presented together here in Fig. 5.88 nicely review the connection that the angle formed by pointing one's arms at the Sun and Moon on Earth is the same as the angle formed by the arrangement of the Sun, Earth, and Moon in space.

The reason that this activity suggests sketching the view from Earth in the morning rather than at noon is that this choice emphasizes that a third quarter Moon is readily visible high in the sky at about 6 am, and will continue to be visible throughout the morning if the sky is clear. If one wants to see such a moon, morning is a good time to look! Also our course meets during the morning, so if the sky is clear, the students can go outside and see a third quarter Moon in the "place in space" where they and everyone else on Earth soon will "be."

This activity also reviews the details expected in sketching such diagrams. This student correctly drew the Sun and the Moon about the same size as seen from Earth but with a large Sun, small Earth, and smaller Moon as seen from space. In both diagrams the moon is shown half lit, with the lit portion facing the Sun. The view from space shows an assumed circular orbit, with a large arrow indicating the counterclockwise direction of the Earth's revolution around the Sun and a small arrow indicating the Earth's movement toward the third quarter Moon along this orbital path as seen from the northern hemisphere. The arrow pointing from the Earth toward the Sun might be confusing, however, if a viewer interpreted it as indicating a motion by the Earth directly toward the Sun.

The format of the handout mirrors the problem-solving processes advocated earlier in weeks 2 and 4 for pinhole math and thermal math problems:

Describe a scenario in words
Make a sketch of the situation
Review any relevant central ideas that you know
Draw a careful diagram if needed
Represent the scenario mathematically
State and justify an equation in words
Define symbols and state the equation in symbols
Solve for the unknown in symbols
Record given values and estimate any needed

Substitute values and calculate answer

Check and reflect on answer

Checking an answer can take many forms; particularly encouraged is seeking a conceptually different approach from that used for the calculation. Such sense-making is more likely to suggest an alternative approach if further thinking is needed.

XI. Pondering Additional Issues

This section explores several additional issues: how things move and interact, what keeps the Moon and the Earth in their orbits, why the oceans have tides, and what happens when objects fall here on Earth and on the Moon?

A. Reviewing understandings about the Sun, Earth, Moon, and Stars

It may be helpful to step back and review before heading into new territory. So far this course has developed the following understandings about light and shadows as well as about the Sun, Earth, Moon, and stars:

What causes shadows? Some shadows occur when an object blocks light and casts a shadow behind it on something else. Other shadows occur when an object blocks light from shining on its own back-side. If you stand facing the Sun on a sunny day, for example, your shadow forms on the ground or a wall behind you; a shadow also forms on your back because your body blocks sunlight from shining there.

Why does it get dark at night? The Sun seems to rise in the morning, move high across the sky during the day, and set in the evening. It gets dark when the Sun appears to sink below the horizon in the western sky and stays dark until the Sun appears to rise above the horizon again in the eastern sky. According to this conceptual model, it gets dark at night because the source of light, the Sun, has moved below the horizon during its apparent daily journey revolving around the fixed Earth. This Fixed Earth, Revolving Sun model is easy to envision and believe because that is what one sees: the Sun, as well as the Moon and many stars, seeming to move daily around a flat motionless Earth.

An alternative conceptual model, however, is that the Sun, Moon, and stars only appear to be moving daily around the Earth; instead it is the Earth that actually is moving, a spherical Earth rotating daily on its axis. According to this conceptual model, it is day on the front side of the spinning Earth, the side that is facing toward a fixed Sun; it is night on the back side of the spinning Earth, the side that is facing away from a fixed Sun. It gets dark at night because the back side of the rotating Earth is in the Earth's own shadow.

According to this Rotating Earth, Fixed Sun model, the body of the Earth itself is blocking the Sun's light from shining on the side of the Earth that is facing away from the Sun.

The Rotating Earth, Fixed Sun model is not as easy to envision as the Fixed Earth, Revolving Sun model. Acting out these two conceptual models for explaining day and night, however, can clarify how these models are alike and different. Also seeing a physical model can help, such as a spinning globe near a lamp in a dark room, particularly if a tiny flag or stick figure stuck to the globe represents a familiar location on the rotating Earth. Understanding and accepting the Rotating Earth, Fixed Sun model requires, however, more detailed observations and intricate reasoning than simply seeing the Sun, Moon, and stars seem to move across the sky on daily journeys revolving around the Earth.

Why does the Moon seem to have different shapes at different times? During about a month, the Moon's shape seems to keep changing, with the lit portion seeming to grow more and more lit until full and then shrinking back to not being visible at all (see Fig. 5.22). Many people believe that these changing phases of the Moon are caused by the shadow of the Earth falling on the Moon. Such a conceptual model matches experiences in which one often sees an object casting a shadow behind it onto something else.

An alternative conceptual model is that the lit shape of the Moon appears to change during about a month, as seen from Earth, because the Moon is revolving around the Earth. The side of the Moon facing toward the Sun is brightly lit by the Sun; the side of the Moon facing away from the Sun is dark, in the Moon's own shadow. According to this Revolving Moon model, the Moon's changing phases as seen from Earth occur because different portions of the lit side are visible from Earth as the Moon revolves around the Earth about once a month (See Figs. 5.42 and 5.43).

Envisioning the Revolving Moon model is easier if one plays with a ball on a sunny day or in a dark room lit by a single lamp. The ball represents the Moon, the Sun or lamp represents the Sun, and one's eyes in one's head represent one's eyes here on the Earth. By holding up the ball and moving it around one's head, one can replicate on the ball the same pattern of changing phases one can see in the sky on the Moon: "new ball" "waxing crescent ball" "first quarter ball" "waxing gibbous ball" "full ball" "waning gibbous ball" "third quarter ball" and "waning crescent ball" positions back to "new ball." Replicating with a ball here on Earth the same sequence of phases of the Moon that one can see in the sky suggests that these have the same cause: the Moon is revolving around the Earth just as the ball is revolving around one's head.

On-going observations of the Moon can reveal a paradox: Why does the Moon seem to move east to west over several hours but west to east over several days? (See Figs. 5.31 and 5.32.) One can infer that the Moon appears to move from west to east over several days because the Moon actually is moving that way while revolving around the Earth about once a month. One also can infer that the Moon only appears to move daily across the sky from east to west because it is the Earth that actually is moving, spinning by the Moon while rotating daily on its axis. Thus the resolution of this paradox uses and confirms one of the two models developed earlier for explaining day and night, the Rotating Earth, Fixed Sun model.

Why are some constellations of stars only visible during certain seasons? Both ancient and current conceptual models assume that the daytime sky is too bright for stars located in the same direction as the Sun to be visible. According to the conceptual model used by many ancient astronomers (Fixed Earth, Revolving Sun), stars revolve around the Earth daily on a large crystalline sphere; the Sun revolves around the Earth daily on a smaller sphere and also moves yearly along a path with respect to the background sphere of the stars. The Sun's position on this path, called the zodiac (See Fig. 5.67), determines which stars would be visible, those not in the same direction as the Sun.

An alternative conceptual model is that some stars are only visible during certain seasons because a rotating Earth revolves around the Sun. The direction on Earth of facing away from the Sun determines which stars one sees at night. These change as the Earth travels in its orbit so that different constellations of stars are visible at different times. This is based upon the currently accepted conceptual model of a spherical Earth that rotates daily on its axis while revolving yearly around the Sun.

B. Understanding motion

Scientific progress occurs through the processes just described of making observations, developing possible explanatory models, and thinking about which models together make the most sense. Typically new questions emerge. If the Moon and the Earth are both moving, for example, how does that happen?

Question 5.47 How are the Moon and the Earth moving?

To explore motion: each group uses a ball.

- Place the ball on the floor so that the ball is not moving.
- Give the ball a push. How does the ball roll along the floor?
- How can you change the ball's direction of motion while it is moving?
- How can you make the ball move in a circle?

An English scientist, Sir Isaac Newton, studied motion in the late 1600's and early 1700's. He summarized his findings in a major work, *Philosophiae Naturalis Principia Mathematica* published in Latin in 1687 and in English, translated by Andrew Motte, as *Mathematical Principles of Natural Philosophy* in 1729.

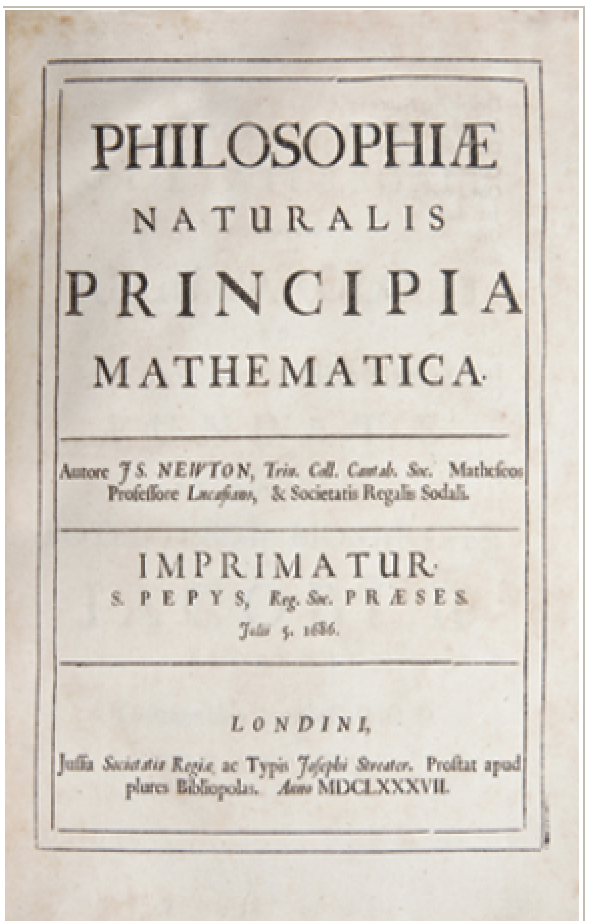


FIG. 5.89 *Front piece of Newton's Principia.* [*https://library.si.edu/digital-library/book/philosophiaenat00newt*](https://library.si.edu/digital-library/book/philosophiaenat00newt) *Dibner Library of the History of Science and Technology, Smithsonian Libraries.*

The *Principia* included three books. Book 1 focused upon the motion of bodies, Book 2 upon the motion of bodies in resisting mediums, and Book 3 on the system of the world. The contents of these volumes have deeply influenced the development of science and society for more than three centuries.

Near the beginning of Book 1, Newton stated *Axioms or Laws of Motion*, including Law I:

Law I

> *Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon.*

(Newton, trans. by Motte, 1729, Book I, *Axioms or Laws of Motion*)

https://archive.org/details/100878576/page/82

According to Newton's First Law of Motion, an object at rest stays at rest or if already in motion, keeps moving at the same speed in a straight line, unless acted on by a force.

Newton's Second Law of Motion addressed what happens if a force acts on a moving object: the object changes its speed and/or direction of motion. If the Moon and the Earth are moving but not in straight lines, what forces might be acting on them to cause their paths to curve?

C. Exploring forces

If one object affects another object in some way, there must be some kind of an interaction happening between them. In physics, the word *force* refers to an interaction between objects, such as pushing or pulling on one another.

Exploring how things push or pull on one another here on Earth can provide some experiences on which to base thinking about forces that might be causing the Moon to revolve around the Earth and the Earth to revolve around the Sun.

Question 5.48 What keeps the Moon and the Earth revolving in their orbits?

> To begin exploring force and motion, each group uses two magnets and a small ball on a string.

- Discuss with your group members some experiences that you have had with things that are pushing or pulling on one another while:

    - touching
    - not touching
    - moving
    - not moving
- Play with the two magnets. How do they interact?
- Play with the ball on a string. How do the ball and the string interact if you swing the ball on the string around your head?

  > (Careful! Be sure you have enough space around you to swing the ball without hitting anyone; also take care to swing without hitting yourself.)

- How would you describe the interaction between the Moon and the Earth as similar and/or different from the interactions:
    - between the two magnets?
    - between the ball and string when you are swinging the ball around your head?

If touching, two magnets may stick together and be hard to pull apart. If brought near but not touching and then released, two magnets may attract one another and move closer together. Or they may repel one another and move farther apart. Such observations indicate that two magnets can interact with one another even though they are not touching.

The interactions between the Moon and the Earth as well as between the Earth and the Sun are similar to the interaction between the magnets in that these bodies also are not touching. These are examples of forces that *act at a distance* because the interactions occur without the objects being close enough to touch one another.

The forces that two magnets exert on one another can be attractive or repulsive in effect.

The interactions between the Moon and the Earth as well as between the Earth and the Sun are different, however, in that these appear to be only attractive effects; these bodies do not appear to be pushing one another apart.

A ball being swung around one's head is pulled inward by the string, which keeps the ball moving in the curved path of its orbit. The orbital motion of the ball seems to be similar to the orbital motion of the Moon. This suggests that there is a similar inward pull on the Moon by the Earth that keeps the Moon moving in the curved path of its orbit.

This is called the *gravitational force* ***by*** *the Earth* ***on*** *the Moon*. In the *Principia*, Newton expressed this as a Proposition and Theorem:

PROPOSITION IV. THEOREM IV.

That the moon gravitates towards the earth, and by the force of gravity is continually drawn off from a rectilinear motion, and retained in its orbit.

(Newton, trans. by Motte, 1729, Book III, Propositions)

https://archive.org/details/100878576/page/390

Similarly there is an inward pull **by** the Sun **on** the Earth that is keeping the Earth in its orbit. This is called the *gravitational force* ***by** the Sun **on** the Earth*. When one object is revolving around another, the gravitational force **by** the larger object **on** the smaller object keeps the smaller object in its orbit.

These gravitational forces are similar to the string pulling inward on the swinging ball. They differ from the force by the string on the ball, however, in that these bodies are not touching one another; the gravitational forces are acting at a distance without touching.

This conceptual model of a gravitational force pulling the Moon inward toward the Earth as the Moon revolves around the Earth raises a new issue: is this interaction between the Moon and the Earth mutual?

Question 5.49 If the Earth pulls on the Moon, does the Moon pull on the Earth?

- Explore what happens here on Earth when two spring scales are pulled apart.

> To explore interacting forces, each group uses two spring scales. 10 Newton or 20 Newton scales are best.

If you pull on a spring scale, it will measure the force with which you are pulling, usually either in pounds or in Newtons. A Newton is a unit of force in the metric system, named after Sir Isaac Newton. The front of the device hides the spring. Spring scales work by stretching a spring uniformly when the scale is pulled so that the indicator moves a distance proportional to the force applied. As shown in Fig. 5.90 spring scales may be circular or rectangular in shape.

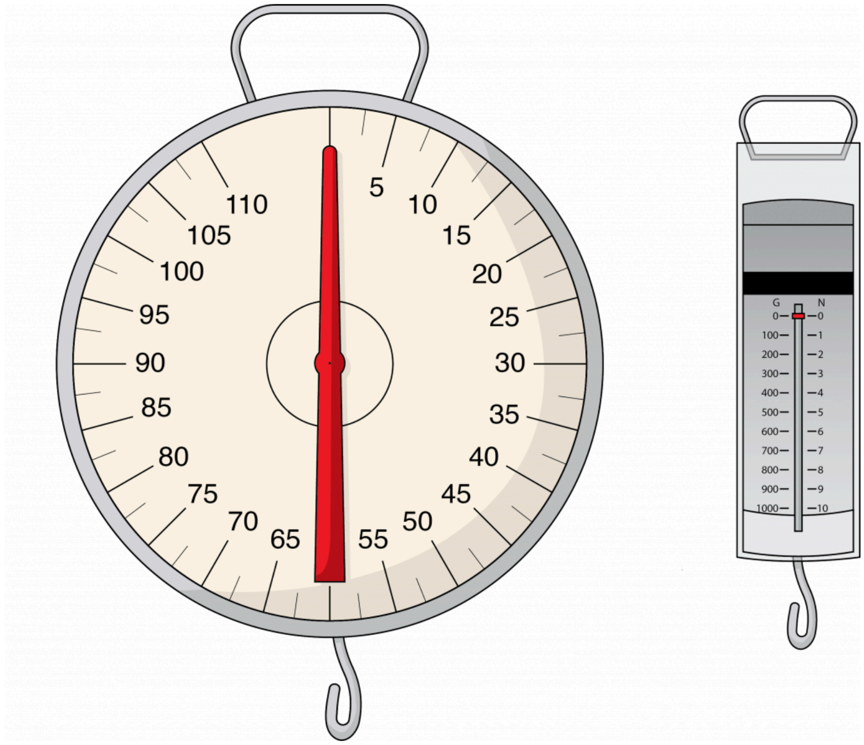


FIG. 5.90 *Two types of spring scales.*

- Play with the spring scales until you understand how they work.
- Have two members of the group hook the two spring scales together and then pull the spring scales apart horizontally. What do you notice?
- Have every member of the group try this. Are your findings consistent?
- What happens when the two people both pull on the spring scales?
- What happens when one person just holds the spring scale that is hooked on to the other person's spring scale while the other person pulls?
- Sketch a picture of what is happening when two people both pull horizontally on spring scales that are hooked together.
- Also sketch what happens when only one person pulls a scale and the other person just holds on to the other scale.
- What do you think would happen if instead of a person just holding on to a scale, the scale is hooked to a wall while the other person pulls on the other scale?
- Can an inanimate object like a wall exert a force?
- Summarize your findings.

Among the laws of motion that Newton stated was Law III:

Law III

To every Action there is always opposed an equal Reaction: or the mutual actions of two bodies upon each other are always equal and directed to contrary parts.

He provided an example:

Whatever draws or presses another is as much drawn or pressed by that other. If you press a stone with your finger, the finger is also pressed by the stone…

(Newton, trans. by Motte, 1729, Book I, *Axioms or Laws of Motion*, p. 83)

https://archive.org/details/100878576/page/82

Newton realized that forces come in pairs; if you press on a stone, the stone presses back with an equal force in the opposite direction. See (http://hyperphysics.phy-astr.gsu.edu/hbase/Newt.html#ntcon) for additional discussion of Newton's three laws of motion.

As shown in Fig. 5.91, two spring scales pulled apart indicate that the force **by** the left scale **on** the right scale is equal to the force **by** the right scale on the left scale but in the opposite direction.

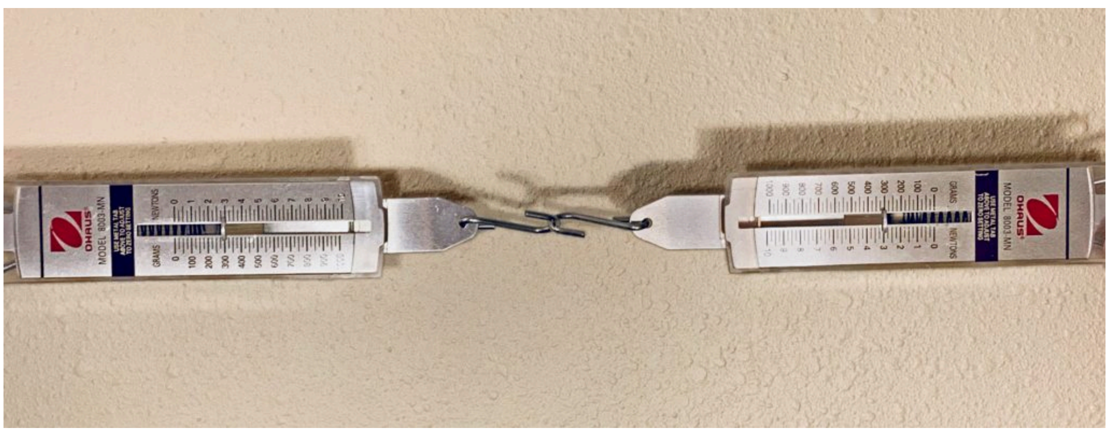


FIG. 5.91 *Two spring scales are hooked together and pulled apart horizontally.*

This has some surprising consequences.

- Push straight down on a table. With what force is the table pushing back up at you?
- How can you justify your response?

D. Developing and using mathematical representations of

gravitational forces

In addition to formulating and articulating ways to use the three laws of motion, Sir Isaac Newton also presented a detailed account of interactions between bodies due to gravitational forces.

Question 5.50 What quantities determine the magnitude of gravitational forces?

In Book III of the *Principia*, Newton proposed that the Sun's gravitational effect on keeping the Earth and other planets in their orbits depends upon how far away they are:

PROPOSITION II. THEOREM II.

> *That the forces by which the primary planets are continually drawn off from rectilinear motions, and retained in their proper orbits, tend to the sun; and are reciprocally as the squares of the distance of the places of those planets from the sun's center.*

(Newton, trans. by Motte, 1729, Book III, Propositions, p. 390)

https://archive.org/details/100878576/page/390

Newton specified that this was a reciprocal relationship; the closer a planet to the Sun, the bigger the gravitational force **by** the Sun **on** the planet, keeping that planet in its orbit, and that mathematically this was a function of the reciprocal of the distance multiplied by itself (the distance squared).

In addition Newton proposed that a gravitational effect occurred with all bodies in the universe and depended upon their masses:

PROPOSITION VII. THEOREM VII.

> *That there is a power of gravity tending to all bodies, proportional to the several quantities of matter which they contain.*

(Newton, trans. by Motte, 1729, Book III, Propositions, p. 397)

https://archive.org/details/100878576/page/396

Stated algebraically, this is known as Newton's Law of Universal Gravitation, where the gravitational force (F) exerted **by** one mass (M) **on** another mass (m) depends upon the size of the masses (M, m) and the inverse square of the distance (r) between them:

$$F = \frac{GMm}{r^2}$$

where G is the Gravitational Constant, $G = 6.67430 \times 10^{-11} \frac{Newton- \, meters^2}{kilograms^2}$

This means that the gravitational force **by** Body A **on** Body B is equal in magnitude and opposite in direction to the gravitational force **by** Body B **on** Body A.

This proposition has some startling implications. Not only does the gravitational force by the mass of the Earth pull on the Moon, it pulls on you as well! The gravitational force **by** the Earth **on** you is what is holding you on the ground rather than floating in space. You are pushing back **on** the Earth (the ground) with an equal and opposite force! Not only that, but as you work together in class, you and your group members also are pulling on each other with equal and opposite gravitational forces (but not noticeably).

E. Explaining the ocean's tides

Newton's Law of Universal Gravitation suggests that the Moon is pulling on the Earth with a force of the same magnitude as the Earth is pulling on the Moon, although in the opposite direction. What evidence is there that this is the case?

Question 5.50 What effect does the gravitational force by the Moon have on the Earth?

People who walk on ocean beaches often notice how far waves are flowing onto shore. People who work on boats tied up to docks often notice how high the boats are floating compared to the height of the dock. This sometimes varies by as much as 45 feet. (See: https://tidesandcurrents.noaa.gov/education.html) Many variables affect tides such as a location's latitude, the shape of its shoreline, shape of a bay and/or estuaries, nearby ocean currents, local winds and weather.

By observing and recording daily tide levels, however, one can identify patterns and make predictions for future dates. Detailed predictions depend upon repeated measurements at a tide-monitoring station and upon complex computer modeling of such data (http://oceanmotion.org/html/background/tides-observing.htm)

As shown in Fig. 5.92, for example, the National Oceanic and Atmospheric Administration (NOAA) provides monthly predictions of the variation in water level at the Yaquina Bay United States Coast Guard station in Newport, Oregon.

- Discuss with your group members how high and low tides are predicted to vary over this month at this tidal monitoring station:
- When are high tides higher than usual and low tides lower than usual so that there is a big difference between high and low tides at this location?
- When are the high tides not so high and the low tides not so low so that there is a smaller difference between high and low tides at this location?

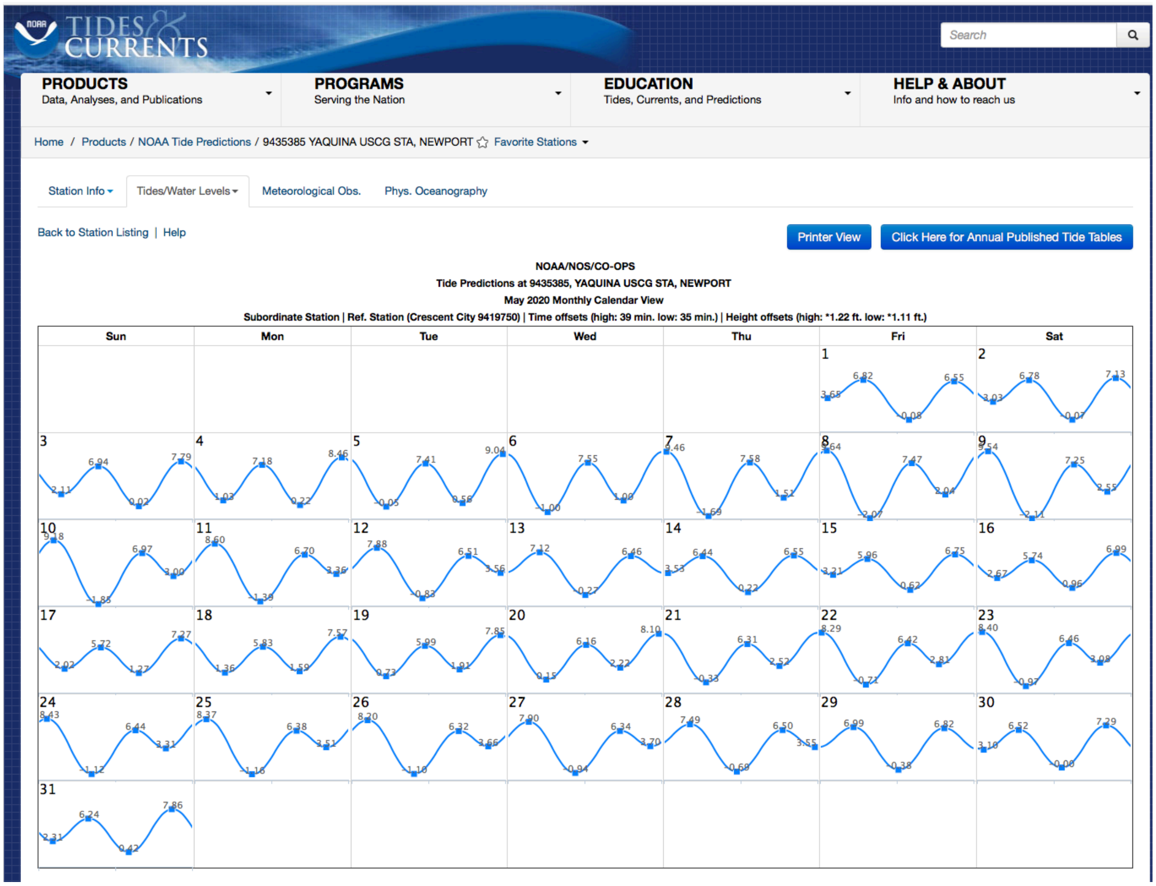


FIG. 5.92 *Predictions for tides at Yaquina Coast Guard Station in Newport for May 2020.* *https://tidesandcurrents.noaa.gov/noaatidepredictions.html?id=9435385&units=standard&bdate=20200501&edate=20200531&timezone=LST/LDT&clock=12hour&datum=MLLW&interval=hilo&action=monthlychart*

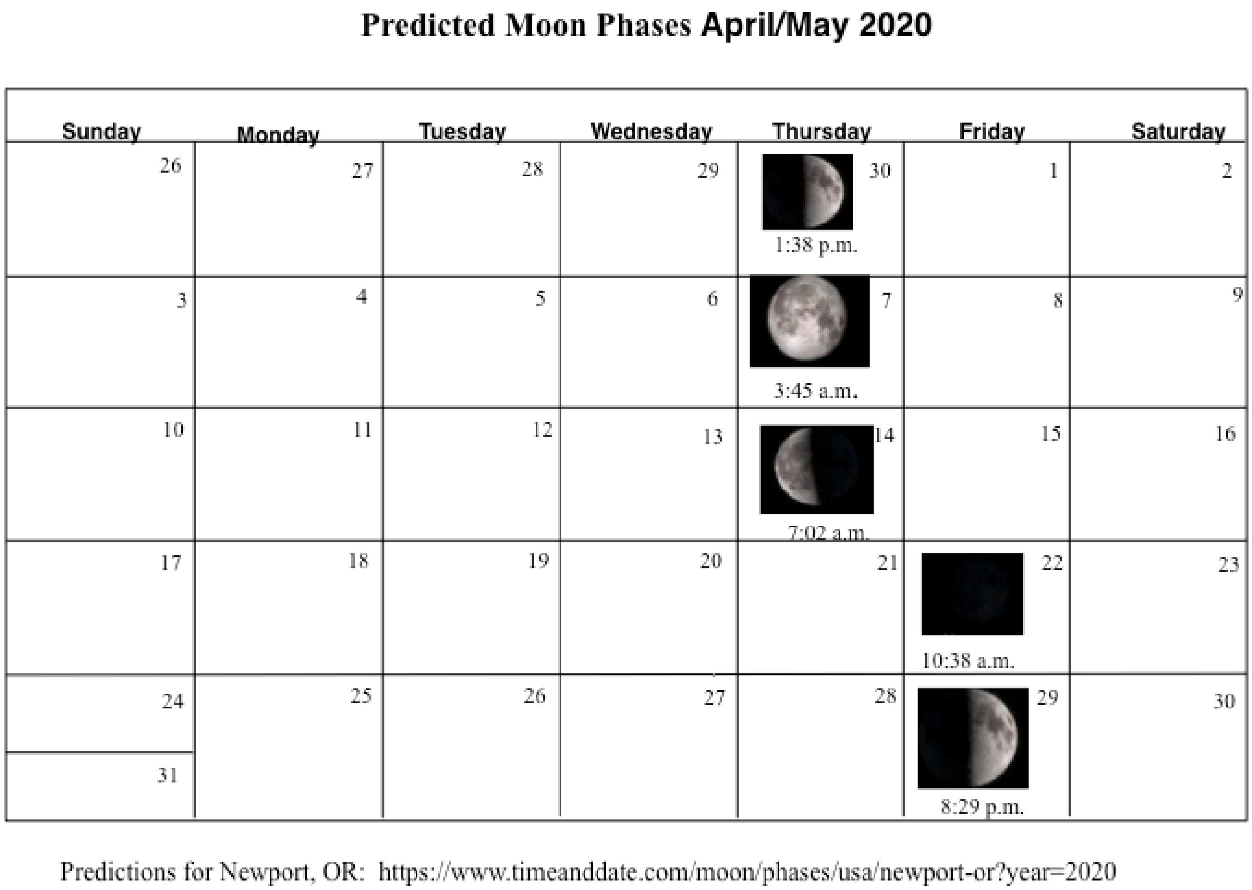
People who live near the ocean may notice a pattern between tidal phenomena and the phases of the Moon.

- Of what connections are you already aware between tidal and Moon phenomena?

- How might you explore this relationship using additional Internet resources?
- Do an Internet search, for example, for "moon phases calendar." Websites such as https://www.almanac.com/astronomy/moon/calendar or https://www.calendar-365.com/moon/moon-calendar.html can provide a monthly calendar of the changing phases of the Moon.
- Enter May 2020 to see the changing phases of the Moon during the same month and year of the tide chart shown in Fig. 5.92. Enter the location of Newport, Oregon, if the moon calendar website includes an option for entering a location.
- Discuss with your group members any patterns you see in the tides predicted in Fig. 5.92 and the predicted phases of the Moon for this time period shown in the moon calendar you are viewing online.
- How are these phases of the Moon related to times of predicted highest high tides and lowest low tides evident in Fig. 5.92?
- How are the phases of the Moon related to times of predicted somewhat high and low tides?
- With your group members, develop a central idea about the relation between the phases of the Moon and tides on the Earth, based upon the predictions of the tidal patterns shown in Fig. 5.92 and of the phases of the Moon shown in the moon calendar you are viewing on the website.

Viewing the entire month of predicted high and low tides, as well as the entire month of predicted phases of the Moon may seem overwhelming. A way to simplify the task would be to look at what is happening during only the primary phases of the Moon (first quarter, full, third quarter, and new).

- Fig. 5.93 shows predictions for the primary phases of the Moon at, Newport, Oregon for the month of May, 2020.



Predicted Moon Phases April/May 2020

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
26	27	28	29	30 1:38 p.m.	1	2
3	4	5	6	7 3:45 a.m.	8	9
10	11	12	13	14 7:02 a.m.	15	16
17	18	19	20	21	22 10:38 a.m.	23
24 / 31	25	26	27	28	29 8:29 p.m.	30

Predictions for Newport, OR: https://www.timeanddate.com/moon/phases/usa/newport-or?year=2020

Fig.5.93 Phases of the Moon predicted for May 2020 in Oregon in the northern hemisphere. https://www.timeanddate.com/moon/phases/usa/newport-or?year=2020

(If you want to compare tide predictions with moon phases for a different place or month, be sure to obtain the dates for phases of the moon for that location. The Sun, Earth, and Moon are lined up at the moment of full moon but the name of this moment depends upon a location's longitude. The predicted time of full moon, for example, in May 2020 is at 3:45 a.m. on May 7 in Newport, Oregon, but at 11:45 a.m., on May 7 universal time in Greenwich, England, and at 8:45 p.m. on May 7 in Melbourne, Australia. For dates and times of phases of the Moon at different locations see https://www.timeanddate.com/moon/phases/ . Enter your location and current date, record the predicted date for the closest major phase of the moon (new, 1st quarter, full, third quarter). For tidal predictions elsewhere, see https://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels.)

Interpreted visually, the calendar for May 2020 at the Yaquina US Coast Guard Station in Newport, Oregon, predicts the highest and lowest tides near the middle to the end of the week of May 3, and somewhat varying high and low tides near the middle to the end of the week of May 10. A less visually salient pattern is evident during the weeks of May 17 and May 24. Near the middle to the end of the week of May 17, the regular pattern of very high and very low tides seems similar to near the middle to the end of the week of May 7 although less extreme. Near the middle to the end of the week of May 24, somewhat varying high and low tides seem similar to near the middle to the end of the week of May 10.

First quarter, full, third quarter, new, and first quarter phases of the Moon are predicted to occur during Thursdays or Fridays during late April and May 2020 (see, for example, https://www.timeanddate.com/moon/phases/usa/newport-or?year=2020. Using the information provided in the tide calendar in Fig. 5.92, the predicted high and low tides can be compared numerically during these phases as shown in Tables V.14 and V.15.

Table V.14 Predicted high and low tides during the predicted dates of full, 3rd quarter, new, and 1st quarter phases of the Moon during May 2020 at the Yaquina Coast Guard Station, in Newport, Oregon

Table V.14 Predicted high and low tides during the predicted dates of full, 3rd quarter, new, and 1st quarter phases of the Moon during May 2020 at the Yaquina Coast Guard Station, in Newport, Oregon				
Phase and Date	1st High tide	1st Low tide	2nd High tide	2nd Low tide
Full Moon on May 7	9.46 ft	-1.69 ft	7.58 ft	1.51 ft
3rd Quarter Moon on May 14	6.44 ft	0.22 ft	6.55 ft	3.21 ft (very early on May 15)
New Moon on May 22	8.29 ft	-0.71 ft	6.42 ft	2.81 ft
1st Quarter Moon on May 29	6.99 ft	-0.38 ft	6.82 ft	3.10 ft (very early on May 30)

A low tide with a negative height, -1.69 feet, is predicted at 6:56 a.m. for May 7. This is a very low tide, lower than the average low tide for a particular tide-monitoring station, which is typically set as the zero point for that station. A minus tide means that tide pools usually under water would be exposed and interesting to explore at low tide early on this date.

To simplify looking for patterns, it sometimes helps to combine data such as calculating average high tides for a given date, average low tides for that date, and then the difference between the average high and low tides as shown in Table V.15.

- What patterns are evident when comparing particular phases of the Moon with:
    - average predicted high tides

- average predicted low tides
- bigger differences between the average predicted high and low tides
- smaller differences between the average predicted high and low tides

at the Yaquina Coast Guard Station at Newport, Oregon, during the full, third quarter, new, and first quarter phases of the Moon during May 2020?

Table V.15 Average predicted high and low tides during the predicted full, 3rd quarter, new, and 1st quarter phases of the Moon during May 2020 at the Yaquina Coast Guard Station, in Newport, Oregon

Table V.15 Average predicted high and low tides during the predicted full, 3rd quarter, new, and 1st quarter phases of the Moon during May 2020 at the Yaquina Coast Guard Station, in Newport, Oregon			
Moon Phase and Date	Average predicted high tide in feet	Average predicted low tide in feet	Difference between average predicted high and low tides
Full Moon on May 7	8.52	-0.09	8.61
3rd Quarter Moon on May 14	6.50	1.71	4.70
New Moon on May 22	7.36	1.05	6.31
1st Quarter Moon on May 29	6.91	1.36	5.55

The average highest high tides and lowest low tides are predicted to occur during the full and new moon phases during May 2020 in Newport. The biggest differences between the average high and low tides are predicted to occur during these full and new moon phases.

Smaller average high tides and bigger average low tides are predicted to occur during third and first quarter moon phases during May 2020 in Newport. The smallest differences between the average high and low tides are predicted to occur during these third and first quarter phases.

These patterns connecting variations in the ocean's tides with the phases of the Moon support the claim that a gravitational force **by** the Moon **on** the Earth exists. A gravitational force **by** the Sun also acts **on** the Earth's oceans and affects the tides, depending upon how the Sun, Earth, and Moon are arranged in space.

Question 5.51 How do gravitational forces by the Moon and by the Sun on the Earth's oceans affect the tides?

- Draw the view from space, as in Fig. 5.38, for the arrangements of the Sun, Earth, and Moon for new, first quarter, full, and third quarter phases.
- Discuss with your group members which of these arrangements would produce the most effect from gravitational forces **by** the Sun and **by** the Moon **on** the Earth's oceans. Which arrangements would affect the Earth's oceans the least?

As shown in Fig. 5.94, during the new and full moon phases, the Sun, Earth, and Moon are arranged in a straight line, with the moon between the Sun and Earth, or beyond the Earth:

New Moon:	Sun	Moon	Earth	
Full Moon:	Sun		Earth	Moon

Fig. 5.94 Arrangements of Sun, Earth, and Moon associated with maximum high and low tides.

During new and full moon phases, the effects of the gravitational forces **by** both the Sun and the Moon contribute to creating bulges of water along this straight line. The gravitational force **by** the Sun and the gravitational force **by** the Moon **on** the Earth's oceans are directly in line during new and full Moon and therefore cause the highest high tides and lowest low tides as the Earth rotates on its axis. These are called *spring tides*, not because they occur only in the spring but because they can be considered as "springing forth" during new and full moons. (For more information about spring tides see https://oceanservice.noaa.gov/facts/springtide.html)

As shown in Fig. 5.95, during first and third quarter phases, the Sun, Earth, and Moon are arranged at right angles with Earth at the vertex, as would be seen from above the solar system while looking down on the northern hemisphere:

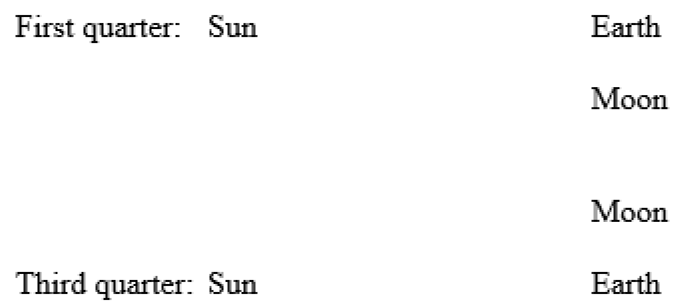


Fig. 5.95 Arrangements of Sun, Earth, and Moon associated with somewhat high and low tides.

During first and third quarter phases, the effect of the gravitational force **by** the Sun **on** the Earth's oceans causes bulges of water in one direction and the effect of the gravitational force **by** the Moon **on** the Earth's oceans causes bulges of water at right angles so these effects together produce smaller net bulges of water as the Earth rotates on its axis. These are called *neap tides*, a term apparently derived from an old English word for *narrow*. (For more information about neap tides see: http://earthsky.org/earth/tides-and-the-pull-of-the-moon-and-sun#neap-tides).

There are bulges of water on both sides of the Earth, which in most places produce two daily high tides as the Earth rotates by a given location. Explanations of the second bulge refer to the difference in gravitational effects on opposite sides of the Earth and on the rigidity of land masses such as continents versus fluidity of water. (see http://earthsky.org/earth/tides-and-the-pull-of-the-moon-and-sun)

Additional variations in high and low tides occur due to variations in the distances between the Earth and the Moon and between the Earth and the Sun because the orbits of the Moon and of the Earth are not perfect circles but ellipses. See http://astunit.com/astunit_tutorial.php?topic=tides and http://oceanservice.noaa.gov/education/kits/tides/tides06_variations.html.

F. Exploring falling objects

One effect of the Earth's gravitational force on objects is that they fall down if dropped.

Question 5.52 What happens when heavy and light objects are dropped from the same height at the same time?

- Respond to the following diagnostic question to document your initial knowledge about falling objects.

1. Documenting initial knowledge about falling objects

Name_______________________ Date___________

Falling Objects Diagnostic Question

Two balls are dropped from the same height at the same instant. The balls have the same diameter but different weights.

Which hits the ground first, the heavy ball or the light ball? Or do they both land at the time? Why?

2. Role playing Galileo's dialogue about falling objects

A Greek philosopher, Aristotle (384–322 BC), stated that heavier objects fall faster than light objects. His ideas were influential for about 2000 years. In 1638, an Italian scientist, Galileo Galilei, wrote a dialogue in which three people discussed this question. In his *Dialogue Concerning Two New Sciences*, Salviati, Sagredo, and Simplicio have a conversation about this topic:

Excerpt from: Galileo Galilei (1638 /1914). *Dialogue concerning two new sciences.* H. Crew & A. de Salvio (trans.), New York: Macmillan.

SALVIATI, SAGREDO AND SIMPLICIO are discussing motion:

> SALV. …***I greatly doubt that Aristotle ever tested by experiment whether it be true that two stones, one weighing ten times as much as the other, if allowed to fall, at the same instant, from a height of, say, 100 cubits, would so differ in speed that when the heavier had reached the ground, the other would not have fallen more than 10 cubits.***
>
> SIMP. His language would seem to indicate that he had tried the experiment,

because he says: *We see the heavier*; now the word *see* shows that he had made the experiment.

SAGR. But I, Simplicio, who have made the test can assure you that a cannon ball weighing one or two hundred pounds, or even more, will not reach the ground by as much as a span ahead of a musket ball weighing only half a pound, provided both are dropped from a height of 200 cubits.

SALV. But, even without further experiment, it is possible to prove clearly, by means of a short and conclusive argument, that a heavier body does not move more rapidly than a lighter one provided both bodies are of the same material and in short such as those mentioned by Aristotle…

SALV**.** If then we take two bodies whose natural speeds are different, it is clear that on uniting the two, the more rapid one will be partly retarded by the slower, and the slower will be somewhat hastened by the swifter. Do you not agree with me in this opinion?

SIMP. You are unquestionably right.

SALV. But if this is true, and if a large stone moves with a speed of, say, eight while a smaller moves with a speed of four, then when they are united, the system will move with a speed less than eight; but the two stones when tied together make a stone larger than that which before moved with a speed of eight. Hence the heavier body moves with less speed than the lighter; an effect which is contrary to your supposition. Thus you see how, from your assumption that the heavier body moves more rapidly than the lighter one, I infer that the heavier body moves more slowly.

SIMP. I am all at sea because it appears to me that the smaller stone when added to the larger increases its weight and by adding weight I do not see how it can fail to increase its speed or, at least, not to diminish it…

SALV. …but we have already concluded that when the small stone moves more slowly it retards to some extent the speed of the larger, so that the combination of the two, which is a heavier body than the larger of the two stones, would move less rapidly, a conclusion which is contrary to your hypothesis. We infer therefore that large and small bodies move with the same speed provided they are of the same specific gravity.

SIMP. Your discussion is really admirable; yet I do not find it easy to believe that a bird-shot falls as swiftly as a cannon ball.

SALV. Why not say a grain of sand as rapidly as a grindstone? But, Simplicio, I trust you will not follow the example of many others who divert the discussion

> from its main intent and fasten upon some statement of mine which lacks a hairsbreadth of the truth and, under this hair, hide the fault of another which is as big as a ship's cable. Aristotle says that "an iron ball of one hundred pounds falling from a height of one hundred cubits reaches the ground before a one-pound ball has fallen a single cubit." I say that they arrive at the same time. You find, on making the experiment, that the larger outstrips the smaller by two finger-breadths, that is, when the larger has reached the ground, the other is short of it by two finger-breadths; now you would not hide behind these two fingers the ninety-nine cubits of Aristotle, nor would you mention my small error and at the same time pass over in silence his very large one.

Galileo's logical argument has three parts:

> Salviati: "If then we take two bodies whose natural speeds are different, it is clear that on uniting the two, the more rapid one will be partly retarded by the slower, and the slower will be somewhat hastened by the swifter."
>
> (If tie two bodies together, they should fall slower because light one drags the heavier back)
>
> Salviati: …the combination of the two, which is a heavier body than the larger of the two stones, would move less rapidly, a conclusion which is contrary to your hypothesis (that heavy bodies fall faster than light bodies)
>
> (If tie two bodies together, they should fall faster because combination is heavier than heavy body)
>
> Salviati: … We infer therefore that large and small bodies move with the same speed.
>
> (The two tied together cannot fall both slower and faster than the heavy body alone)

Galileo apparently wrote about this question in dialogue format because he did not feel free to write directly explaining his views as he was already under house arrest for publishing a dialogue about whether the Earth was the center of the universe or revolved around the Sun.

In 1543, Nicolaus Copernicus (1473-1543) published *De revolutionibus* in which he proposed that the earth revolves around the sun rather than the sun around the earth.

Ninety years later, in 1632, Galileo published *Dialogue on the Two Chief World Systems: Ptolemaic and Copernican*. In 1633 Galileo was tried for heresy by the Holy Office of the Inquisition of the Catholic Church; *Dialogue* was prohibited. Galileo was forced to recant his claim that the Earth was not the center of the universe, which he had claimed based on his observations with a telescope that the moons of the planet Jupiter revolved around Jupiter. He had used these observations to support his claim that the Earth moved around the Sun. He was placed under life-long house arrest. In 1638, his *Dialogue Concerning Two New Sciences* was published in Holland. He died in 1642.

In 1979, Pope John Paul II called for theologians, scholars, historians, to reexamine Galileo's case. In 1992, Pope John Paul II publicly endorsed Galileo's support of the Copernican system, that the Earth revolves around the sun (http://www.nytimes.com/1992/10/31/world/after-350-years-vatican-says-galileo-was-right-it-moves.html) .

For information about Galileo's life see: https://plato.stanford.edu/entries/galileo/

For a fascinating story based on Galileo's daughter's letters to him, which have survived and are located at the National Central Library of Florence Italy, see:

Sovel, D. (1999). *Galileo's daughter: A historical memoir of science, faith, and love.* New York: Penguin Books.

3. Modeling Galileo's exploration of falling objects

To explore what happens when a heavy object and a light object of the same shape and size fall from the same height at the same time, each group uses : two objects of similar shape, different masses (light and heavy object about the same size and shape), board from which to drop them, pad (rug, cardboard) on which they can fall, digital camera (cell phone) with which to video their landing.

- Place two small objects with same shape but different masses on a board
- Place a pad (rug or cardboard) on the floor
- Hold the board high above the pad
- Turn on a video camera focused on the pad
- Tip the board so the two objects start falling at the same time from the same height
- **Listen (and watch**) to see if they hit at different or the same time
- What do you observe?

Question 5.53 Why do light and heavy objects fall the way they do?

To explore what happens when one pushes a light object and a heavy object, each small group uses light and heavy objects of similar shapes and sizes such as a heavy block made of wood, brick, or concrete and a light block made of Styrofoam, both covered with duck-tape so that they appear the same when sitting at rest on a flat table top

- Place both blocks on a table top:

Invite each member of the group to push both blocks at the same time

- Which block is harder to get moving? Why?

The inference is that although the Earth pulls harder on the heavier object, the heavier object is also harder to get going; it has a bigger *inertia*. This means that the objects accelerate at the same rate when falling toward the Earth as long as they do not encounter differences from air resistance as they fall. A person with a parachute falls slower that the person would without a parachute, for example, because of the role of air resistance in slowing the parachute's fall.

Note that Sir Isaac Newton was apparently sitting under an apple tree while admiring a moon in the sky. He is said to have had the insight there that the moon was "falling" toward the earth in the same way that an apple from the tree was falling to the Earth, both being pulled toward the center of the Earth by a gravitational force by the Earth. As shown in Fig. 5.96, an object shot out of a canon at various velocities might fall to the Earth near the canon, fall farther from the canon, 'fall' into a circular orbit around the Earth, 'fall' into an elliptical orbit around the Earth, or 'fall' away from the Earth into space.(http://www.thestargarden.co.uk/Newtons-theory-of-gravity.html)

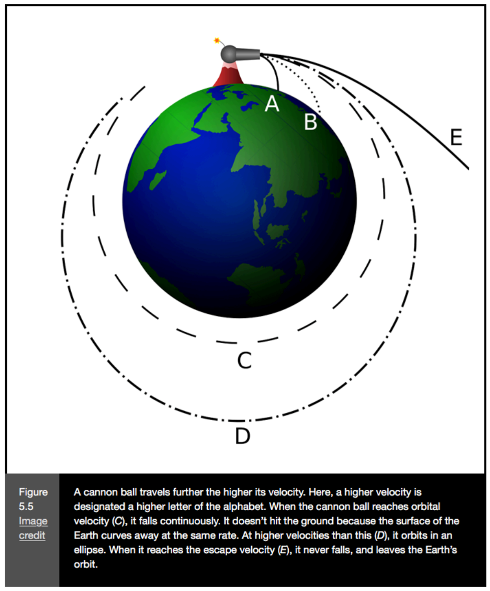


Fig. 5.96 Possible paths of a "falling object" shot out of a canon at various velocities.
http://www.thestargarden.co.uk/Newtons-theory-of-gravity.html
Brian Brondel, https://commons.wikimedia.org/wiki/File:Newton_Cannon.svg.
Licensed under an Attribution-ShareAlike 4.0 International (CC BY-SA 4.0) *license, https://creativecommons.org/licenses/by-sa/4.0/.*

Question 5.96 What happens when heavy and light objects drop from the same height at the same time on the moon?

- Watch astronauts dropping a hammer and a feather on the moon at https://www.youtube.com/watch?v=5C5_dOEyAfk
- What did they observe?

• Complete entries in Table V.16. Then write a summary of what you have learned about the role of gravitational forces in the Sun/Earth/Moon system.

Exploring the Role of Gravitational Forces in the Sun/Earth/Moon System

Table V.16 Developing Additional Central Ideas about the Sun/Earth/Moon System

Table V.16 Developing Additional Central Ideas about the Sun/Earth/Moon System			
URL	Sketch of set up Evidence	Central Ideas	Vocabulary
https://theory.uwinnipeg.ca/mod_tech/node24.html		When two objects interact, each exerts an equal but opposite force on the other.	Newton's Third Law
http://www.physics.uwyo.edu/~davec/teaching/Astro1050Summer2013/10_Newton.pdf		A gravitational force is exerted by one mass on another mass that depends on the size of the masses and the square of the distance between them: F = GMm/r2	Newton's Universal Law of Gravitation
http://scienceline.ucsb.edu/getkey.php?key=770		When one object is revolving around another, the gravitational force by the larger object on the smaller object is keeping the smaller object in its orbit.	
http://earthsky.org/earth/tides-and-the-pull-of-the-moon-and-sun http://oceanservice.noaa.gov/education/kits/tides/tides06_variations.html		Gravitational forces from the Moon and Sun influence the ocean's tides on Earth	
http://galileo.rice.edu/sci/theories/on_motion.html		Light objects and heavy objects speed up at the same rate as they fall near the surface of the Earth.	Aristotle Galileo inertia

https://www.youtube.com/watch?v=5C5_dOEyAfk http://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_15_feather_drop.html		Light objects and heavy objects speed up at the same rate when falling near the surface of the Moon.	

- Diagram arrangements of the Sun/Earth/Moon system that influence tides on Earth:

Highest and lowest tides

Smallest tidal effects

4. Interpreting first grade students' thoughts about falling objects

Question 5.55 What ideas do first grade students have about falling objects?

- Read and discuss Jamie Mikeska's reflection upon engaging first grade students in exploring falling objects.

J. Mikeska, "First graders discuss dropping a book and a piece of paper," In *Seeing the science in children's thinking*, edited by D. Hammer and E. H. van Zee (Heinemann, Portsmouth, NH, 2006), pp. 71-83.

References

J. Mikeska, "First graders discuss dropping a book and a piece of paper," In *Seeing the science in children's thinking*, edited by D. Hammer and E. H. van Zee (Heinemann, Portsmouth, NH, 2006), pp. 71-83.

I. Newton, *The mathematical principles of natural philosopy*. Translated into English by Andrew Motte (London: Printed for Benjamin Motte, at the Middle-Temple-Gate in Fleetstreet, 1729). https://books.google.com/books?id=Tm0FAAAAQAAJ&printsec=frontcover&dq=Newton+mathematical+principles+Motte&lr=&as_drrb_is=b&as_minm_is=12&as_miny_is=1720&as_maxm_is=12&as_maxy_is=1800&num=20&as_brr=3#v=onepage&q=Newton%20mathematical%20principles%20Motte&f=false

P. P. Urone, R. Hinrichs, K. Dirks, and M. Sharma, *College Physics* (*OpenStaxCollege*, BC

campus, 2018). https://opentextbc.ca/physicstestbook2/chapter/newtons-universal-law-of-gravitation/

XII. Making Connections to Educational Policies

This section completes this unit. As an informed citizen in your community, you should become aware of the local standards for teaching science, particularly if you are a teacher, preparing to become a teacher, or a parent advocating for more science to be taught in elementary schools.

Question 5.57 What are the current standards for teaching science at various grade levels where you live?

- Contact your local department of education to find out about current standards for teaching science at various grade levels in your area. The Oregon Department of Education's announcement, for example, is at http://www.oregon.gov/ode/educator-resources/standards/science/Pages/Science-Standards.aspx . This state has adopted the *Next Generation Science Standards* (NGSS *Lead States*, 2013, https://www.nextgenscience.org.) These standards recommend *disciplinary core ideas*, *science and engineering practices* and *crosscutting concepts* that students should learn and use at various grade levels.

Q*uestion 5.58 How would you use your community's standards for teaching science to engage children in learning about astronomical phenomena within the Sun/Earth/Moon system?*

A. Learning more about the US *Next Generation Science Standards*

- Briefly review the following:
  - *Disciplinary Core Ideas* about Earth and Space Sciences, particularly pages 380-381 at https://www.nap.edu/read/18290/chapter/11,
  - the eight recommended *Scientific and Engineering Practices* at https://www.nap.edu/read/18290/chapter/12 ,

    - the seven *Crosscutting Concepts* recommended for emphasis at https://www.nap.edu/read/18290/chapter/13 .
- For each of the three dimensions being advocated, indicate at least one element that seems most of interest to you. Why?
- Discuss an example of ways in which you might engage children of the age you want to teach in learning about earth and space science by developing a disciplinary core idea, using at least one of the science and engineering practices and one of the crosscutting concepts that are of interest to you. Or discuss an example drawn from the aspects indicated in Table V.17 below.

Table V.17 Dimensions of US *Next Generation Science Standards* relevant to exploration of Moon phases

Table V.17 Dimensions of US *Next Generation Science Standards* relevant to exploration of Moon phases				
Dimensions	Element	Grades K-2	Grades 3-5	Grades 6-8
Disciplinary Core Idea	Earth Space Science ESSI-A	Patterns of movement of the sun, moon, and stars as seen from Earth can be observed, described, and predicted.	The Earth's orbit and rotation, and the orbit of the moon around the Earth cause observable patterns	Solar system models explain and predict eclipses, lunar phases, and seasons
Science and Engineering Practice	Engaging in Argument from Evidence	Construct an argument with evidence to support a claim	Construct and/or support an argument with evidence, data, and/or a model.	Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem
Cross Cutting Concepts	Patterns	Children recognize that patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence	Students…identify patterns related to time, including simple rates of change and cycles, and to use these patterns to make predictions.	Students… use patterns to identify cause and effect relationships, and use graphs and charts to identify patterns in data.

B. Reflecting upon watching the sky

Nothing needs to be bought or assembled to engage children anywhere on Earth in learning about the Earth's Moon. All one needs is the time and intention to look up at the sky whenever the Moon is visible. A class field trip to the school's playground, a brief conversation while the children line up to come in from recess, a greeting as students enter or leave the building all are venues within which one can teach about the Moon and its relation to the Sun when both are visible in the sky during school hours. Also engaging families in watching the Moon together at home can be an effective way to establish a positive home/school connection. It is important, however, to warn students and their families to protect their eyes by never looking directly at the Sun!

Students observed and developed understandings about the Moon and the Sun throughout the course. They began by responding to diagnostic questions that recorded their initial ideas about why it gets dark at night, why it is cold in the winter and hot in the summer, and why the moon seems to have different shapes at different times. They also recorded observations of the Moon and the Sun during class and at home during the first four weeks, identified patterns in their observations, used these patterns to predict when each phase of the Moon appears to rise, transit, and set, and responded to homework and a midterm question that focused on what they had observed but did not yet ask them to explain the phenomena observed.

After the midterm, students developed explanatory models for day and night, the phases of the Moon, and the Earth's seasons. Typically about a third of the students experience major changes in their understandings about the Sun/Earth/Moon system. These include that the dark part of the changing phases of the Moon is caused by the Moon's own shadow rather than the shadow of the Earth and that the Earth's seasons are caused by the tilt of the Earth's axis as the Earth revolves around the Sun rather than by how close or far the Earth is to the Sun. When time permits, students also consider the role of gravitational forces in the Moon's orbital motion around the Earth and in causing the Earth's tides.

Acting out the inferred motions of the Moon around the Earth while the Earth moves around the Sun can lead to a surprising inference: when one is looking at a third quarter Moon, one is looking at the "place in space" where everyone on Earth is heading next during the Earth's orbit around the Sun! How soon will we all get there? An estimate of about 3.5 hours emerges from using the assumption of circular orbits, relevant mathematics, and information about the distance between the Earth and the Moon as well as the distance between the Earth and the Sun! (When looking at a first quarter Moon, the inference is that one is looking at the “place in space” where all of us on Earth have just been!)

Making observations and consulting Internet resources provided evidence for which constellations of stars are visible during which seasons. Such evidence provides support for the inference that the Earth revolves around the Sun each year rather than that the Sun revolves around the Earth each day. Making observations and consulting Internet resources also provided evidence for where along the horizon the Sun appears to rise and set, how the length and direction of a gnomon’s shadow changes during a sunny day, and how high above the horizon the Sun transits as it seems to move across the sky. Such evidence supported the inference that the Earth rotates on a tilted axis as the Earth revolves around the Sun.

An important aspect of this model is that the tilt is always in the same direction throughout the Earth’s journey around the Sun. The northern and southern hemispheres experience the effects of this tilt, however, in opposite ways. When one hemisphere is tilted toward the Sun, the other hemisphere is tilted away from the Sun.

This complex model explains that hot summers occur during the Earth’s revolution around the Sun when a hemisphere’s tilt is toward the Sun so that the Sun is high in the sky at local noon, shines more directly down through the atmosphere, and is visible above the horizon for more hours than not visible below. Cold winters occur during the Earth’s revolution around the Sun when a hemisphere’s tilt is away from the Sun so that the Sun is low in the sky at local noon, shines at more of an angle through the atmosphere, and is visible above the horizon for fewer hours than not visible below.

During spring and fall, neither hemisphere is tilted toward or away from the Sun: one hemisphere is tilted toward the direction of the Earth’s motion around the Sun; the other hemisphere is tilted away from the Earth’s direction of motion around the Sun. Acting out these aspects of the Earth’s revolution around the Sun, by leaning always in the same direction while revolving around a lamp in a dark room, can be both challenging and fun for students, whether children or adults.

The unit closes by making connections to educational policies as articulated in the US *Next Generation Science Standards* (NGSS, Lead States, 2013). As a last homework or question on the final, students use their initial and later responses to the diagnostic questions as evidence for reflecting upon what and how they learned about the Sun/Earth/Moon system during this course.

C. Making connections to NGSS understandings about the nature of science

The *Next Generation Science Standards* (NGSS Lead States, 2013) recommends that students engage in three dimensions of learning science by using *science and engineering practices* and *cross cutting concepts* while learning *disciplinary core ideas*. In this unit, for example, developing explanatory models for day and night, the phases of the Moon, and the Earth's seasons are examples of the NGSS science and engineering practice of *constructing explanations*. Constructing such evidence-based accounts of natural phenomena also exemplifies the crosscutting concept of *identifying patterns* while learning *disciplinary core ideas* about the *Earth and the solar system*.

Children in grades K-2, for example, should learn that *patterns of movement of the sun, moon, and stars as seen from Earth can be observed, described, and predicted.* During this unit, students predicted rising, transiting, and setting times for each phase of the Moon by interpreting their observations of the shape of the lit portion of the Moon and the angle formed by their arms when pointing at the Sun and Moon if both were visible,

This unit also has provided many examples of the nature of science as articulated in Appendix H of the *Next Generation Science Standards* (NGSS, Lead States, 2013) https://www.nextgenscience.org/resources/ngss-appendices . Appendix H includes tables that provide insights about the development of these understandings about the nature of science across grade spans of K-2, 3-5 (elementary), 6-8 (middle school), and 9-12 (high school).

That *scientific knowledge is based on empirical evidence*, for example, is emphasized throughout this course. Unit 5 models NGSS recommendations that children in grades K-2 learn that *scientists look for patterns and order when making observations about the world*, that upper elementary students in grades 3-5 learn that *science findings are based on recognizing patterns*, that middle school students in grades 6-8 learn that *science knowledge is based upon logical and conceptual connections between evidence and explanations*, and that students in grades 9-12 in high school learn that *science arguments are strengthened by multiple lines of evidence supporting a single explanation.*

That *scientific knowledge assumes an order and consistency in natural systems* is key to understanding, for example, the cause of the phases of the Moon. By observing the Moon during the first four weeks of the course, the students documented how the shape of the lit portion of the Moon seemed to change. Next, if the Moon were visible during class, they could go outside, each hold a ball up next to the Moon in the sky, and see that the portion of their balls lit by the Sun matched the lit portion of the Moon in the sky (or if inside a dark room with a single lamp, they could each hold up a ball so that its lit portion would match the shape of the lit portion of the Moon they expected to see in the sky that day if the Moon were visible). Then by moving their balls around their heads, they also could make the changing shape of the lit portion of their balls match the same changing shape of the Moon they had been observing in the sky. Finally, they used the understanding that the *basic laws of nature are the same everywhere in the universe* (grades 3-5) to infer that the changing phases of the Moon they had seen in the sky were caused by the Moon revolving around the Earth just as the changing phases of their balls were caused by moving their balls around their heads.

This unit illustrated that *scientific knowledge is open to revision in light of new evidence* in several ways. When considering two explanatory models for day and night, for example, an obvious model is that the Sun revolves daily around the Earth. This is what students can infer when they compare the Sun's changes in position in the sky over several hours. This geocentric model also is embedded in our language with descriptions of sunrise and sunset as well as in tools such as analogue clocks, whose hands sweep clockwise in a circle, like the Sun's apparent daily rising, moving high across the sky, and setting when viewed from the northern hemisphere.

Some students initially answer the question, "why does it get dark at night?" with a version of the "the sun goes down". The alternative model is much harder to envision, of an Earth rotating daily on its axis so that the side of the Earth facing away from the Sun is in the Earth's own shadow. Seeing the model of a spinning globe in a dark room lit by a single lamp helps; in this course, an argument based on evidence occurs in resolving a paradox. After observing the Moon for several weeks, students start to notice that the Moon seems to move daily from east to west during several hours, like the Sun, but also from west to east during several days. They can explain this paradox by understanding that the Earth's daily rotation on its axis causes the apparent east to west daily motion of the Moon whereas the apparent west to east motion of the Moon over several days occurs because the Moon actually is moving that way as it revolves around the Earth.

Such complex reasoning, based on logic and evidence, is an example of the way scientists gain confidence in one model versus another in their explorations of the natural world. One goal of this course has been to foster such understandings of the nature of science in a context that is familiar and accessible to all.

Question 5.59 What have you learned about science learning and teaching from your

explorations in this unit?

XIII. Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 5

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 5			
When used	For instructor and demonstrations	For each group of 3	For each student
Week 1 Unit 5.IIA **Question 5.1 What do you already know about the Sun, Moon, and stars?**			U5H2 Diagnostic Questions about Sun, Moon, and Stars:
Unit 5 IIB **Question 5.5 How do people talk together about the Moon?**			Reading: Deborah Roberts. The sky's the limit: Parents and first grade students observe the sky. *Science and Children*, 31(1), 33-37. (September, 1999).
Unit 5.III.A,B **Question 5.6 Where is the Sun in the sky right now?** **Question 5.7 Where is the Moon in the sky right now?**	Sky Journal (If moon is visible during class hours, take sky journal and class outside to model how to make an observation of the Sun and Moon. **Warn students to not look directly at the Sun**!)		Sky journal (To make sky journals ahead of class: cut 4 pieces of paper (8.5"x11") in half to make 8 sheets (8.5"x5.5"), fold in half to make pages (4.5"x5.5") and staple folded pages along the edge.)

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 5			
When sunny during Week 1, 2, or 3 Unit 5.III.A,B **Question 5.8 How does the Sun seem to move across the sky?**	Sky Journal Sunny day	Documenting a student gnomon's shadow during field trip on sunny day: Chalk, meter stick, protractor, digital camera or cell phone. Documenting a pole gnomon's shadow on a sunny day: chalk, pole; pencil; or bent paper clip, paper, manila folder or cardboard; or pencil, paper, nail in shadow board	Documenting sunrise/sunset at home: piece of paper, clipboard or cardboard, pencil. Reading: Marletta Iwasyk, "Kids questioning kids: "Experts" sharing. *Science and Children*, 35(1), 42-47. (September 1997). U5H3 Shadow Plot Sketches
Week 2 Unit 5.III.B Unit 1.VI.A **Question 5.9 How big is the Sun?**	Sunny day	Pinhole in sheet of aluminum foil taped in cardboard holder, paper screen taped on cardboard, meter stick, pencil; If not sunny, use observations made by students in prior courses	(Part of Unit 1 : U1H12 Diameter of the Sun U1H13 Solving Pinhole Math Problem U1H11 Sun Pinhole problem stated if rainy day)
Unit 5.III.C **Question 5.10 What questions about the Moon do you want to explore? How will you do that?**		Large white board, 3 white board markers, 3 white board erasers	U5H4 Questions about the Moon
Week 3 Unit 5.III.C **Question 5.12 What new question do you and your group members have about the Moon?**		Large white board, 3 white board markers, 3 white board erasers	

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 5			
Unit 5.III.D **Question 5.14 What have you learned about the Moon from your observations so far? What do you think will happen next?**			U5H5 Sun and Moon Calendar Template
Last session Week 4 Unit 5.III E, F **Question 5.19 How can you predict when a phase of the Moon will rise, transit, and set?**			U5H6 Predicting 1st Quarter Moon U5H7 Table.V.1 Moon Findings U5H8 TableV.2 Central Ideas about the Moon;
Week 5 Unit 5.III E, F **Question 5.20 What is the duration of each phase of the Moon?**	Access to Internet to discuss website about connection between the phases of the Moon and days of the week: https://www.timeanddate.com/calendar/days/7-days-week.html		(U5H7 and U5H8 may extend into this week)
Week 6	Day 11: review Day 12: midterm		
Week 7 Unit 5.IV, A, B **Question 5.22 Why does it get dark at night?**	Lamp without a shade to represent the Sun, Dark room, Globe to represent the Earth; Access to the Internet for photo of Foucault pendulum, Wind currents showing Coriolis effect, https:www.myradar.com , Copernicus quote, Galileo	Access to cell phone with free app www.myradar.com, Scroll through "layers" until see "wind" for worldwide map of wind currents showing the Coriolis effect	U5H10 Table.V.3 Day and Night

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 5			
Unit 5.V A, B, C **Question 5.23 Why does the Moon seem to have different shapes at different times?**	Sunny day or lamp inside without shade to represent the Sun; dark room		Small ball (ping pong, golf, or Styrofoam) on stick U5H11 Table.V.4 Moon Phases
Week 8 Unit 5.V D **Question 5.24 Why does the Moon seem to move east to west over several hours but west to east over several days?** **Question 5.25 Does the Moon rotate while it revolves around the Earth?**	Lamp without a shade to represent the Sun; Dark room		For **pairs** of students; Basketball to represent the Moon; U5H12 Table.V.5 Moon Paradox
Unit 5.V.E **Question 5.26 What do the phases of the Moon look like from other places on the Earth?**			Reading: Akiko Kurose,(2000). Eyes on Science: Asking questions about the Moon on the playground, in class, and at home.(pp. 139-147). In J. Minstrell and E.van Zee (eds.) *Inquiring into inquiry learning and teaching in science*. Washington, D.C.: American Association for the Advancement of Science. https://www.aaas.org/sites/default/files/s3fs-public/InquiryPart2.pdf
Unit 5.V.F **Question 5.27 How are the Sun, Earth, and Moon arranged in space?**	Lamp without a shade to represent the Sun; Dark room; Basketball to represent the Moon		

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 5			
Unit 5.V.F **Question 5.28 What are the relative sizes of the Sun and the Moon?**	Wall clock or other object to compareto thumb from far away		
Unit 5.V. F **Question 5.29 How does the view of the phases of the Moon from Earth compare with the view from above the solar system?**	Need access to the internet to show and discuss various ways of showing diagrams of view from Earth and from above the solar system as shown in Fig. 5.44, 5.45, 5.46		One piece of 8.5"x11" paper or U5H13 Table.V.6. Compare ViewsU5H14 Tables V.7 and V8 Eclipses
Unit 5.V.F **Question 5.30 Does the Moon revolve around the Earth in the clockwise or counter-clockwise direction?**	Need access to the internet to show and discuss various ways of representing the Moon revolving around the Earth as shown in Fig.5.29, 5.30, 5.32, 5.42-5.45, 5.44, 5.45, 5.46		Ball on stick to represent the Moon
Unit 5.V, G **Question 5.31 What causes solar and lunar eclipses?**	Lamp without a shade to represent the Sun; Dark room		Ball on stick to represent the Moon
Unit 5.VI	Review of explanatory models for day and night, phases of the Moon Lamp without a shade to represent the Sun; Dark room		Ball on stick to represent the Moon
Week 9 Unit 5.VI.A **Question 5.33 What seasonal patterns are evident in the constellations visible at night?**	4 pieces of chart paper, each with a sketch of a constellation (spring, summer, fall, winter), Masking tape to post on four walls of classroom		U5H15 V.9 SeasonalStars

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 5			
Unit 5.VI.B **Question 5.34 What seasonal patterns are evident in how the Sun seems to move across the sky?**	Sunny day, area outside in Sun throughout classAccess to Internet https://www.timeanddate.com/sun/	Chalk, Meter stick	U5H16 Table.V.10 Seasonal Shadows U5H17a Table V.11 blank for use elsewhere; Example of solar data for Corvallis,Oregon, during March 2019 equinoxes and solstices
Unit 5.VI.C **Question 5.35 What is the connection between seasonal differences in the Sun's apparent daily motion and regional climates**	Access to the Internet		U5H17b V.12 Seasonal Sun Apparent Motions
Unit 5.VII.A **Question 5.36 Why are there seasonal patterns in the constellations visible at night? Question 5.37 Why is it hot in the summer and cold in the winter?**	Lamp without a shade, Dark room; Masking tape, 4 seasonal constellations on chart paper; Globe of the Earth with tilted axis	Circular lid	U5H18 Table.V.13 Earth's Seasons
Following depend upon the time available, especially if have a semester rather than a quarter term			
Unit 5.VIII **Question 5.38 How can one estimate the tilt of the Earth's axis of rotation?**	Globe of the Earth with tilted axis		Gnomon, meter stick,Chalk, Trig table or calculator with trig functions or protractor

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 5			
Unit 5.X A, B **Question 5.44 How are the motions of the Moon revolving around the Earth related to the motions of the Earth revolving around the Sun?**			U5H19 Where Heading Next?
Unit 5.XI.B, C, D, E **Question 5.47 What keeps the Moon and the Earth revolving in their orbits?**	2 magnets, Small ball on string2 spring scales Tide handout Moon handout		U5H20 Tides in Newport, OR U5.H21 Effect of Moon on Tides
Unit 5.XI.F **Question 5.52 What happens when heavy and light objects are dropped from the same height at the same time?**		Light and heavy objects of similar shape, Board to hold objects, then flip, Pad to protect floor, Cell phone with video camera	U5H22 Diagnostic Question U5H23 Galileo excerpt U5H24 Tabl V.16 Gravity
Unit 5.XI. F **Question 5.53 Why do light and heavy objects fall the way they do?**	Heavy brick, Wood 'brick' of same size and shape		Reading: Mekeska, J. in *Seeing the science in children's thinking*,edited by D. Hammer and E. H. van Zee (Heinemann, Portsmouth, NH, 2006) ,pp. 71-83.
Week 10 Unit 5.XII **Question 5.56 What are the current standards in your area for teaching about the Sun/Earth/Moon system at various grade levels?**			U5H25 V.7 NGSS in this context U5H26 NGSS dimensions in this course

Exploring Physical Phenomena: Summary of Equipment and Supplies for Unit 5			
End of Course			U5H27 End of course questionnaire U5H28 Review for Final

UNITS 1 HANDOUTS

Handout #	Section #	Page #	Question #	Content
		Link		Unit 1 Handout Guide
		Link		Unit 1 Equipment List
U1H1	First class	Link		Example *Welcome*
U1H2	First class	Link		Example Student Information Form
U1H3	Each class	Link		Exit ticket template
U1H4a	III.A Each class	Link		Physics Notebook Page with Explanations (pdf file)
U1H4b	III.A Each class	Link		Physics Notebook Page with Explanations (docx file)
U1H5a	III.A Each class	Link		Physics Notebook Page Template (pdf file)
U1H5b	III.A Each class	Link		Physics Notebook Page Template (docx file)
U1H6	II.A.	Link	1.1	Each Group: Aspects that Foster Science Learning
U1H7	II.B	Link	1.2	Diagnostic Questions about Light and Learning

U1H8	Unit 5 II.A.1	Link	5.1	Diagnostic Questions about the Sun, Moon, and Stars
U1H9	III.A	Link	1.3-1.7	Table I.1 Explorations of Light Phenomena (light and shadows)
U1H10	III.B IV.D	Link	1.9 – 1.11 1.12	Pinhole Phenomena Handout (2 figures; Table I.1 (continued) Table 1.2 Variables in exploration of pinhole phenomena)
U1H11	VI.A.	Link	1.14- 1.16	Pinhole Phenomena Problem: Estimate of the Diameter of the Sun
U1H12	VLA	Link	1.9 – 1.16	Diameter of the Sun Handout 2 figures, Table 1.3,
U1H13	VLA	Link	1.9 – 1.16	Solving a Pinhole Math Problem
U1H14	VII.A	Link	1.18	Table 1.1 (continued) Reflection
U1H15	VII.B	Link	1.21	Table 1.1 (continued) Refraction
U1H16	VII.C	Link	1.23	Table 1.1 (continued), Dispersion
U1H17	X	Link	1.25	Table 1.4 NGSS practices

UNIT 2 HANDOUTS

Handout#	Section #	Page #	Question #	Content
	If needed	Link		Physics Notebook Page with Explanations (docx file)
	If needed	Link		Physics Notebook Page with Explanations (pdf file)
	Each class	Link		Physics Notebook Page (docx file)
	Each class	Link		Physics Notebook Page (pdf file)
		Link		EPPUnit2equipment
		Link		EPPUnit2HandoutGuide
U2H1	End of each class	Link		Exit Ticket Template
U2H2	II.B	Link	2.2	Diagnostic Question about Temperature
U2H3	III.B	Link	2.4	Table II.1 Central Ideas about Thermal Phenomena (Exploring the difference between heat and temperature)
U2H4	V.B	Link	2.7	Table II.1 Central Ideas about Thermal Phenomena (continued) (graphs of equal, unequal temperatures)
U2H5	VI.B.2	Link	2.9	Graphs of changes in temperature templates
U2H6	VI.B.4	Link	2.9	Table II.1 Central Ideas about Thermal Phenomena (continued) (inverse ratios of masses and changes in temperature) (students create Table II.2)
U2H7	VII.A	Link	2.11	Table II.3 Developing a mathematical expression for change in energy
U2H8	VIII.A	Link	2.18	Solving Thermal Math Problems

U2H9	X.A.	Link		NGSS Crosscutting Concepts (NGSS Lead States, 2013) during Units 1 and 2)

UNIT 3 HANDOUTS

Handout #	Section #	Page #	Question #	Content
	If needed	Link		Physics Notebook Page with Explanations (docx file)
	If needed	Link		Physics Notebook Page with Explanations (pdf file)
	Each class	Link		Physics Notebook Page (docx file)
	Each class	Link		Physics Notebook Page (pdf file)
		Link		EPPUnit3equipment
		Link		EPPUnit3HandoutGuide
U3H1	End of each class	Link		Template for Exit Ticket
U3H2	II.B	Link	3.2	Diagnostic Question about Changes in States of Matter
U3H3	III.A	Link	3.2	Table III.1 Central ideas about changes in states of matter
U3H4	III.D	Link	3.6	Table III.2 Central ideas about the influence of light and thermal phenomena on local weather, including the water cycle
U3H5	III.D	Link	3.6	Water cycle diagram
U3H6	IV.A	Link	3.7	Table III.3 Central ideas about the properties of materials; graph of temperature vs time changes for sand and water
U3H7	V.B	Link	3.9	Sea breeze diagram
U3H8	VII	Link	3.13	NGSS cross cutting concepts
U3H9	Feedback in class	Link		Example Week 6 anonymous in class questionnaire

U3H10	Review	Link		Table III.5 NGSS practices review
U3H11	Review	Link		Table III.6 NGSS crosscutting concepts review
U3H12	Feedback online	Link		Example Anonymous Online Survey

UNIT 4 HANDOUTS

Handout #	Section #	Page #	Question #	Content
		Link		Physics Notebook Page with Explanations (docx file)
		Link		Physics Notebook Page with Explanations (pdf file)
	Each class	Link		Physics Notebook Page (docx file)
	Each class	Link		Physics Notebook Page (pdf file)
	Weeks 7-9	Link		EPP5ELessonPlanTemplate.docx
		Link		EPPUnit4equipment.docx
		Link		EPPUnit4HandoutGuide.docx
U4H1		Link		Template for Exit Tickets
U4H2	II.A	Link	4.1	Diagnostic Question about Global Climate
U4H3	III.A, III.B	Link	4.4, 4.6	Table IV.1
U4H4	IV.A, IV.B	Link	4.7, 4.8	Greenhouse gas figures
U4H5	V.A.	Link	4.9	Table IV.2 Central Ideas about evidence that the Earth's average global temperature is increasing
U4H6	V.A.1.	Link	4.9	Exploring Internet Resources about Evidence Climate Change is Occurring
U4H7	VI.A	Link	4.11-4.12	Exploring Internet Resources about Rising Sea Levels (small groups use in class)
U4H8	VI.A.	Link	4.11-4.12	Table IV.3 Central ideas about rising sea levels (individuals use at end of class or at home)
U4H9	VI.B	Link	4.13	Exploring Internet Resources for Calculating One's Carbon Footprint
U4H10	VII.A	Link	4.14	Graph analogy: tossed ball
U4H11	VII.B	Link	4.15	Graph analogy: Greenland glacier mass loss

U4H12a	VII.C	Link	4.16	Table IV.4a Analogy between moving and melting phenomena
U4H12b	VII.C	Link	4.16	Table IV.4b Analogy between moving and melting phenomena
U4H12c	VII.C.2	Link	4.16	Table IV.4b Analogy between moving and melting phenomena
U4H13	VIII	Link	4.17	Exploring Internet Resources for Taking Action about Climate Change
U4H14	IX	Link	4.18	Table IV.4 Relevant NGSS disciplinary core ideas for teaching about climate change

UNIT 5 HANDOUTS

Unit 5 Handouts

Name of Handout	Section #	Page #	Question #	Content
	If needed	Link		Physics Notebook Page with Explanation (docx file)
	If needed	Link		Physics Notebook Page with Explanation (pdf file)
	Each class	Link		Physics Notebook Page (docx file)
	Each class	Link		Physics Notebook Page (pdf file)
		Link		EPPUnit5equipment.docx
		Link		EPPUnit5HandoutGuide.docx
U5H1		Link		Exit Ticket Template
U5H2	II.A	Link	5.1	Diagnostic Questions Sun Moon and Stars
	III.A	Link	5.6	Sky Journal (directions are described in Handout Guide)
U5H3		Link		Shadow Plot Sketches
U5H4		Link		Questions about the Moon
U5H5	III.D	Link	5.15 – 5.18	Sun and Moon Calendar Template
U5H6	III.F.1	Link	5.19	Predicting 1st Quarter Moon
U5H7	III.F.1	Link	5.19	Table V.1 Moon Findings
U5H8	III.F.1	Link	5.19	Table V.2 Powerful Ideas about the Moon
U5H9	Feedback in class	Link		Example Week 6 Anonymous Questionnaire
U5H10	IV.A	Link	5.22	Table V.3 Explanatory Models for Day and Night
U5H11	V.C	Link	5.23	Table V.4 Explanatory Model for Phases of Moon
U5H12	V.D	Link	5.24	Table V.5 Moon Paradox
U5H13	V.F.	Link	5.29	Table V.6 Comparison of Views
U5H14	V.G	Link	5.29	Tables V.7 and V.8 Eclipses

U5H15	VI.A	Link	5.33	Table V.9 Seasonal Differences in Visible Stars
U5H16	VI.B	Link	5.34	Table V.10 Seasonal Differences in Shadow Plots
U5H17a	VI.B	Link	5.34	Table V.12 Solar Data during Equinoxes and Solstices for _
U5H17b	VI.B	Link	5.34	Table V.12 Seasonal Differences in Sun's Apparent Motions
U5H18	VIII.A	Link	5.37	Table V.13 Explanatory Model for Earth's Seasons
U5H19	X.B.1	Link	5.46	Where Are We All Heading Next?
U5H20	XI.E	Link	5.50	Tides in Newport, Oregon (Data source for Table V-14)
U5H21	XI.E	Link	5.50	Table V.15 Effect of the Moon on Tides
U5H22	XI.F.1	Link	5.52	Diagnostic Question Falling Objects
U5H23	XI.F.2	Link	5.52	Galileo Excerpt
U5H24	XI.F	Link	5.52	Table V.16 Gravitational Effects
U5H25	XII	Link	5.57	Table V.17 US *Next Generation Science Standards* in context of Sun/Earth/Moon system
U5H26	XII	Link		US NGSS Dimensions Explored in This Course
U5H27		Link		End of Course Questionnaire
U5H28		Link		Review for Final

10 week Example Schedule

Example Schedule	link
Detailed Schedule	link

Example Equipment for Remote Learning

	Task	Students at home:
All units	Interact online Respond to homework Read free open source text and course readings	Access to the Internet Ability to use Canvas and Zoom Ability to download file, print, respond, scan, upload responses Access to the Internet

	Task	Students at home:
Unit 1	Exploring light phenomena: Make a sky journal to document observations of Sun and Moon Explore light and shadows Explore pinhole phenomena Explore reflection phenomena Explore refraction phenomena Explore dispersion phenomena (Make your own rainbow!)	4 sheets of copy paper (8.5×11”), scissors or paper cutter, 3 staples; Dark room, lamp without shade or flashlight, ball; book or object as barrier, wall or cardboard as screen; (Yard stick or meter stick if possible) Dark room, lamp without a shade or flashlight; Empty toilet paper roll, paper towel roll or paper cup; Square of wax paper or translucent cereal box liner to cover one end of roll or top of cup Square of Al foil or aluminum candy bar liner to cover other end of roll; 2 rubber bands or tape to keep squares on ends of roll; needle or push pin; ruler Mirror, 2 rulers, flashlight, dark room 2 paper cups, pen, water, ruler Prism, crystal, glass dish and mirror that fits in it, water; or hose to create a spray of water; and sunlight or bright light

	Task	Students at home:
Unit 2	Explore thermal phenomena:	Kitchen or other items made of steel, aluminum, wood, and paper or Styrofoam; Cups of hot and cold water; Measuring cup; tray; towel if spills At least 1, preferably 2, thermometers to put in cups of hot and cold water

	Task:	Students at home:
Unit 3	Consider influence of light and thermal phenomena on local weather: a) What happens in context of the water cycle? b) Why is sand hot but water cool at the beach even though the Sun shines on both in the same way for the same time? c) Why do cloudy skies and sea breezes often appear late in the afternoon after a sunny day at the beach?	Pot, ice cubes, heat source (hot plate or burner on stove), stirrer; Liquid water, ice cubes, food coloring, plastic or glass bowl, glass jar, Cup with some sand or rice or dried peas or beans, cup with some water; 2 thermometers; ruler; Lamp that can shine on both cups in the same way or 2 identical lamps (can use textbook photo and data if necessary)

	Task	Students at home:
Unit 4	Consider influence of light and thermal phenomena on global climate change in context of: a) What is the greenhouse effect? b) What is the evidence that the global temperature is increasing at a much faster rate than in the past? c) What is the evidence that sea levels are rising in destructive ways? d) What are individuals, communities, nations, and world organizations doing to address global climate change issues?	Slinky (if available) 2 identical plastic or glass containers 2 thermometers if possible, 2 rulers Cover for one container Sunny day or lamp Access to Internet resources Access to Internet resources Access to Internet resources 2 identical small trays (such as frozen dinner trays), flat rock that fits in a tray, Ice cubes, liquid water; blue food coloring if available to make blue ice cubes and blue liquid water Bulb and tube thermometer (if available) Access to Internet resources

	Task	Students at home:
Unit 5	Observe Sun and Moon Make shadow plot Develop explanations for: a) day and night b) phases of the Moon c) seasonal stars d) Earth's seasons	Sky journal (4 pieces of paper) Monthly calendar (download file) Manila folder, paper clip, paper Lamp without shade in dark room or sunny day; ball Access to online constellation guide Globe with tilt (if available)

Example Homework

Title	Page #	File
Example Homework 1	link	EPPExampleHomework1.doc
Example Homework 2	link	EPPExampleHomework2.doc
Example Homework 3	link	EPPExampleHomework3.doc
Example Homework 4	link	EPPExampleHomework4.doc
Example Homework 5	link	EPPExampleHomework5.doc
Example Homework 6	link	EPPExampleHomework6.doc
Example Homework 7	link	EPPExampleHomework7.doc
Example Homework 8	link	EPPExampleHomework8.doc
Example Homework 9	link	EPPExampleHomework9.doc
Example Homework 10	link	EPPExampleHomework10.doc
Lesson Plan	link	EPP5ELessonPlan.docx
Reading Strategies	link (docx) link (pdf)	EPPReadingStrategies.docx
Notebook Pages	link (docx) link (pdf)	EPP.notebookpages.docx
Notebook Pages with Explanations	link (docx) link (pdf)	EPP.notebookpages.withexplainations.docx

Creative Commons License

Recommended Citations

APA outline:

Source from website:

- (Full last name, first initial of first name). (Date of publication). Title of source. Retrieved from https://www.someaddress.com/full/url/

Source from print:

- (Full last name, first initial of first name). (Date of publication). Title of source. Title of container (larger whole that the source is in, i.e. a chapter in a book), volume number, page numbers.

Examples

If retrieving from a webpage:

- *Berndt, T. J. (2002). Friendship quality and social development.* Retrieved from insert link.

If retrieving from a book:

- Berndt, T. J. (2002). Friendship quality and social development. *Current Directions in Psychological Science*, 11, 7-10.

MLA outline:

Author (last, first name). Title of source. Title of container (larger whole that the source is in, i.e. a chapter in a book), Other contributors, Version, Number, Publisher, Publication Date, Location (page numbers).

Examples

- Bagchi, Alaknanda. “Conflicting Nationalisms: The Voice of the Subaltern in Mahasweta Devi’s Bashai Tudu.” *Tulsa Studies in Women’s Literature*, vol. 15, no. 1, 1996, pp. 41-50.
- Said, Edward W. *Culture and Imperialism.* Knopf, 1994.

Chicago outline:

Source from website:

- Lastname, Firstname. “Title of Web Page.” Name of Website. Publishing organization, publication or revision date if available. Access date if no other date is available. URL .

Source from print:

- Last name, First name. *Title of Book*. Place of publication: Publisher, Year of publication.

Examples

- Davidson, Donald, *Essays on Actions and Events.* Oxford: Clarendon, 2001. https://bibliotecamathom.files.wordpress.com/2012/10/essays-on-actions-and-events.pdf.
- Kerouac, Jack. *The Dharma Bums.* New York: Viking Press, 1958.

Versioning

This page provides a record of changes made to this guide. Each set of edits is acknowledged with a 0.01 increase in the version number. The exported files for this toolkit reflect the most recent version.

If you find an error in this text, please fill out the form at bit.ly/33cz3Q1

Version	Date	Change Made	Location in text
0.1	**MM/DD/YYYY**		