INSTRUCTOR'S MANUAL

21st Century Astronomy

SIXTH EDITION

INSTRUCTOR'S MANUAL

21st Century Astronomy

SIXTH EDITION

LAURA KAY ◆ STACY PALEN ◆ GEORGE BLUMENTHAL

ANA LARSON
University of Washington

W ◆ W ◆ NORTON & COMPANY ◆ NEW YORK ◆ LONDON

W. W. Norton & Company has been independent since its founding in 1923, when William Warder Norton and Mary D. Herter Norton first published lectures delivered at the People's Institute, the adult education division of New York City's Cooper Union. The Nortons soon expanded their program beyond the Institute, publishing books by celebrated academics from America and abroad. By mid-century, the two major pillars of Norton's publishing program—trade books and college texts—were firmly established. In the 1950s, the Norton family transferred control of the company to its employees, and today—with a staff of four hundred and a comparable number of trade, college, and professional titles published each year—W. W. Norton & Company stands as the largest and oldest publishing house owned wholly by its employees.

Associate Digital Media Editor: Arielle Holstein
Production Manager: Ashley Horna
Composition by Westchester Publishing Services

W. W. Norton & Company, Inc., 500 Fifth Avenue, New York, NY 10110
www.wwnorton.com

W. W. Norton & Company Ltd., 15 Carlisle Street, London W1D 3BS

1 2 3 4 5 6 7 8 9 0

Contents

Part 2 **Answers to Starry Night Workbook Exercises**

Preface

For each chapter of the textbook, you will find a corresponding chapter in the Instructor's Manual that contains all or most of the following sections:

INSTRUCTOR NOTES

- This section provides a brief overview of the chapter and a list of major topics discussed. It often includes common misconceptions to address and recommendations for additional resources.

DISCUSSION POINTS

- This section suggests important discussion topics and activities. The chapter Learning Goal associated with each item is noted.

PROCESS OF SCIENCE

- This section provides a brief overview of the chapter's Process of Science figure. We also have questions in Smartwork5 that relate to the figure.

ASTROTOUR ANIMATIONS

- The AstroTour animations are narrated, conceptual overviews with a consistent structure of Introduction—Explanation—Conclusion. This section of the Instructor's Manual briefly describes each AstroTour animation associated with the chapter and notes the corresponding section of the textbook.

ASTRONOMY IN ACTION VIDEOS

- The Astronomy in Action Videos are a series of mini-lectures and demos done by textbook author Stacy Palen. This section of the Instructor's Manual briefly describes each Astronomy in Action Video associated with the chapter and notes the corresponding section of the textbook as well as the length of the video.

INTERACTIVE SIMULATIONS

- Textbook author Stacy Palen has created seven Interactive Simulations that pair with selected Exploration activities. This section briefly describes each Interactive Simulation associated with the chapter and notes the corresponding section of the textbook.

TEACHING READING ASTRONOMY NEWS

- This section contains the worked solutions and discussion of the Reading Astronomy News questions.

CHECK YOUR UNDERSTANDING SOLUTIONS

- This section provides answers and supporting information for all of the in-chapter Check Your Understanding questions.

END-OF-CHAPTER SOLUTIONS

- This section provides worked solutions to all of the end-of-chapter questions and problems (Test Your Understanding, Thinking about the Concepts, and Applying the Concepts).

EXPLORATION

- This section briefly describes the Exploration activity and provides worked solutions to each question.

LEARNING ASTRONOMY BY DOING ASTRONOMY: COLLABORATIVE LECTURE ACTIVITIES

- This section introduces activities from the *Learning Astronomy by Doing Astronomy* workbook that are relevant to the chapter. The textbook reference of the associated topic is noted.

For adopters of *The Norton Starry Night Workbook*, the answers to the exercises are included at the end of the manual.

We hope that you will find the information in this manual useful. We welcome your comments, questions, and suggestions (contact your local Norton representative: http://books.wwnorton.com/books/find-your-rep/).

Finally, we would like to thank Ricardo Covarrubias of Milikin University and Jay Dunn of Georgia State University, Perimeter College, whose careful review improved the accuracy and usefulness of this manual.

Additional resources:

Norton Interactive Instructor's Guide (IIG)
iig.wwnorton.com/astro6

This new and searchable online resource is designed to help instructors prepare for lecture in real time. All of the content in this Instructor's Manual, and more, is located on the IIG. In addition to this manual's content, you will find: the Test Bank, AstroTour animations, Astronomy in Action videos, Interactive Simulations, Lecture PowerPoint slides, all of the textbook's art, photos, and tables, and Learning Management System Coursepacks (available in Blackboard, Canvas, Desire2Learn, and Moodle formats).

Smartwork5 Online Activities and Assessment
digital.wwnorton.com/astro6

More than 2,00 questions support *21st Century Astronomy, Sixth Edition*—all with answer-specific feedback, hints, and ebook links. Norton offers pre-made assignments for each chapter of the text to make it easy to get started, but Smartwork5 is also fully customizable.

Questions include ranking, labeling, and sorting exercises based on book and NASA art, selected end-of-chapter questions, versions of the Explorations (based on AstroTours and new Simulations), and questions that accompany the Reading Astronomy News feature in each textbook chapter. Astronomy in Action video questions focus on overcoming common misconceptions, while Process of Science guided inquiry assignments take students through the steps of a discovery and ask them to participate in the decision-making process that led to the discovery.

PART I:

Instructor's Manual

CHAPTER 1

Thinking Like an Astronomer

INSTRUCTOR NOTES

Chapter 1 is an introduction to the measures and methods of astronomy. Major topics include:

- our cosmic address; that is, the hierarchy of structures from the Solar System to the Laniakea Supercluster.
- relevant and relative distance scales, including the light-year, and relating those scales to an equivalent time.
- the scientific method and relevant vocabulary, with an emphasis on distinguishing a *theory* from an *idea.*
- mathematics as a way to recognize patterns, how to read both linear and logarithmic graphs, and unit conversion and scientific notation.

Students enroll for introductory astronomy courses for many reasons, but the most common one is to fulfill a general education requirement. We have found that in a large lecture hall (say 200 students or more) of a major university, the spread of educational backgrounds can be large. We teach students at every level, from incoming freshmen with no major declared to graduating seniors who have majored in a science, technology, engineering, and mathematics (STEM) field. For an open-enrollment, two- or four-year college, we have students who are earning college credit while still in high school, students who are also working full time, and some who are raising a family along with attending school. Returning students may not have had any exposure to basic math for a decade or more.

The goal of this first chapter is to ease all these students into their study of astronomy. It captures their interest by covering our cosmic address and translating huge distances into terrestrial time examples for a better grasp of large numbers. We may be quite comfortable discussing wavelengths in nanometers, particle densities in atoms per cubic centimeter, masses in 10^{30} kilograms, and distances in megaparsecs, but students are not. We find it useful to conduct exercises with Figures 1.1 and 1.3 or show a version of the "Powers of Ten" montages available online to provide students with some visual context for the ranges of size, mass, speed, and time that are discussed in this course.

Too often we hear the phrase "it's just a theory" as a way of dismissing facts that are personally unacceptable. Here the concepts of questioning, predicting, testing, disproving, and more about the scientific method are presented in a way that is relatable to everyday occurrences. Students are given practice with scientific notation and the graphing of data. The mathematics is presented as the language of, as well as a valuable tool for, science. Much of the quantitative problem solving in this course can be achieved through proportional reasoning, so in addition to asking questions about scientific notation and unit conversion, we can also introduce some basic ideas of how area or volume changes with size.

For many of our students, this is the last formal science course they will ever take. We have included learning outcomes that help them learn the process of science, gain scientific literacy, and understand the difference between science and pseudoscience. The seeds of these outcomes are sown in this first chapter, not only through discussion of the scientific method, but also through the various logical fallacies presented in the Exploration. Although science is ideally independent of culture or creed, it has often collided with religious or other strongly held beliefs. Therefore, because science is a human activity carried out by individuals who may hold nonscientific beliefs, we emphasize that we must construct safeguards within our work to counteract any personal bias that might taint the results. The emphasis is on how science is all about searching for objective truths that lead to conclusions that cannot be falsified, at least at this time.

DISCUSSION POINTS

- Have students look at the sketches shown in Figures 1.1 and 1.3. Ask them if they are familiar with any of the shapes and structures shown. Where have they encountered them before? (LG 1)
- Have students think about the times given in Figure 1.3. Discuss the distances and times between our planet and nearby stars, and relate that to the likelihood that we will communicate with extraterrestrials in our lifetime (remind students that we have only been broadcasting and listening for less than 100 years). (LG 1)

- Astronomers need to keep collecting data from the objects in the universe to find unexpected trends and to test hypotheses. Discuss how this process has analogies in students' own experiences. Have they ever had to collect data to learn something or to explore the unknown? Share in pairs and then with the class. (LG 2)
- Students could formulate a testable hypothesis about how the number of hours spent studying in a course will affect their grade in that course. Would the outcome depend on whether the course was in their chosen major? What other variables might affect the outcome of their efforts in a course? (LG 2)
- Ask students if they are familiar with any scientific equations. Discuss differences and similarities between a well-known scientific equation (for example, $F = ma$ or $E = mc^2$) and a world-renowned work of art. What processes went into creating each of these? How is each example used? (LG 3)
- How can we describe our astronomical origins? Start with the hydrogen atom minutes after the Big Bang and have students build a story of the "life" of that hydrogen atom from its beginning to its presence in their DNA. Set up a think-pair activity, and then randomly select a pair or pairs to share their stories. (LG 4)
- The chapter-opening image is the one taken of Earth by astronaut William (Bill) Anders in 1968 as part of the *Apollo 8* mission, as the orbiter came around the Moon and Earth appeared to "rise." What do students already know about the image? Do they think it was taken from a lander or an astronaut on the surface of the Moon? The question asked is, "Why is this considered one of the most famous photos ever taken?" The answer is that it was the first image taken of Earth from space by humans on a mission to another world. NASA put together a short 45th anniversary commemorative video that combined actual flight recordings, photo mosaics, and elevation data from the Lunar Reconnaissance Orbiter. The video is narrated by Andrew Chaikin, and sketches of the orbiter containing Anders, Jim Lovell, and Frank Borman are included for a more complete perspective of how the Earthrise picture was obtained. The video can be found at https://youtu.be/dE-vOscpiNc.

PROCESS OF SCIENCE

The Process of Science figure for this chapter introduces the basics of the scientific method. The emphasis is on how the process will repeat indefinitely as scientists continue to test the theory. Subsequent chapters in this text will emphasize actual examples of how the scientific method "works."

ASTROTOUR ANIMATIONS

None for this chapter.

ASTRONOMY IN ACTION VIDEOS

None for this chapter.

INTERACTIVE SIMULATIONS

None for this chapter.

TEACHING READING ASTRONOMY NEWS

1. Because light has a finite speed, it takes time for the light to get to us from distant galaxies. We assume that galaxies in the universe all formed at roughly the same time. For those galaxies that are the farthest away, light left them when they were very young, just forming. These galaxies will look the youngest to us. Galaxies that are closer will look older. Telescopes are like time machines.
2. If we are looking extremely far away, such as when the galaxies were only a few billion years old (a look-back time of around 12 billion years), and we see many more small galaxies than large galaxies, then that suggests that galaxies started small.
3. The observable universe is that part where light has had time to reach us. We cannot see the entire universe because there hasn't been enough time for light beyond there to reach us.
4. Since the question asks for learner statements, answers will vary.
5. Students are asked to do a search on galaxies. Answers will vary.

CHECK YOUR UNDERSTANDING SOLUTIONS

1.1 **(d)** radius of Earth **(a)** light-minute **(e)** distance from Earth to the Sun **(c)** light-hour **(f)** radius of the Solar System **(b)** light-year. Use Figure 1.3.

1.2 **(b)** Theories must be testable, and a theory is valid up until a test fails.

1.3 **(c)** Patterns and order are indicative of a physical process at play.

END-OF-CHAPTER QUESTIONS AND PROBLEMS SOLUTIONS

TEST YOUR UNDERSTANDING

1. **(f, e, c, b, a, h, g, d)** is the correct order from smallest to largest size.

2. **(a)** See Figure 1.3.
3. **(b)** We can connect facts through an underlying idea. Note that (a) one must accumulate facts to consider how they are related, and (c, d) that science makes predictions based on these relationships, but "understanding" is the development of these relationships.
4. **(a)** The universe is understood to be homogeneous and isotropic on its largest scales.
5. **(d)** The Sun is the center of our Solar System, just one of the billions of stars in our galaxy, and one of the billions of galaxies in the universe.
6. **(a)** It is the distance that light travels in one year.
7. **(c)** Occam's razor suggests that nature relies on the simplest (or most straightforward) processes.
8. **(d)** Distance units in terms of light speed are very convenient but sometimes odd to think about at first because we seem to be using *time* to refer to distance. This problem shows us two ways of considering the meaning of light distance.
9. **(d)** A reading of Figure 1.7b indicates that the answer cannot be obtained from a linear plot. A reading of the log-linear plot in Figure 1.7c, however, shows that at time step 4, the number of viruses is more than 10 times what it was at the start.
10. **(d)** As the answer indicates, science relates only to the natural world.
11. **(c)** Our understanding must be tested, and at any time, a test could show that it is wrong. Note that this is not an issue of being worthless or incomplete, but merely reflects the fact that we are constantly testing our theories and hypotheses.
12. **(c)** Light travels a light-year in one year, so a star that is 10 light-years away emitted its light 10 years ago for us to see it today.
13. **(d)** Carbon is made inside stars.
14. **(b)** Except for hydrogen and helium (and a tiny bit of lithium), all of the elements found on Earth were produced in stars. Note that the beryllium produced in the Big Bang was unstable and decayed long before Earth formed.
15. **(b, d, a, c, e)** The material for the Sun had to come before the Sun could be formed. Gas came first (b), the gas formed stars to make heavier elements (d), the stars blew up to spread those elements around (a), and then the gas had to collect (c) before it could form the Sun and the planets (e).

THINKING ABOUT THE CONCEPTS

16. Tau Ceti e, Tau Ceti, Milky Way Galaxy, Local Group, Virgo Supercluster, Laniakea Supercluster, universe
17. The cosmological principle essentially states that observers in the universe should find that the natural laws governing their local region are representative of the natural laws governing the universe as a whole. Consequently, they should derive the same natural laws that an observer on Earth derives.
18. 8.3 minutes (see Figure 1.3).
19. Andromeda is about 2.5 million light-years away (see Figure 1.3), so it would take 2.5 million years for the light from the exploding star to reach Earth.
20. Answers will vary. An example is general relativity superseding Newtonian mechanics, which began at the first step of the Process of Science for this chapter when Einstein reinvisioned gravity and spacetime. Another example occurred in the 1920s when it was predicted that the Andromeda galaxy was just in a distant part of the Milky Way, perhaps 300,000 light years distant. Edwin Hubble employed the "observe" step and found that the result did not support the hypothesis: the Andromeda galaxy was, in fact, millions of light years away.
21. This does not qualify as a scientific theory because it is not falsifiable. Although it is possible that we may someday stumble upon irrefutable evidence that aliens visited Earth in the remote past, the absence of evidence today cannot be used to refute the hypothesis. In fact, proponents of the theory will simply argue that we just have not found any evidence yet. Evidence that could support the theory would include finding advanced technology in ancient archaeological sites or buried in old geological layers. The only tests we can think of to refute the hypothesis are either to demonstrate that every piece of technology and archaeological monument could have been reasonably constructed with human knowledge of the time or else invent a time machine and return to the most likely times for aliens to have visited Earth. Because option 2 is utterly implausible and option 1 does not preclude alien visitations, it is impossible to falsify the hypothesis.
22. *Falsifiable* means that something can be tested and shown to be false or incorrect through an experiment or observation. Some examples of ideas that cannot be falsified are religious beliefs, political views, emotional statements, and opinions. Students may have a wide variety of these and other ideas, but all sacred cows are usually considered to be not falsifiable by the people holding those beliefs. Falsifiable ideas include cause and effect and logic.
23. A *theory* is generally understood to mean an idea, regardless of any proof, evidence, or way to test it. A *scientific theory* is an explanation for an occurrence in nature that must be based on observations and data and make testable predictions.

24. A *hypothesis* is an idea that might explain some physical occurrence. A scientific *theory* is a hypothesis that has been rigorously tested.
25. (a) Yes, this is falsifiable. (b) Find a sample of a few hundred children born during different moon phases, who come from similar backgrounds and go to similar schools and follow their progress for a number of years.
26. In 1945, our distance-measuring methods were not correctly calibrated and, as a result, our calculation of the distance to Andromeda was wrong. As we improved that calibration, we found different and more reliable measurements of its distance. In science, statements of "fact" reflect our current best understanding of the natural universe. A scientific "fact" does not imply that science has determined absolute truth; rather, it is simply a statement that this is the best understanding of nature that our current knowledge and technology supports. Over time, all scientific "facts" evolve as our knowledge base and technology grow.
27. Answers will vary. Depending on the generality of the horoscopes, students may provide a wide array of answers for this question. For general statements, students might find that several, if not all, of the horoscopes on a given day could describe their experience. For a very specific horoscope, we expect that it should match approximately 1/12th of the students, regardless of their astrological sign. In any event, if astrology accurately reflected some natural truth, we would expect nearly everyone to find one and only one horoscope each day that describes his or her experience, that the horoscope would match the person's astrological sign, and that the daily horoscope would be accurate for each person for the entire week of record keeping. Students should perform this experiment and be honest with themselves about the results. Students need to be aware of any bias by those who have prior beliefs in horoscopes and who will likely not provide objective data.
28. Taken at face value, this is a ridiculous statement, but there are several items to consider critically before we apply a label of "not reputable." First, was this statement a sound bite taken out of context? Did the scientist simply misspeak when he or she might have been trying to say that we have not yet found extraterrestrial life? If, in fact, the statement can be taken at face value, then the credibility of the scientist might be called into question because he or she has forgotten that absolute truth is not falsifiable (and therefore not scientific) by definition.
29. Some scientific fields rely heavily on math, but not all. Following the scientific method is the important part, not use of mathematics.
30. Only hydrogen and helium (with perhaps a trace amount of lithium) were created in the Big Bang. Heavier elements such as carbon, oxygen, nitrogen, sodium, silicon, iron, and more are manufactured in the interiors of massive stars. At least one generation (and more likely several generations) of stars must die in massive supernova explosions to make heavy elements available to construct planets and serve as the building blocks for life. Therefore, because all the heavy elements in our bodies were originally manufactured in stars, it is fair to claim that we are truly made of stardust.

APPLYING THE CONCEPTS

31. **Setup:** To convert to scientific notation, remember that when the number is greater than one count all digits to the right of the first non-zero digit, and when the number is less than one count the number of digits between the decimal point and first non-zero digit.
    Solve: (a) 7×10^9 (b) 3.46×10^{-3} (c) 1.238×10^3
    Review: A good way to check is to use a scientific calculator, where "times 10 to the" is usually the "EE" key.
32. **Setup:** To convert scientific to standard notation, move the decimal point the number of digits indicated in the exponent, to the right if the number is positive, and left if negative.
    Solve: (a) 534,000,000 (b) 4,100 (c) 0.0000624
    Review: Again, you can test this by using your calculator.
33. **Setup:** Distance is given in terms of speed and time by $d = vt$, where v is speed and t is time. If speed is in km/h, then use time in hours, for which we may have to convert. Remember that there are 60 minutes in an hour.
    Solve: (a) $d = vt = 35\,\frac{\text{km}}{\text{h}} \times 1\text{h} = 35\,\text{km}$

    (b) $d = vt = 35\,\frac{\text{km}}{\text{h}} \times \frac{1}{2}\text{h} = 17.5\,\text{km}$

    (c) $d = vt = 35\,\frac{\text{km}}{\text{h}} \times \frac{1}{60}\text{h} = 0.58\,\text{km}$

    Review: A good sanity check is to make sure the distance traveled becomes smaller if the time traveled decreases.
34. **Setup:** We are given the relationship that surface area, A, is proportional to radius, r, squared, or $A \propto r^2$. To work a proportional-reasoning problem, insert the factor by which one variable changes into the formula to see how the result changes.
    Solve: (a) If r doubles, then $r \rightarrow 2r$, or r changes by a factor of 2. Putting this in our formula shows $A \propto 2^2 = 4$, or that the area changes by a factor of 4. (b) If r triples, then it changes by a factor of 3, or $A \propto 3^2 = 9$.

(c) If r is halved, then $r \to \frac{1}{2}r$, or r changes by a factor of $\frac{1}{2}$; therefore, $A \propto \left(\frac{1}{2}\right)^2 = \frac{1}{4}$. (d) If r is divided by 3, then $r \to \frac{1}{3}r$ and $A \propto \left(\frac{1}{3}\right)^2 = \frac{1}{9}$.

Review: Note first that the change in area is much larger than the change in radius, which reflects the dependence on radius squared. Note also how easy it is to do proportional reasoning rather than using the full surface-area formula ($A = 4\pi r^2$), when all we need to know is how much the result changes.

35. **Setup:** In this problem, we convert among distance, rate, and time with $d = vt$, or solving for time, $t = d/v$. The problem is straightforward because the units of distance are already the same.

Solve: $t = \frac{d}{v} = \frac{384{,}000 \text{ km}}{800 \text{ km/h}} = 480 \text{ h}$. There are 24 hours in a day, so this would take $480 \text{ h} \times \frac{1 \text{ day}}{24 \text{ h}} = 20 \text{ days}$, or about two-thirds of a month (assuming the typical month is 30 days).

Review: A typical flight from New York to London takes about 7 hours and covers a distance of about 5,600 km. The moon is about 69 times farther away, so it would take about $69 \times 7 \text{ h} = 483$ hours to reach the Moon using these estimates. This is basically the same amount of time as we found by exactly solving the problem.

36. **Setup:** In this problem, we will convert between distance, rate, and time with $d = vt$ or, solving for speed, $v = d/t$. The problem is straightforward because the units of distance are already the same.

Solve: $v = \frac{d}{t} = \frac{384{,}000 \text{ km}}{3 \text{ days}} \times \frac{1 \text{ day}}{24 \text{ h}} = 5{,}333 \text{ km/h}$.

This is about $\frac{5{,}333 \text{ km/h}}{800 \text{ km/h}} = 6.7$ times faster than a jet plane.

Review: Using the result from problem 35, we have to travel $\frac{20 \text{ days}}{3 \text{ days}} = 6.7$ times faster than a jet plane, which agrees with our solution.

37. **Setup:** We are given the problem in relative units, so we don't need to use our speed equation or use the actual speed of light. Instead, we will use ratios.

Solve: (a) If light takes 8.3 minutes to reach Earth, then it takes $8.3 \text{ min} \times 2 = 16.6$ minutes to go twice as far. Neptune is 30 times farther from than the Sun than Earth is. When Neptune and the Earth are on the same side of the Sun (Neptune is in opposition), Neptune is 29 AUs from Earth. This means that light will take $8.3 \text{ min/AU} \times 29 \text{ AU} = 240.7$ minutes, or $240.7/60 = 4.0$ hours.

(b) This means that sharing just one sentence will take about 8 hours, so it could take a few days just to say hello, talk about the weather, and think of something else to say. This is the shortest possible time happening when Neptune is at its closest approach to Earth.

Review: If you watch *2001: A Space Odyssey,* you will note that the televised interview between Earth and David Bowman had to be conducted over many hours and then edited for time delays. This was factually correct. Because Neptune is about six times farther away than Jupiter, it stands to reason that it would take light and communication a lot longer still.

38. **Setup:** Light travels at approximately 3×10^5 km/s. To find the travel time, use $d = vt$ or $t = \frac{d}{v}$.

Solve: $t = \frac{d}{v} = \frac{5.6 \times 10^7 \text{ km}}{3 \times 10^5 \text{ km/s}} = 187 \text{ s}$

Likewise, using $t = \frac{d}{v} = \frac{4 \times 10^8 \text{ km}}{3 \times 10^5 \text{ km/s}} = 1330 \text{ s}$.

Review: Light takes about 8.3 min to travel from the Sun to Earth, or about 498 s. If, as an estimate, Mars's distance from Earth ranges from 0.52 AU to 2.52 AU, then the light travel time will range from 260 s to 1255 s. Given the eccentricity of the orbit of Mars, our numbers are consistent with these approximations.

39. **Setup:** We are given the relationship surface area $A \propto r^2$. To work a proportional-reasoning problem, insert the factor by which one variable changes into the formula to see how the result changes.

Solve: The Moon's radius is about one-fourth that of the surface of Earth; therefore, its surface area is $A \propto \left(\frac{1}{4}\right)^2 = \frac{1}{16}$ the area of Earth's surface.

Review: We saw this same behavior in problem 34.

40. **Setup:** We will use the equation $d = vt$, where the distance is 3.6×10^4 km, one way, and light travels at $v = c = 3 \times 10^5$ km/s.

Solve: $t = \frac{d}{c} = \frac{2 \times (3.6 \times 10^4 \text{ km})}{3 \times 10^5 \text{ km/s}} = 0.24$ s, or about $\frac{1}{4}$ of a second

Review: If we are receiving information by an Internet satellite on a regular basis, we almost never notice a lag so the time has to be short, on the order of what we found (much less than 1 second).

41. **Setup**: Let the horizontal axis be time and vertical be population. If we choose to plot a graph in linear space, then a constant population will be a horizon-

tal line followed by a sharp, curved increase in the population, resembling Figure 1.7b. An exponential growth will look similar to the log-linear graph of Figure 1.7c. After a 50-year time step, an almost vertical line down will represent a crash, back down to the original population number. Two of these would be represented by a ramp up to a 50-year time followed by a vertical line down, whether a linear or long-linear graph is used.

Solve: Answers will vary. The question gives an example in which the baseline population is 1 unit.

Review: Note the growth starts out very slowly, jumps up very rapidly, and takes a nosedive down.

42. **Setup:** We need our assumptions of speed. A car goes 60 miles per hour, on average, if we include filling up with gas, eating, and restroom breaks. We also need to relate distance, rate, and time with the formula distance equals rate times time, or $d = vt$.

Solve: Solving for time, $t = d/v$, so by car, $t = 2{,}444$ miles/60 mph = 41 "car" hours. Because there are 24 hours in a day, the car takes 41/24 = 1.7 "car" days. Note these assume you travel around the clock, which we do not usually do unless working with a team.

Review: If you drive "almost" nonstop, you can go from NY to LA in 3 days. This is consistent with our value, because that assumed no stops at all.

43. **Setup:** For water to freeze, it has to cool down to 0°C; then the liquid has to become solid.

Solve: (a) This theory makes no sense to us because hot water will have to cool down to the starting temperature of the cold water before it starts to freeze. That takes time that was not needed by the water that started out cold.

(b) Yes, this is easily testable. Simply try it in a freezer.

(c) We tried it, and it took about five times longer for the hot water to freeze, confirming our hypothesis.

Review: Going back to our original physical reasoning, we see that this theory could be easily refuted without experimentation. Sometimes refuting a theory is not as straightforward, however, and experiments must be performed.

44. **Setup:** On the surface, it seems that the two pizzas cost the same number of dollars per inch; but remember that each pizza is a thin cylinder, so we eat the volume, not the diameter.

Solve: If both pizzas have the same thickness, then we only need to worry about area, $A = \pi r^2$. Since the area goes as radius squared, the area of the 18-inch pizza is four times larger than the area of the 9-inch one. Since the 18-inch pizza costs only twice as much, it is more economical to buy the larger pizza.

Review: Often, larger items cost less per unit than smaller ones because almost the same amount of labor went into making them, and labor is generally the highest part of the cost. This is why you should always check the unit price when buying things.

45. **Setup:** For part (a), use the formula given, $= 2\pi r$. For part (b), we need to relate distance, speed, and time by $d = vt$, where we will solve for time. We use the formula again for part (c), where we must remember there are 24 hours in one day.

Solve: (a) $C = 2\pi r = 2\pi \times (1.5 \times 10^8 \text{ km}) = 9.4 \times 10^8 \text{ km}$

(b) $$v = \frac{d}{t} = \frac{9.4 \times 10^8 \text{ km}}{8{,}766 \text{ h}} \approx 1.075 \times 10^5 \text{ km/h}, \quad \text{or}$$

about 107,500 km/h

(c) Because $d = vt$, and because there are 24 hours in one day, Earth moves about 2,580,000 km per day.

Review: It is amazing that we are hurtling around the Sun at more than 100,000 km/h and do not even realize it. Why? It's because everything else (planets, the Sun, other stars) is so far away that we have no reference point to enable us to observe this breakneck speed.

USING THE WEB

46. Europa, Eris, Pluto, and Triton are about the size of the United States. Venus is about the size of Earth. Lots of stars are larger than an astronomical unit, but Rigel, Gacrux, and Alnitak are about that size. *Voyager 1* is 17 billion km, 0.002 light-years, or 0.73 light-days away. The Stingray and Cat's Eye Nebulae and Gomez's Hamburger are about the same size as the distance from the Sun to nearest star. The Milky Way is 120,000 ly / 2 ly = 60,000 times larger than the Solar System, which includes the Oort Cloud. The Local Group is 10 million ly across while the Milky Way is 120,000 ly in diameter, a ratio of ~80. The observable universe is 93 billion ly across; ratio of the universe to the Local Group is 9,300.

47.(a) Radio broadcast programs have traveled 70 ly. The Sun is not particularly luminous once we get beyond the nearby red dwarf stars. Answers will vary about the video's effectiveness.

(b) Answers will vary concerning the "Powers of 10" circles in explaining the size and scale of the universe.

48. Students go to the Astronomy Picture of the Day and choose an archived picture or video to describe. Answers will vary.

49. Involves investigating news articles about astronomy or space. Answers will vary.

50. Involves going to a blog about astronomy or space. Answers will vary.

EXPLORATION

This exploration asks students to consider the logic behind a variety of statements, many of which they had not considered before. Besides the examples given in the exploration, ask students to come up with one of their own examples that can be classified as one of the logical fallacies included here.

EXPLORATION SOLUTIONS

1. This is an example of *post hoc ergo propter hoc*, in which we assume that the chain mail caused the car accident.
2. This is a slippery slope, because we are assuming that our performance on the first event must influence the next.
3. This is a biased sample, or the use of small-number statistics, because we assume that our small circle of friends represents everyone.
4. This is an appeal to belief, where we argue that because most people believe it, it must be true.
5. By attacking the professor rather than the theory, we are committing an *ad hominem* fallacy.
6. This is an example of begging the question (a bit of a syllogism, too) in which the proof of the assertion comes from another person's assertions.

LEARNING ASTRONOMY BY DOING ASTRONOMY: COLLABORATIVE LECTURE ACTIVITIES

The *Learning Astronomy by Doing Astronomy* workbook activities that are relevant to Chapter 1 are introduced here. For more information, please see the *Learning Astronomy by Doing Astronomy* workbook, the *Instructor's Manual* for the workbook, and the PowerPoint clicker question slides associated with the workbook. Our goal is to have complete coverage across all topics in an introductory astronomy course.

ACTIVITY 1: MATHEMATICAL AND SCIENTIFIC METHODS

This activity reviews the mathematics that students may encounter in this course. This activity helps with tools such as working with logarithms, the small-angle formula, scientific notation, or scaling exercises, like those used to find the scale of a map; laboratory techniques concerning measurements; the uncertainties in those measurements; and statistical analysis. In the first six sections, students review specific mathematical topics and laboratory techniques. These sections include explanations and practice problems. In the last section, students pull multiple concepts together to analyze images of three galaxies. Activity 1 covers the majority of math concepts presented in the workbook. Each individual activity has a set of preactivity questions that tutor students on the math that is included. Specifically, students will:

- demonstrate knowledge of the essentials of mathematics through practice and review of:
- scientific notation and powers of 10;
- algebra;
- logarithms;
- the small-angle formula;
- the use of scale factors and scaling;
- statistics and uncertainties in measurements.
- describe the process of science and the scientific approach as personally experienced.

ACTIVITY 2: ASTRONOMICAL MEASUREMENTS: EXAMPLES FROM ASTRONOMICAL RESEARCH

In this activity students explore the relationship among apparent brightness, luminosity, and distance and learn to manipulate more advanced equations used in astronomy. Specifically, students will:

- apply the small-angle formula.
- distinguish between apparent magnitude and absolute magnitude and relate them correctly to the concepts of apparent brightness and luminosity.
- relate the ratio of distances to the brightness ratio for stars of equal luminosity.
- solve for the distance to a star using the parallax angle.
- find absolute magnitude from apparent magnitude and distance.
- demonstrate proficiency in manipulating more advanced equations used in astronomical research.

CHAPTER 2

Patterns in the Sky—Motions of Earth and the Moon

INSTRUCTOR NOTES

Chapter 2 covers the causes and effects of the apparent motions of the stars, the Sun, and the Moon in our sky. Major topics include:

- the celestial sphere.
- the daily and yearly paths and motions of stars in our sky.
- Earth's axial tilt as the cause of the seasons.
- Moon phases.
- solar and lunar eclipses.

Many students come into our classes believing that Earth's shadow causes Moon phases and that summer happens because Earth is closer to the Sun. There is a video from the late 1980s called *A Private Universe* that shows schoolchildren trying to learn the real causes of the seasons and the phases of the Moon. After a full lesson, most of the students have incorporated these original misconceptions into the actual reasons to make new, but still incorrect, explanations. The video then takes us to Harvard University, where it shows graduating seniors and faculty being asked the same questions, and only a physics professor answers both correctly. The point is not to humiliate any of the students, but rather to highlight that: (1) it is very hard to unravel a misconception and replace it with a correct model; and (2) a very large number of people believe in incorrect explanations of the regular rhythms of our world.

There is, of course, much more in this chapter than just the causes of the Moon phases and the seasons. During these lessons, many of our students discover that they never consciously noticed that the days are longer or that the Sun is higher in the sky during summer than winter; that stars move across our sky on angled paths rather than going from due east to the zenith to due west; or that the Moon can be visible during the day. Thus, we find it advisable to devote extra time to the topics presented in this chapter, as needed or as the curriculum allows. Out of everything that students will learn in the whole course that can be of practical use for the rest of their lives, we find the contents of this chapter are most relevant.

We encourage our students to take full advantage of the AstroTours, Astronomy in Action videos, and simulations included in this chapter, and emphasize that they should develop the habit of doing so whenever they come across a link in the text. These supplementary materials, plus those given in the *Learning Astronomy by Doing Astronomy* workbook, are excellent for helping students master these confusing but fundamental concepts outside class.

DISCUSSION POINTS

- Apply the dependence of the perspective on the celestial motions shown in Figure 2.8 to the location of the classroom. Engage students coming from other countries or states to discuss the perspective on the sky from their birthplaces. The goal is to have them realize that these perspectives are only similar for places with similar latitudes but do not change with longitude, even though they may be very far apart. (LG 1)
- Figure 2.7 shows the brightest stars around the north celestial pole during timed exposures from different locations. The current north celestial pole (NCP) is marked, and it lies very close to the "North Star," Polaris. To familiarize the students with the night sky, discuss how to identify Polaris from your location, based on Figure 2.9. (LG 1)
- What are the consequences of similar perspectives of the sky on the perception of the seasons in different places? What are the differences in regions with different latitudes? Have students make individual lists and then share with their neighbors and then the class. Discuss how it all depends on the altitude of the Sun. (LG 2)
- During winter in the Northern Hemisphere, Earth is closer to the Sun than at any other time of the year. Discuss how this observation disproves the conception that the changing Earth–Sun distance is the reason for Earth's seasons. (LG 2)
- Use Figure 2.20 to show why Earth's shadow does not cause the phases of the Moon. Start by illustrating what a typical shadow looks like, and then have the students try to create a shadow that "hits" a first quarter Moon. (LG 3)
- Use the same figure to explain why we can sometimes see the Moon during the day. Discuss how this figure

can incorrectly imply that if people living on one side of Earth have a full Moon on the meridian during their local midnight, people living on the opposite side of Earth have a new Moon in their daytime sky. (LG 3)

- Figures 2.24 through 2.31 provide spectacular pictures and pedagogical graphics of eclipses. To test that students have mastered the understanding of eclipses, discuss limiting cases: What would happen if Earth's rotation rate and the Moon's revolution rate were perfectly synchronized? What if the Moon's orbit were not tilted with respect to the ecliptic? What about if the apparent size of the Moon were double that of the Sun? What about if the apparent size of the Moon were half that of the Sun? (LG 4)
- The opening figure for this chapter shows the Sun during a total solar eclipse. The question asked is, "What causes a solar eclipse?" There was the total eclipse of the Sun viewed across the United States on August 21, 2017, and a future one is coming on April 8, 2024, with the path of totality running from Mazatlan, Mexico, to the Maritime Provinces of Canada. Find out how many students witnessed either a partial or total solar eclipse in 2017. Have them share what they experienced. Have students share any experiences with lunar eclipses and discuss why total eclipses of the Moon occur more often than total eclipses of the Sun.

PROCESS OF SCIENCE

The Process of Science for this chapter covers "Theories Must Fit All the Known Facts." The three hypotheses about the reason for the seasons are the (1) Earth is closer to the Sun in the summer and farther away in winter, (2) the tilt of Earth's axis causes one hemisphere to be closer to the Sun, and (3) the tilt of Earth's axis changes the distribution of energy between the hemispheres. Reasons are given for the first two hypotheses being falsified.

ASTROTOUR ANIMATIONS

The following AstroTour animations are referenced in Chapter 2 and are available from the free Student Site. These animations are also integrated into assignable Smartwork5 online homework exercises.

THE CELESTIAL SPHERE AND THE ECLIPTIC

This animation starts with the ancient model of Earth and the celestial sphere, and why it is a useful concept. This is followed by side-by-side perspectives of the view of the revolving night sky from backyards in both the Northern and Southern Hemispheres and an "outside" view of Earth embedded in a concentric celestial sphere. The observations of planets are next. The content of the rest of the animation focuses on the ecliptic, showing the motion of the Sun, the Moon, and constellations relative to one another.

Text reference: Sections 2.1 and 2.2

THE VIEW FROM THE POLES

This animation shows how Earth's rotation corresponds to the movement of the stars in the sky and the rotation of the stars around Polaris, which is very nearly at the north celestial pole. It also explores the precession of Earth's rotation, including how the movement of the stars will look when Polaris is no longer the North Star.

Text reference: Sections 2.1 and 2.2

EARTH SPINS AND REVOLVES

This animation shows Earth as it is positioned with respect to the Sun, including motion along its orbit; the direction of its spin as viewed from the North Pole; the apparent daily motion of the celestial sphere; spin axis tilt; a discussion of the causes for the seasonal variation in climate in terms of latitude and the angle of incident sunlight; and comparisons of the processes to processes on other planets.

Text reference: Sections 2.1 and 2.2

THE MOON'S ORBIT: ECLIPSES AND PHASES

This interactive animation explores the Earth-Moon-Sun system, building on the elements of two previous animations ("The Celestial Sphere and the Ecliptic" and "Earth Spins and Revolves"). It shows a changing point of view from the size scale of Earth's orbit down to the size scale of the Moon's orbit, followed by emphasis on the Moon's orbit to distinguish the concept of an eclipse versus a phase, and shows the relative configurations of Earth, the Moon, and the Sun.

Text reference: Sections 2.3 and 2.5

ASTRONOMY IN ACTION VIDEOS

These videos mix live demos with mini-lectures developed by Stacy Palen. They provide students visual preparation for class or a review of what they have learned; they are listed here in the order presented in the text. All videos are available on the free Student Site. Assignable assessment questions can be found in Smartwork5 and the Coursepack.

VOCABULARY OF THE CELESTIAL SPHERE

Dr. Palen divides the basic vocabulary used when we refer to locations on the celestial sphere into two categories: the vocabulary that is specific to each individual and the vocabulary that is used in general because it applies to everyone everywhere. The meaning of each word or phrase is actively demonstrated. Specific words: zenith, nadir, horizon, and meridian. General terms: North and South Pole, equator; north and south celestial poles, celestial equator; ecliptic, tilt of Earth's axis, rotation of Earth. (Length: 6:49)

Text reference: Section 2.1

THE CAUSE OF EARTH'S SEASONS

The cause of Earth's seasons is twofold: the varying length of the days throughout a year and how light from the Sun affects the surface of Earth. An unusual but effective demonstration involves a large amount of uncooked spaghetti wrapped so that it stays in a column. The individual noodles represent rays from the Sun. Dr. Palen draws a circle around the column when the rays are striking perpendicular to the surface of a sheet of paper and compares this to the larger-area, elongated oval when the "rays" hit at an angle. (Length: 2:23)

Text reference: Section 2.2

THE EARTH-MOON-SUN SYSTEM

Three students work together with Dr. Palen in an open field to demonstrate the rotation of Earth, the orbit of the Moon while Earth also rotates, and finally the rotation of the Sun while the (still-rotating) Earth orbits it and the Moon orbits Earth (keeping one side always facing Earth). The part showing the motion from high overhead is especially effective. This demonstration must have taken a lot of practice. (Length: 3:21)

Text reference: Section 2.2

THE PHASES OF THE MOON

This video ends with a request that the students go and do this demonstration "right now." It will enhance their understanding of why the Moon goes through phases probably more than any other demonstration. A bright light source, Dr. Palen's head representing Earth, and an orange held at arm's length are used to show what the Moon phase will be based on the Sun-Earth-Moon relative positions. The names of the phases (new, waxing crescent, first quarter, waxing gibbous, full, waning gibbous, third quarter, and waning crescent) are all given. (Length: 3:42)

Text reference: Section 2.3

INTERACTIVE SIMULATIONS

Interactive simulations are available free at the Digital Resources Page, on the Student Site.

PHASES OF THE MOON

The interactive simulation Phases of the Moon is included as part of the Exploration for this chapter. Students are able to locate the Sun, Earth, and the Moon at various positions and times and see the geometry of the orbits as well as the phase of the Moon as seen from Earth.

Text reference: Section 2.3 and Ch2 Exploration

TEACHING READING ASTRONOMY NEWS

1. The shadow of the Moon will travel across Earth's surface—whether on land or over water—because the Moon is orbiting Earth from west to east, "dragging its shadow" with it.
2. Scientists had not had extended time coverage of the corona of the Sun, part of the Sun's atmosphere that is best seen during a total solar eclipse.
3. The corona is so diffuse that the brilliance of the photosphere totally blocks our view of it.
4. A total eclipse of the Sun occurs during a new Moon phase when the Moon is on one of the nodes of its orbit. A full Moon phase happens around 14 or 15 days later, so the answer may depend on the interpretation of "near the date" of the solar eclipse. A quick check shows that occasionally a partial eclipse of the Sun may be followed by a total eclipse of the Moon about 2 weeks later, but definitely not during every solar eclipse.
5. During the period while this instructor's manual was being developed, no results had been published, although there were many articles on the science goals. Good science requires time to analyze the data and publish results.

CHECK YOUR UNDERSTANDING SOLUTIONS

2.1A. **(b)** Earth rotates about the North and South Poles, and the celestial poles are just an extension of Earth's rotation axis to the sky.

2.1B. **(d)** If we are at 90° latitude at the North Pole, Polaris is directly overhead. If we are at 0° latitude at the equator, it is at 0° altitude above the northern horizon. It follows that its altitude in our sky and our latitude are the same number of degrees.

2.2. **(d)** The greater the tilt, the more severe the seasons.

2.3. A full Moon is rising as the Sun sets. At noon, a third-quarter Moon will be setting. See Figure 2.20 for both answers.

2.4. If the synodic period of the Moon phases were precisely 30 days, and Earth took precisely 12 months to orbit the Sun, the current "wandering" holidays would always fall on the same days from year to year.

2.5. **(b)** If the Moon were twice as far away, its angular size would be smaller (half the size it is now), and it could no longer cover the Sun to make a total eclipse, but could create annular eclipses. However, Earth's shadow would still cover the Moon, so lunar eclipses would happen. They would not last as long since Earth's shadow would be smaller at the new distance.

END-OF-CHAPTER QUESTIONS AND PROBLEMS SOLUTIONS

TEST YOUR UNDERSTANDING

1. **(c)** Constellations are groupings of stars that appear close together on the sky and generally form a familiar pattern. However, in reality the stars are quite far from one another.
2. **(c)** Use Figure 2.8.
3. **(b)** The rotation of Earth on its axis brings the Sun into and out of our sky, causing day and night.
4. **(b)** Currently Polaris is located very close to the north celestial pole, meaning that to the naked eye, it does not appear to move as the sky rotates.
5. **(a)** Refer to Figure 2.16, which shows how the Sun's path compares to our orbital plane and the celestial equator.
6. **(e)** Seasons happen both because (b) days are longer in the summer and because (c) light is more direct in the summer.
7. **(d)** On an equinox, the ecliptic crosses the celestial equator, the Sun rises due east, and one has exactly 12 hours of daylight unless at the North or South Pole.
8. **(b)** The Moon is in a "tidal lock" with Earth, so it spins at the same rate as it orbits.
9. **(d)** Using Figure 2.20, the Moon must be in the third quarter phase.
10. **(a)** A lunar eclipse happens when Earth's shadow falls on the Moon.
11. **(c)** Different civilizations merged their cultural beliefs into the daily, monthly, and yearly noninteger lengths of time. Some let holidays wander, some held end-of-year festivals, and some adjusted their calendar periodically to solve the problem.
12. **(d)** The stars that we see at night depend on all of the options listed.
13. **(c)** The Tropic of Cancer is the northern tropic, and so in summer, the Sun is above the Tropic of Cancer and there is 24 hours of daylight above the Arctic (northern) Circle.
14. **(b)** If you read carefully, all other answers are incorrect.
15. **(a)** "On the meridian" means the highest the Moon will be in the sky. If the Moon is in the first quarter phase and at this position, then by using Figure 2.20, we find it is sunset and the Sun is on the western horizon.

THINKING ABOUT THE CONCEPTS

16. Magellan could not use the North Star (Polaris) for navigation because he was in the Southern Hemisphere; thus, Polaris was never above the horizon.
17. Because the north celestial pole is an extension of the North Pole on Earth, if you are standing on the North Pole, you will see the north celestial pole at your zenith.
18. If Gemini is high in the night sky in winter, it is high in the daytime sky in summer, and the Sun's light blots out all light from the stars.
19. If I am flying in a jetliner, (a) I can tell that I am moving by watching stationary objects go past me below; (b) backward, toward the way the jetliner just came.
20. Our first question as an expert witness is whether the full Moon casts very pronounced shadows or illuminates things quite brightly and, in this reader's opinion, that only happens if one is in an area that is otherwise *extremely* dark, which does not really happen in cities. That being said, the next question is whether the full Moon can cast a long shadow at midnight. To cast a long shadow, the object (Sun or Moon) must be very low in the sky, but at midnight the Moon will be at the meridian. For most observers, this is relatively high in the sky, which negates the defendant's claim. However, if one were living around the Arctic Circle, then this argument might have some credibility because the Moon would never rise to be very high in the sky.
21. The observation is "seasons happen." In Take 1, the hypothesis is that "seasons are due to distance from the Sun." The prediction is that "both hemispheres will be hot at the same time." The test is that "the seasons are opposite for the two hemispheres." Because this is a failure, we return to a new hypothesis in Take 2. Here, the hypothesis is that "one hemisphere is closer to the Sun than the other because of our tilted axis." The prediction is that "the closer hemisphere will be hotter." The test is that "the difference in distance is too small to account for such temperature differences." Our hypothesis failed, so on to a new

hypothesis in Take 3. Here, we propose that "the tilt of our axis changes the distribution of energy on the surface." The prediction is that "more energy will hit Earth in summer," which we test and confirm. With a confirmed test, we make a new prediction: "summer days are longer." This is true, and we make another prediction, and so on.

22. The average temperatures on Earth lag a bit behind the formal change in seasons because it takes time for Earth to heat up or cool down, the temperatures being modulated by the vast oceans. Thus, although the winter starts officially in December, it takes 1 to 2 months for Earth to cool down, making the coldest months January and February.
23. (a) The Earth takes 24 hours to complete one rotation (about its axis) with respect to the Sun—23 h 56 m with respect to the stars. (b) The Earth takes 26,000 years to complete one "wobble."
24. The full Moon crosses the meridian around midnight, and the first quarter Moon rises (i.e., on the eastern horizon) around noon. To answer these, use a figure such as Figure 2.20.
25. (a) Over the course of one orbit, Earth will stay in a fixed position in the observer's sky, because the same side of the Moon always faces Earth. (It would also rotate almost 30 times over the course of the orbit.) (b) The phases of Earth as viewed from the Moon will be the opposite of those of the Moon as viewed on Earth; that is, if on Earth we see a full Moon, then on the Moon we would see a new Earth.
26. We would see a solar eclipse from the Moon. See Figure 2.29.
27. A total eclipse of the Sun casts a very small shadow on Earth and thus can be seen from only very narrow strips of Earth, whereas the partial shadow covers a much larger area and can thus be seen by many more observers.
28. To see an eclipse at each full or new Moon requires that the Moon's orbit be in the same plane as Earth's orbit around the Sun. Because this is not the case, we see eclipses only on those occasions when the two planes line up, about twice a year, which are referred to as nodes.
29. Let's start at the North Pole. If Earth's tilt axis were 90°, the Sun would be at the zenith at the North Pole and the South Pole would be completely in the dark and extremely cold. Over the course of 3 months, the Sun would be at the zenith at decreasing northern latitudes as it moved slowly down to being over the equator. It would then be at the zenith over increasing southern latitudes until it reached the South Pole at 90° south. The South Pole would be very hot, and the North Pole would be in a deep freeze. The Sun would then be at the zenith for decreasing southern latitudes, over the equator in 3 months, and over the North Pole again in another 3 months. The Sun would swing 180° in the sky compared to the 47° it swings now.
30. A cyclic change in the tilt would vary the height of the Sun in the sky, thereby changing the seasonal temperatures from their current pattern and either making the temperatures more extreme in their range or less than what they are now.

APPLYING THE CONCEPTS

31. **Setup:** We know that it takes 24 hours for Earth to make one revolution, so using $d = vt$, we can find the circumference of Earth. To find the diameter, we will use $C = \pi d$, where d is the diameter.

    Solve: If the speed $v = 1{,}674$ km/h at the equator, then the total distance traveled in 24 hours is $1{,}674\ \frac{\text{km}}{\text{h}} \times 24\ \text{h} = 40{,}176\ \text{km}$. Earth's diameter is then

    $$d = \frac{C}{\pi} = \frac{40{,}196\ \text{km}}{3.1416} = 12{,}795\ \text{km}.$$

    Review: We can think of two ways to check this answer. First, look in the Appendix 4 of the textbook, which lists 6,378 km as Earth's equatorial radius. Second, it is about 3,000 miles from New York City to Los Angeles, and there are 3 hours of time change between them, which means there are about 1,000 miles, or 1,600 km per hour of change. There are 24 time zones total, so the circumference of Earth is about 24,000 miles, or 38,000 km. This is close enough to the 40,176 km we calculated, so it is a reasonable check.
32. **Setup:** For this problem, use Figure 2.6, which gives the angle between the horizon and the north celestial pole (NCP) for an observer at 60° north latitude and Figure 2.8, which shows the celestial sphere as viewed by observers at four latitudes. The NCP and the motion of the stars around it clearly show the NCP altitude decreasing above the northern horizon.

    Solve: (a) Answers will vary with latitude but they should resemble Figure 2.6. Students should start by measuring rhe center-equator-latitude angle that equals their latitude. They then draw a line from Earth's center, through their location, and out long enough to identify the zenith. They can then draw a tangent line on Earth's surface at their latitude to represent their horizon. The direction arrow to the NCP will always be parallel to the N direction and the direction arrow to the celestial equator will always be parallel to the plane of the equator. They would now have all of the angles defined and measureable.

(b) Combining Figures 2.6 and 2.8, one finds the maximum and minimum altitude of the Sun at noon on the solstices will be 23.5° above or below the celestial equator, and the celestial equator appears L degrees below the zenith, or $90° - L$ degrees above the horizon, where L is your latitude. Thus, the Sun reaches $(90° - L) \pm 23.5°$ on the solstices.

Review: Activity 5: Altitudes of Objects on Your Meridian in *Learning Astronomy by Doing Astronomy: Collaborative Lecture Activities, 1st ed.,* has students do this very thing. If a student has access to a plastic celestial sphere with a movable Sun inside, using this tool is the best way to review the motion of the Sun in our sky and the relative positions of the zenith, celestial equator, and north celestial pole. It is worth investing in at least one of these for every introductory class.

33. **Setup:** For this problem, use Figures 2.7 and 2.8, which show in graphics and time-lapse photography how stars move around the north celestial pole. This problem may be easier for students to solve if they have just completed the previous problem.

    Solve: If Polaris is D degrees from the zenith, then your latitude is $L = 90° - D$. In this problem, Polaris is 40° from the zenith, therefore we are at latitude 50° N, which is in the southernmost part of Canada, and where Polaris is 50° above the northern horizon.

    Review: Activity 5: Altitudes of Objects on Your Meridian in *Learning Astronomy by Doing Astronomy: Collaborative Lecture Activities, 1st ed.,* has students do this very thing. If a student has access to a plastic celestial sphere, using this tool is the best way to review the answer. It is worth investing in at least one of these for every introductory class.

34. **Setup:** For this problem, use Figure 2.8, which shows how the stars move across our celestial sphere for four different locations.

    Solve: If you are living in the United States, then, as shown in Figure 2.8, you could see a star in the southern part of the celestial sphere if it is more than L degrees from the southern celestial pole. Therefore, if you want to see a star 65° from the celestial equator, that means it is $90° - 65° = 25°$ of the south celestial pole. To see it in the Northern Hemisphere, you would need to be at this latitude or below. The only states that reach this low latitude are Florida and Hawaii.

    Review: If a student has access to a plastic celestial sphere, using this tool is the best way to review the answer. It is worth investing in at least one of these for every introductory class.

35. **Setup:** For this problem, use Figure 2.14 and note that panel (b) corresponds to the summer solstice in the Southern Hemisphere. Have students also locate the Antarctic Circle in this figure.

    Solve: As Earth rotates, an observer on the South Pole will not move with respect to the Sun. In other words, the Sun will stay at the same height in the sky all day long on the solstice. Using the same argument as in problem 32, the maximum height the Sun will reach in your sky is $(90° - L) + 23.5°$, or 23.5° above the horizon. This is the height of the Sun (a) at noon and (b) at midnight on the solstice.

    Review: One can also visualize this by viewing Figure 2.17, which shows the midnight Sun for latitudes greater than 66.5° north or south.

36. **Setup:** For this problem, use Figure 2.14, which shows how the Sun illuminates Earth at different times of year.

    Solve: Because the tropics are D degrees above (north latitude) and below (south latitude) our equator, and the (Ant)Arctic circles are D degrees below (decreasing latitude) the poles, we see that for this problem, the tropics would be at latitudes 10° north and 10° south of the equator. The Arctic Circle would be at north 80° and the Antarctic Circle at south 80°.

    Review: Imagine Earth had no tilt; then where would the tropics and circles be? (There would be no tropics or circles because there would be no seasons.) Now tilt Earth by a tiny amount and then answer the question. One can easily derive the logic used in the solution in this way to verify that it is correct.

37. **Setup:** For this problem, use Figure 2.16, which shows how the Sun's path compares to our orbital plane and the celestial equator.

    Solve: On the equinox, the highest the Sun in your sky will be L degrees below the zenith or $90° - L$ degrees above the horizon, where L is your latitude. Therefore, the highest the Sun will be on the summer solstice will be $(90° - L) + 23.5°$, and if the Moon can be up to 5° above that, then in Philadelphia, the Moon can be as high as $(90° - 40°) + 23.5° + 5° = 78.5°$ above the horizon.

    Review: The Figure 2.16 shows this situation as described.

38. **Setup:** For this problem, use Figure 2.14a that shows how the Sun illuminates Earth when it is summer in North America.

    Solve: According to this figure, (a) we will have to travel to latitudes of 66.5° or higher and (b) make this trip as close to the summer solstice as possible, then the Sun will never set.

Review: There are a number of small towns north of the Arctic Circle that you could visit in Russia, Finland, Sweden, Norway, Greenland, Canada, and Alaska.

39. **Setup:** Follow the worked example in Working It Out 2.1 but replace 185 meters with 157.5 meters. Alternatively, in the final answer given in the example, divide by 185 and multiply by 157.5 to remove one unit and replace the other.

Solve: Following the first method, we use:

$$\frac{1}{50} \times C = 5{,}000 \text{ stadia} \times 157.5 \frac{\text{m}}{\text{stadion}} \times \frac{1 \text{ km}}{1{,}000 \text{ m}}$$
$$= 5 \times 157.5 \text{ km} = 787.5 \text{ km}$$
$$C = 787.5 \text{ km} \times 50 = 39{,}375 \text{ km}$$

The modern value is 40,075 km; this is only 1.7% off.

Review: Check using the second method. Using 185 meters per stadion, the example found a circumference of 46,250 km: $46{,}250 \text{ km} \times \frac{157.5}{185} = 39{,}375 \text{ km}.$

40. **Setup:** (a) We need to know how much time it takes for the vernal equinox to move from one constellation to another. Let us assume all constellations are equally distant from the next, then how much time is spent in each constellation for a total circuit of 26,000 years (the period of Earth's wobble)? (b) Use Figure 2.18b.

Solve: (a) There are 12 constellations, and if they are distributed roughly uniformly around the zodiac (as in Figure 2.13, although the astronomical zodiac constellations are not evenly divided), it takes roughly $\frac{26{,}000 \text{ yr}}{12 \text{ constellations}} \approx 2{,}200 \text{ yr}$ for the equinox to move from one constellation to the next.

(b) If the vernal equinox has moved from Aries to Pisces over about 2,200 years, then 4,000 years ago it would have been in Taurus.

Review: (a) Note that the question asked how long the equinox spends in a constellation, not how much time it takes to move between the two. If we assume that they are all about the same size and equally spaced apart, then the two questions are really the same. (b) Given that we determined it takes about 2,000 years to move one constellation, we need to move only two constellations back from Pisces.

41. **Setup:** Looking at Figure 2.18b, Vega is around 13,000 to 14,000 CE. The question is, how long will it take to move from Polaris (today) to Vega? We have all the information we need, as long as we remember that today is 2,000 CE.

Solve: 13,500 yr − 2,000 yr = 11,500 yr.

Review: We could also estimate this from Figure 2.18a as an angle. It looks like the angle between Polaris and Vega (as measured from the center of the image) is almost 180°. That means it will take about half of the total period, or $\frac{1}{2} \times 26{,}000 = 13{,}000$ years, which is close to what we found.

42. **Setup:** To solve this problem, remember that a circle measures 360°, and it takes about 27.3 days for the Moon to orbit once with respect to the fixed stars on the sky. We must find out how long it takes to move 1°.

Solve: If the Moon moves 360° in 27.3 days, then it takes $\frac{27.3 \text{ days}}{360^\circ} = 0.076$ days to move 1°, or $0.076 \text{ day} \times \frac{24 \text{ h}}{1 \text{ day}} \approx 1.8$ hours to move 1°. We want the Moon to move half a degree, it angular size, which will take half as long, or about 55 minutes.

Review: On average, the Moon rises about 50 minutes later each day. This can be explained by Earth having to rotate just a bit more for a given location to "catch up" to it.

43. **Setup:** The problem gives us the formula that $\text{apparent size} \propto \frac{\text{diameter}}{\text{distance}}$. We need to compare the ratio of the values for the Sun and the Moon. Since diameter is stated for the formula, but the values are for radii, we will solve this as many students might by converting radii to diameters. We are talking about the apparent sizes of the Sun and the Moon.

Solve: For the Sun, the ratio is $\frac{2 \times 696{,}000 \text{ km}}{1.469 \times 10^8 \text{ km}} = \frac{1.39 \times 10^6 \text{ km}}{1.469 \times 10^8 \text{ km}} = 9.48 \times 10^{-3}$, and for the Moon, $\frac{2 \times 1{,}737 \text{ km}}{3.78 \times 10^5 \text{ km}} = \frac{3{,}474 \text{ km}}{3.78 \times 10^5 \text{ km}} =$ 9.19×10^{-3} The two are indeed just about the same size.

Review: If the two were not roughly the same size, then the Moon would not seem to almost perfectly cover the face of the Sun during a solar eclipse. The fact that the orbit of the Moon is not a perfect circle and the distance to the Moon varies means that the apparent size of the Moon varies by about 12 percent, and we view annular eclipses.

44. **Setup:** Using the form of the small-angle formula from the previous problem, we know that the $\text{apparent size} \propto \frac{\text{diameter}}{\text{distance}}$. In the case of our problem,

the Earth–Moon distance is the same, and so the ratio between the apparent size of the Moon as seen on Earth, and the apparent size of Earth as seen on the Moon, will be the ratio

$$\frac{\text{Apparent size (Earth)}}{\text{Apparent size (Moon)}} = \frac{\text{Diameter (Earth)}}{\text{Diameter (Moon)}}.$$

Solve: Again, as many students might insist on using the diameters, and we might want the chance to show how some numbers or variables cancel: Given the values in the text, $\frac{\text{Apparent size (Earth)}}{\text{Apparent size (Moon)}} = = \frac{2 \times 6{,}371 \text{ km}}{2 \times 1{,}737 \text{ km}} = 3.67$. Earth appears 3.67 times larger to the observer on the Moon.

Review: Try setting out a tennis and basketball some distance apart, and then observe each object from the other's location. It will become clear that the change in angular size varies with the size of each object.

45. **Setup:** Refer to Figure 2.31, which shows why eclipses happen only at certain times of the year.

    Solve: If the inclination of the Moon's orbit drops, then there is a longer period of time during which the Moon can pass through Earth's shadow. Hence, the lunar eclipse seasons would become longer. The solar eclipse still requires a very accurate alignment of the Sun-Earth-Moon system, so this season would probably not change.

    Review: You can try this for yourself by going into a dark room with a single lightbulb and holding a tennis ball at arm's length. The bulb represents the Sun, your head is Earth, and the ball is the Moon. By turning around, you can cause solar and lunar eclipses.

USING THE WEB

46. Involves looking up times for sunrise and sunset and changing lengths of the days. Answers will vary.
47. Involves viewing Earth from different locations, dates, and times. Answers will vary.
48. Involves phases of the Moon on current date and changes with time. Answers will vary.
49. Involves observing the Moon over a period of time, sketching, and analyzing. Answers will vary.
50. Involves determining when the next lunar and solar eclipses will occur at students' locations, and the types of eclipses to be observed. Answers will vary.

EXPLORATION

Many students seem to have difficulty letting go of their misconceptions about the phases of the Moon, and this exploration continues the emphasis this chapter has on dispelling those misconceptions. Combine with the other methods presented, this exploration gives students another approach to learning about where the Moon is located in the sky at the new, first quarter, full, and third quarter phases, as well as when it rises and sets at certain phases.

EXPLORATION SOLUTIONS

1. At startup, the time is noon, because the Sun is going to be at the meridian (i.e., the highest in our sky that it will reach).
2. The Moon is crossing the meridian because it is located at the same position in the sky as the Sun.
3. The Moon is new, as shown on the top right panel. Also, none of the illuminated face is toward us.
4. I would see a "full" Earth, that is, fully illuminated.
5. The Moon orbits counterclockwise.
6. The right side of the Moon is illuminated first.
7. If the horns of the crescent Moon point right, it must be a waning Moon.
8. At midnight, the first quarter Moon is setting on the western horizon.
9. The full Moon crosses the meridian at midnight.
10. At noon, the third quarter Moon is on the western horizon.
11. At 6 P.M., there is a full Moon rising.

LEARNING ASTRONOMY BY DOING ASTRONOMY: COLLABORATIVE LECTURE ACTIVITIES

The *Learning Astronomy by Doing Astronomy* workbook activities that are relevant to Chapter 2 are introduced here. For more information, please see the *Learning Astronomy by Doing Astronomy* workbook, the *Instructor's Manual* for the workbook, and the PowerPoint clicker question slides associated with the workbook.

ACTIVITY 3: WHERE ON EARTH ARE YOU?

Students learn about the coordinate systems that are used on Earth and how our location on Earth and Earth's orbit around the Sun are related to the seasons. They should also be able to:

- recognize that the Sun and stars appear differently at different locations on Earth.
- summarize how these differences lead to seasons on Earth.
- state where the seasons are most and least extreme on Earth and how this difference follows from the location of the Sun in the sky.

Text reference: Section 2.2

ACTIVITY 4: STUDYING THE PHASES OF THE MOON FROM A PRIVILEGED VIEW

This activity requires visualizing the Earth-Moon-Sun system in three dimensions. In this activity, students develop this ability by learning how to:

- successfully replicate the motions of Earth and the Moon, as well as their positions with respect to the Sun at each lunar phase.
- explain the continuity of the Moon phases worldwide.
- use an Earth-Moon figure to disprove a common misconception that Moon phases are caused by Earth's shadow.
- correctly order the phases of the Moon.

Text reference: Section 2.3

ACTIVITY 5: ALTITUDE OF OBJECTS ON THE MERIDIAN AT YOUR LOCATION

Students learn to connect the altitudes of celestial objects as those objects cross the celestial meridian to their latitudes on Earth. In addition to helping them develop abstract reasoning visualization skills, this activity will also help them:

- reproduce the altitudes of the north celestial pole, celestial equator, a star, and the Sun (at solstices and equinoxes) on the meridian for their locations.
- explain why there are different seasons throughout the year.
- explain how the stars appear to move through the sky and how the motion of the stars differs when viewed from different latitudes on Earth.

Text reference: Sections 2.1 and 2.2