INSTRUCTOR'S MANUAL

Understanding Our Universe

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CONTENTS

Part 1: Instructor's Manual

Part 2: Answers to *Starry Night Workbook* Exercises

CHAPTER ONE

Our Place in the Universe

SUMMARY

Astronomy often deals with distances and sizes that are very large and times that are very long. Sometimes it is hard for students to comprehend these large numbers without any relative measure to their familiar world. It is helpful to use comparisons to put ages, distances, and sizes in perspective. The instructor should emphasize the relations between us and our immediate environment, such as the Earth, the Sun, and the Moon. For example, humans are newcomers; we have lived on this planet for less than 0.1 percent of Earth's age. Earth, however, is a mature planet with an age equivalent to a third of the time that has elapsed since the Big Bang. The fact that we are made out of cosmic stuff that originated in the Big Bang and in previous generations of stars cannot be overstated. There were many generations of stars that died and polluted the interstellar medium with chemical elements, such as oxygen, that are essential for life and had to be formed before life could arise here on Earth.

Over 500 years have elapsed since the invention of the telescope, and over 50 years have gone by since the first launch of an artificial satellite. In the 21st century we have the best observing facilities in the history of civilization: space observatories such as the Chandra X-ray satellite, the Hubble Space Telescope, and the Kepler mission; these are ground-based giant telescopes with light-gathering power that exceeds by a factor of a million that of Galileo's telescope. Such tremendous developments of our capabilities for observing the universe have been accompanied by a revolution in the performance of computers. Science also needs a universal language so that all scientists can understand each other, and mathematics is that language. Students must get to know and use some basic mathematics in order to appreciate the elegance and usefulness of science. Astronomy is now in a golden era of technology, but is advanced technology enough for us to fully understand the universe?

The accumulation of raw observational data is just one part of what is needed for us to understand how the universe works. Ideas that lead to testable predictions are also vital. The scientific method shows that hypotheses usually stem from finding unexplained trends in collected data and are constructed to be falsifiable. Scientists use the tools at their disposal to try to disprove new hypotheses, and they often need to develop new technologies in order to carry out the experiments that may falsify the hypothesis under investigation. Hypotheses that stand the empirical tests designed to disprove them (falsify them) become accepted as part of our general understanding of the universe. Such understanding is codified in a set of physical laws and scientific principles and theories that have been shown repeatedly to be valid. This process of always testing the predictions of scientific knowledge makes it provisional but reliable.

While 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, scientists must construct safeguards within their experiments to counteract any personal bias that might taint their results. Thus, science is all about searching for objective truths that lead to conclusions that are repeatedly found to be unfalsifiable.

DISCUSSION POINTS

- Have students look at the sketches shown in Figure 1.1. Ask them if they are familiar with any of the shapes and structures shown. Where have they encountered them before?
- Have students think about the times given in Figure 1.2. Discuss the limitations that the finite speed of light imposes on our ability to detect changes in the universe, but also have them think about the protective effect of being relatively isolated. Discuss parallelisms with the history of civilization. Should we try to remain isolated or should we try to reach out?
- Astronomers need to keep collecting data from the objects in the universe to find unexpected trends and to test new and old 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?
- Why do scientists adhere to the Occam's razor principle? Is that principle an objective truth? Discuss examples of applications of the Occam's razor principle and examples of objective truths.
- Ask students if they are familiar with any scientific equations. Discuss differences and similarities between a well-known scientific equation and a world-renowned work of art.

- Discuss how the reclassification of Pluto as a dwarf planet rather than as a major planet makes sense in light of current scientific evidence and our understanding of the Solar System. Why did the case of Pluto create so much emotional turmoil among astronomers and the public? Is the final result of the voting at the meeting of the IAU in Prague representative of the majority of the astronomical community?

TEACHING READING ASTRONOMY NEWS

NOTE TO INSTRUCTORS

If you would prefer to save the article in the book about Pluto for use later in your course, the following alternate article may be of use. This story will provide a platform for further discussing the scientific method and pseudo-science.

ALTERNATE NEWS STORY

"Many Gather to Ponder End of Maya Days; Ancient Calendar Ends in 2012. Does Calamity Await? Or a Rebirth?" Louis Sahagun, *Los Angeles Times*, Nov. 3, 2008. http://articles.latimes.com/2008/nov/03/local/me-mayan3

EVALUATING THE NEWS

1. Is the 2012 prediction based on a theory, an observation, a hypothesis, a physical law, a physical principle, or none of the above? Explain.
2. There are two competing ideas about what will happen on December 21, 2012. The first says the world will end. The second says nothing will happen. Which choice does the Occam's razor principle support? Why?
3. How does the 2012 apocalypse claim presented in the story fit with the scientific method? Go back to Figure 1.7 and give examples of how it does and does not fit with each step of the scientific method.
4. What will happen to this "theory" on December 12, 2012?
5. What is the likely motivation for progenitors of "2012-ology"? How does this bias their ability to look at this prediction scientifically?
6. What hypothesis is offered for the immense popularity of apocalypse claims? Is this hypothesis scientific? Explain.

TEACHING EXPLORATION

NOTE TO INSTRUCTORS

The Exploration activity for this chapter discusses logical fallacies. The following are additional examples of logical fallacies that can be used in conjunction with the discussion provided in the chapter. The following logical fallacies come from product, service, and political advertisements.

GOAL

- To get students to use logic to critically evaluate claims.

REQUIRED MATERIALS

- Computer with Internet access

PRE/POSTASSESSMENT QUESTION

Suppose someone were to say to you, "Most pedestrian accidents occur at crosswalks. Therefore, people would be safer crossing the street in the middle of the road." This statement would be an example of what kind of logical fallacy?

a. biased sample
b. appeal to belief
c. post hoc ergo propter hoc
d. slippery slope

Answer: a

PREACTIVITY INTRODUCTION

There are a plethora of videos on YouTube that give examples of logical fallacies. "The Fallacy Project: Examples of Fallacies from Advertising, Politics, and Popular Culture" is one such video, and it makes an excellent introduction to common logical fallacies. You can view this video at www.youtube.com/watch?v=fXLTQi7vVsI.

Exploration: More Logical Fallacies

The following videos are real-world examples that can be shown to your students in order to generate discussion about the types of logical fallacies presented in this chapter's Exploration.

- Lyndon B. Johnson's famous "Daisy" political ad against Barry Goldwater is an excellent example of a ridiculous slippery slope (vote for Johnson or there will be atomic war). You can view this video at www.youtube.com/watch?v=63h_v6uf0Ao.
- An *ad hominem* political ad for Robert Barber, running for comptroller general in Charleston, SC. You can view this video at www.youtube.com/watch?v=PAPi_my4uIg.
- An ad for Miss Cleo, a purported psychic medium, appeals to people's beliefs in psychic powers. You can view this video at www.youtube.com/watch?v=pWyHiV3l3MA.

POSTACTIVITY DEBRIEFING

Understanding logical fallacies, a crucial part of scientific thinking, is one of the most applicable skills gained in non-science-majors courses. Enforce this by having students write a brief, timed essay (5 minutes or less) on one or both of the following writing prompts:

1. "Why is it important to be able to spot a logical fallacy?"
2. "Think of an example of a logical fallacy you have encountered outside of class. What type of fallacy is it?"

DEMONSTRATIONS AND ACTIVITIES

Activity 1: Scale Model of the Solar System

NOTE TO INSTRUCTORS

Give students a "tour" of the Solar System by making a scale model on your campus and giving a walking tour complete with sample objects to show the scales of the planets. You can dispel misconceptions about the perceived scale of astronomical objects by asking students along the way where they think the next planet will be and what its scaled size is. Wikipedia has a nice roundup of various well-known scale models that can be discussed in substitution if you are not able to construct a model on your campus. You can visit the Wikipedia page at http://en.wikipedia.org/wiki/Solar_system_model.

GOAL

- To give students a sense of the size scales of objects and distances in astronomy

REQUIRED MATERIALS

- A very large open space (anything from a large field to your entire campus)
- Various objects, to scale, to represent the celestial bodies of the Solar System

INSTRUCTIONS

1. Calculate the distances to and sizes of the major objects to the size scale of your open area. Online tools (such as those found at www.exploratorium.edu/ronh/solar_system/) can make this job easier. A Sun that is 24 inches in diameter will result in an Earth that is roughly the size of a peppercorn.
2. Set out your objects representing the bodies in the Solar System.
3. Take students from object to object. Discuss with them the distance to, and the size of each, object in relation to the others. Relevant questions to ask on the tour are listed next.
4. When you ask about the speed of light, have one student actually move at your scaled light speed.

QUESTIONS TO ASK STUDENTS ALONG THE TOUR

1. Where do you think the next planet will be?
2. How big do you think the next planet will be?
3. As you walk from Mars to Jupiter, how likely is it that you will "hit" an asteroid?
4. How fast does light travel on this scale?
5. How far is it to the next star?
6. If you were an alien flying through our Solar System, how likely is it that you would accidentally hit a planet?

Activity 2: Solar System in Your Pocket

NOTE TO INSTRUCTORS

If you are not able to conduct Activity 1 for any reason, this activity should prove to be a relatively suitable substitute and has the advantage of being able to be performed in any weather. The most effective part of this activity is having students estimate the distribution of planets first (Steps 1 and 2) so they can compare later to the real positions of planets.

GOAL

- To have students realize that the objects in the Solar System are not evenly spaced, as many believe they are.

REQUIRED MATERIALS

- A 5-foot long piece of paper tape, at least 2 inches wide, for each student

INSTRUCTIONS

1. Have students draw and label the Sun on one end of the tape and Pluto/Kuiper Belt on the opposite end.
2. Have students draw and label on the tape the rest of the planets, placing them where they think they should be, according to each planet's average distance from the Sun.
3. When finished, have the students turn the tape over and then draw and label the Sun and Pluto/Kuiper Belt on opposite ends. Make sure students draw and label the Sun and Pluto/Kuiper at the same ends that they did on the other side of the tape. In other words, the Sun should be on both sides of the same end of the tape.
4. On the blank side, have students fold the tape in half and make a line at this half-way point between the Sun and Pluto.
5. Ask students to guess which planet should be placed at this half-way point. Have them label the line on the fold "Uranus."
6. Have students fold the paper in half and then in half again, so that the tape is in quarters. Have them label the crease closest to Pluto "Neptune."
7. Have students guess which planet is located at the crease that's closest to the Sun. Have them label it as "Saturn."

8. Have students place the Sun end of the tape at Saturn's orbit and then crease the paper into an even fold. Have them label this crease "Jupiter."
9. Have students place the Sun at Jupiter's orbit and then crease the tape into an even fold. Ask students what region is inside Jupiter's orbit. Have them label the crease "Asteroid Belt."
10. Have students place the Sun at the Asteroid Belt and then crease the tape into an even fold. Have them label this crease "Mars."
11. Have students fold the Sun to meet Mars's orbit, crease it, and then fold it again. Unfold the tape, and you should have three creases, for Mercury, Venus, and Earth, in that order from the Sun.
12. Have students unfold their tape and compare this Solar System to their original model on the opposite side.

QUESTIONS FOR STUDENTS

1. For the scale of the Solar System on this tape, where would the nearest star be? (Answer: About 6 miles away.)
2. For this scale, how big would the Sun and planets be? (Answer: The Sun would be smaller than a grain of sand—about the size of the period at the end of this sentence. You couldn't see any of the planets without a strong magnifying glass!)
3. As you traveled from Mars to Jupiter, how likely is it that you would collide with an asteroid? (Answer: Very unlikely.)
4. How fast does light travel on this scale? (Answer: About 11 meters per hour or 0.007 miles per hour.)
5. If you were an alien flying through our Solar System, how likely is it that you would accidentally hit a planet? (Answer: Very unlikely.)

LECTURE NOTES

SLIDE 2: WHAT IS MODERN ASTRONOMY?

- In this chapter, we will discuss what science is and how it works. We'll also mention a few results of scientific inquiry. Modern science has revealed our place in the universe—and it is not a very special place.
- The science of **astronomy** not only catalogs the inventory of the universe, but also tries to understand how the universe and all of its parts work, as well as what the universe is.
- **Astronomy** is the science of the exploration of the universe. The universe is the total of all things we can observe, either now or in the future. The universe contains matter and energy. Matter is what ordinary material substances are made of. In addition, the universe also contains more mysterious forms of matter that we only partly understand. Energy comes in many different forms—especially light—but energy is also contained in atoms, planets, stars, and galaxies.
- It is important for students to begin to realize what they themselves can study of the universe from Earth, as well as how astronomers can study the universe in general.

SLIDE 3: OUR PLACE IN THE UNIVERSE

- Earth is a small planet. Many other planets we know about—either in our Solar System or around other stars—are far larger than Earth.
- Earth orbits a medium-sized star called the Sun. There are some stars that are larger than the Sun and some that are smaller.
- The Sun is one of about 100 billion stars in a flattened, disk-shaped collection of stars called the Milky Way Galaxy. The Sun is located about halfway between the center of the galaxy and its edge. The Milky Way is a relatively large galaxy, though some galaxies are far larger.
- At least 100 billion galaxies are visible in our universe. Even the nearest ones are located at great distances from Earth. The entire universe is a vast extent of space. The universe contains vast amounts of matter and energy, the majority of which does not emit light.
- The age of the universe is approximately 13.7 billion years.

SLIDES 4–5: THE SPEED OF LIGHT AND A LIGHT-YEAR

- One way to appreciate large distances and long times is to use the travel time of light. We can express distances in terms of the amount of time it takes for light to go from one place to another.
- In everyday language, we often use times to specify distances. We do this most often when we talk about traveling. We can say that a friend's house is two hours away. In saying this, both the speaker and the listener know that they are talking about travel by car or by plane, for example. In astronomy, the **speed** of light is the appropriate speed for expressing distances.
- It is important for students to realize this connection, and that it is not appropriate to use familiar units like miles or kilometers.
- Light travels very fast. Its speed is 300,000 kilometers/second (or, in scientific notation, 3×10^5 km/s), which is the greatest speed in the universe. However, it is a finite speed. Due to this finite speed, light takes time to get from place to place.
- Many people know about the light-year, which is the distance that light travels in 1 year.

- Light can travel all the way around Earth in one-seventh of a second, about as long as it takes to snap your fingers.

SLIDES 6–7: LIGHT TRAVEL TIMES

- Even at its very high speed, light takes 1¼ seconds to reach Earth from the Moon.
- The Sun is much farther away from Earth than the Moon is. It takes 8.3 minutes for sunlight to arrive from the Sun. We therefore say that the Sun is 8.3 light-minutes away from Earth (about 150 million kilometers).
- The outer planets in the Solar System are much farther away from the Sun. Sunlight takes 8.3 hours to get to Neptune. This is about 60 times longer than it takes to reach Earth.
- Even the most distant objects in our Solar System are very close compared to the stars. Light takes 4.2 *years* to reach Earth from even the nearest star. The closest stars are about 300,000 times more distant from Earth than the Sun is.
- Light takes about 100,000 years to cross the Milky Way Galaxy. Now we are entering a domain in which the light travel times themselves are very large numbers.
- The nearest big galaxy to the Milky Way is called Andromeda. It is 2.5 million light-years away, meaning that the light we see from that galaxy took 2.5 million years to arrive on Earth.
- The most distant galaxies are incredibly distant. Their light is now arriving after 10 billion years of transit.

SLIDES 8–9: WHY STUDY THE UNIVERSE? WE ARE STARDUST

- Earth and all it contains are a part of the universe. Many connections between Earth and space have been uncovered by astronomical studies. One fascinating connection is between the material in our bodies and the energy production in stars.
- Our bodies contain many different types of atoms—hydrogen, oxygen, carbon, calcium, iron, and others. These make up our bones, flesh, blood, and so on. Except for the hydrogen in the water (H_2O) that our bodies contain, all the atoms were made in stars that lived their lives long ago. The event of the **Big Bang** could not have created all these more complex elements.
- Stars generate energy by making heavier elements out of lighter ones. The Sun shines because it is combining hydrogen, the lightest element of all, into helium. These new, heavy elements may be ejected into space when the star dies. Sometimes stars die quietly, while at other times they die in gigantic explosions. Many atoms are formed during the lifetime of the star, while others are made in the explosion itself.
- The newly formed atoms are ejected into space and mix with material that is already present.
- New stars and planets (including life on these planets) form from material that includes atoms made by older stars. We are literally stardust!
- This is a great motivation to study the universe, since humans are products of it.

SLIDE 10: ASTRONOMY IS AN EXPLORATION

- Astronomy is one of the physical sciences. One key aspect of science is that scientific ideas are tested by observations. Astronomers make observations about the universe using tools that are both on the ground on Earth and also out in space.
- Space exploration has also expanded our view of the various planets and other bodies in our Solar System. In a few cases, humans have traveled to Earth's orbit or to the Moon. Most of the exploration has been done with robotic spacecraft.
- Astronomers use telescopes on the ground and satellites in space to extend our observations to regions beyond ordinary human experience. We can explore objects that are very large, very distant, or emit light our eyes cannot see. This gives us the experience we need to test our ideas about the universe.

SLIDE 11: SCIENTIFIC INVESTIGATION

- Scientific understandings go through a progression. First, they begin simply as ideas. Once an idea is well-formulated, it becomes a **hypothesis**.
- This hypothesis must be analyzed and tested. Tests can disprove the hypothesis and any predictions it can make. Once tests continually fail to disprove a hypothesis, it becomes a **theory**. This new status does not mean that it has been "written in stone." It has become more accepted as a truth, but is not an undisputed fact. Its predictions must still be tested, and must still be correct.
- If a theory has been well tested and has proven itself many, many times, and if its predictions are continually verified, it can become a **physical law**. Such an idea most likely has a fundamental importance, with predictions and implications concerning many phenomena. An example of this would be gravity.

SLIDES 12–13: AN IMPORTANT ASSUMPTION

- There is a key assumption that scientists make when studying nature, called the **cosmological principle**. It states that there is nothing special about our place in the universe. Naturally, Earth has some things that are unique about it, but we assume we are in a position to learn about nature and that what we learn here is true everywhere. This assumption allows the scientific method to be applied to the larger scheme of the universe.

- There are two levels to the cosmological principle. On the first, we assume that the details we see around us are typical.
  - We assume that our view from Earth is not special or unique. We assume that we are not in some special part of the universe where the workings of nature are different from other places.
  - We assume that distant objects in space are like the ones that are closer to us. We can therefore study the latter in detail and learn about faraway objects.
- Generally, the cosmological principle assumes that matter and energy obey the same physical laws everywhere. Gravity on Earth should be the same gravity that causes the Moon to orbit Earth and the planets to orbit the Sun. Nitrogen in our atmosphere has the same atomic structure as the nitrogen in extremely distant quasars.

SLIDE 14: SCIENCE IS A PROCESS

- We often think of the products of **science**, but science is principally a process. It is a way of asking questions and creating explanations about nature.
- All sciences use basically the same methods to study **nature**. The principal methods of science are captured in the idea of the **scientific method**:
  - Ideas must be tested—they should not just remain ideas. These tests come from observations or from computations. One of the key goals of science is to come up with good tests for our ideas.
  - The tests are mainly designed to *falsify* ideas. This is an extremely important concept! Science is about rejecting ideas that do not work or are not useful. For example, we might suggest the Sun shines because it is made of burning coal. Observations, however, show that the Sun is not made of coal and that its energy does not come from oxidation (burning). Our idea is rejected. Our tests can *support* our ideas, but never prove them.
  - The scientific method is also a cyclical process. Once an **idea** is made, a **hypothesis** formed, and a **prediction** made, a test must be done. If the test rejects the idea, the process must start over.

SLIDE 15: SCIENCE MUST BE TESTED

- All scientific ideas, even those with strong support, are provisional. New and better ideas may come along, or better observations may cause us to reject our current ideas. That all knowledge is provisional does *not* mean that all ideas are equally valid. Many ideologies (astrology, for example) have already been rejected many times by observations.
- For a theory to be given serious scientific consideration, it *must be falsifiable*. There must be some way to use the scientific method to try to disprove the theory. Through this, new (and old) ideas can be checked for validity, allowing science to progress.

SLIDES 16–17: SCIENTIFIC REVOLUTIONS

- Recall that one main goal of science is to falsify and reject ideas. This is true even for ideas that have been around a long time and are widely held by many people. Scientific ideas are vulnerable to scrutiny—and that helps give science its credibility.
- Existing ideas must constantly be held in check by the scientific method. New scientific ideas require support from evidence given by nature or calculations. Scientists spend a lot of time developing supporting arguments for their ideas. If there is enough support for the new ideas, then previously held concepts have to be rejected.
- New evidence can arise, better theories can be invented, and in fact, major overhauls can completely change human understanding. This has happened many times in the history of science. The most famous example is when Newton established a very successful set of rules for gravity and mechanics; later, Einstein proved Newton's laws are incomplete because they donít apply to objects that are moving fast or have very strong gravity (special and general relativity).
- Who decides what ideas are right and wrong? Nature does! Ideally, our observations guide us, not any special imposed authority.

SLIDES 18–19: SCIENCE, PATTERNS, AND MATHEMATICS

- Science tries to discover patterns and rhythms in nature.
- Most natural phenomena work regularly and predictably. Gravity does not change its strength from day to day, nor does it work for some objects and not for others. It is this regularity that allows us to learn about nature.
- The constellations and seasons are regular patterns familiar to many people.
- One aspect of science is that it is intimately coupled with mathematics. This can be scary to many students. Mathematics, generally, is the language of patterns that are often applied to numbers.
- Mathematics and science work together because mathematics works when it is used to describe nature and the patterns we see. The seasons repeat with predictable frequency. We can find distant asteroids and compute their future orbits to check whether they might collide with Earth. We are confident that if we do the job right our predictions will be correct.

SLIDE 20: THINK LIKE AN ASTRONOMER

- This class will challenge the students to think in different ways, but in so doing they join the many humans over the ages who have tried to make sense of our place in the universe.

- The students should:
  - Read the text actively, and try to visualize the concepts. Visualizations (drawings, photos, graphs, etc.) are very helpful tools in understanding science.
  - Ask "What if?" to go beyond the material and to better understand it. What if Earth were farther from the Sun? What if the Sun did not exist?
  - Talk to others, share ideas. Trying to explain something to a friend shows you just how much you know of a subject.
  - Do not be afraid of the math. The instructor should speak about what the math means whenever it is being used, being sure to make it relevant. In line with this textbook's philosophy, it is most important to talk about the mathematical concepts and the meaning behind mathematical relationships, rather than mathematical techniques.

SLIDE 21: CONCEPT QUIZ—ASTROLOGY AS SCIENCE

- This quiz requires the students to reflect on the characteristics of science and apply them to astrology. It does not matter whether they know anything about astrology. The idea is *if* they find that statements A, B, or C hold, would they conclude that astrology is or is not a science?
- The correct answer is D. If it can be shown that any of the other statements is correct, then we would conclude that astrology does not work the same way that science does. Note that this is independent of whether astrological explanations are valid or not. It is a statement about how astrology works.

SLIDE 22: CONCEPT QUIZ—PRINCIPLES

- This quiz asks the students to reflect on the cosmological principle and to see how other statements compare to it.
- The correct answer is B. We assume that the laws of physics are the same in all places.
- Option A is incorrect because the universe does not have to be the same everywhere, meaning that conditions are everywhere identical. This is a subtle point for many students, and it would be worthwhile to spend some time distinguishing this answer from B.

SLIDE 23: CONCEPT QUIZ—WORLDVIEW

- The question asks the student to compare different statements and determine which ones are consistent with the characteristics of science outlined in this chapter.
- The correct answer is C. This is one of the key features of science.
- Option A is incorrect, because it flatly contradicts C. Nature is the arbiter of science.
- Option B is incorrect because science is (or should) question even well-established ideas.

END-OF-CHAPTER SOLUTIONS

Evaluating the News

1. When Pluto was first discovered, astronomers called it a "planet" because it orbited the sun. But as more information was obtained, we realized that it did not share many common characteristics with the other planets (i.e., its size, mass, and the shape of its orbit). We didn't classify Ceres as a planet, even though it has a mass similar to Pluto's, since we knew early on that it was really just a large asteroid. However, as we discovered more Pluto-sized objects, we had to decide whether to keep increasing and changing the number of planets or accept that these really belonged to a different group of objects. Pluto didn't change, but our understanding of it did, and we realized that our initial categorization of Pluto as a planet had to be reevaluated.
2. Science is not a belief system, but a process of skepticism and testing that leads us to constantly reevaluate what we know (or think we know) as new discoveries are made and predictions are investigated. When we find that long-held ideas are wrong, it may be difficult to let them go or it may take a long time to accept change, but science follows data, not faith. Dr. Brown was referring to this when he discussed "strong emotions" (i.e., we all grew up knowing Pluto was a planet and naturally wanted to keep it that way).
3. We constantly reclassify things, but they generally receive little public attention. Two examples from biology are the duck-billed platypus and the colugo, both of which are sufficiently strange that they didn't fit into common biological classifications (Kingdom, Phylum, Class, etc.) and eventually needed new classifications of their own.
4. Suppose we call all Pluto-like things a planet. Many astronomers are constantly searching the skies for new objects orbiting the sun, so while today there might be 12 "planets," each year we will probably add one or two more. In a few years there might be 20 planets, or 200, or more! The list will just keep growing. If nothing else, this is very impractical, especially considering that small, cold, dead moon-sized objects will dominate the list. As you will learn in later chapters, these will not teach us much about

the formation of our Solar System compared to Jupiter- and Earth-like planets.

5. The scientific method makes a prediction, tests it, and evaluates the prediction based on the results. Consider Ceres: it was predicted to be a planet until astronomers discovered that it was just one example of a huge sea of similar objects. The test failed because no other planet is part of a belt of similar objects. Thus, Ceres was demoted. Essentially the same thing happened with Pluto, except the test involved mass.

Summary Self-Test

1. **Its age**. Figure 1.2 shows that "the age of the observable universe is like three times the age of the Earth."
2. **b, d, a, c, e**. You have to make the material to form the sun before you can make the sun. You have to make gas first (B), then make stars to make heavier elements (D), then the stars blow up to spread those elements around (A), and then the gas has to collect (C), all before you can form the sun and planets (E).
3. **Falsify**. The scientific method involves skepticism and testing, and you can only test something that could be proven wrong.
4. **(b)** Summary point 1.2 explains that "we know we understand when we find the underlying connections that allow us to predict the results of new observations."
5. **(c)** Our explanation and understanding of the universe would not be very useful if things only applied here on Earth.
6. **Mathematics**. Mathematics gives us the tools to make predictions, and as we have learned, predicting is part of the scientific process.

Questions and Problems: True/False and Multiple Choice

7. **False:** You can test a theory, but you can't prove it is true because another piece of evidence could come along and prove it wrong. All you can do is disprove something.
8. **True:** We build our understanding by watching and explaining patterns.
9. **False:** A theory is "a carefully constructed proposition . . . of how the world works." It is never a guess.
10. **False:** Scientists never stop testing a theory, since it is just our best explanation at the time. A better one can always come along!
11. **True:** Astronomers use a variety of scientific instruments that are used in many different fields beyond astronomy.
12. **(c)** A galaxy is full of stars, and our Solar System only has one star (the Sun).
13. **(d)** The Sun is the center of our Solar System, just one of the billions of stars in our galaxy, which is one of the billions of galaxies in the universe.
14. **(a)** It is the distance that light travels in one year.
15. **(d)** The big bang made mostly hydrogen and helium and a very small amount of lithium.
16. **(c)** This is a just a restatement.

Conceptual Questions

17. Zorg, Alpha Centauri, Milky Way Galaxy, Local Group, Virgo Supercluster.
18. Answers will look like Figure 1.1, with Earth replaced by Zorg and the Solar System replaced by Alpha Centauri.
19. Answers will vary. For example, the distance from the Sun to Neptune is about the time needed to fly from New York City to London.
20. 8.5 minutes. This is the amount of time it takes for light that leaves the Sun to reach us.
21. 2.5 million years. This is the amount of time it takes for light that leaves Andromeda to reach us.
22. Only hydrogen and helium (with perhaps a trace amount of lithium) were created in the Big Bang. Heavier elements like carbon, oxygen, nitrogen, and iron 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 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.
23. Erich von Daniken's theory is a pseudoscientific 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 I can think of to refute the hypothesis are (1) to demonstrate that every piece of technology and archaeological monument could have been reasonably constructed with human knowledge of the time, or (2) to invent a time machine and return to the most likely times for aliens

to have visited Earth. Because option 2 is utterly implausible, and since option 1 does not preclude alien visitations, it is impossible to falsify the hypothesis.

24. *Falsifiable* means that something can be tested and shown to be false/incorrect through an experiment or observation. Some examples of nonfalsifiable ideas might include religious beliefs (such as Jesus is Messiah), political views (such as less government is better), and emotional statements (such as love conquers all). Students may have a wide variety of these and other ideas; but all sacred cows are usually considered to be nonfalsifiable by the people holding those beliefs. Falsifiable ideas include cause and effect (coffee puts hair on your chest) and logic (if I drink coffee I will not sleep tonight).
25. A *theory* is generally understood to mean an idea a person has, whether or not there is any proof, evidence, or way to test it. A *scientific theory* is an explanation for an occurrence in nature, must be based on observations and data, and must make testable predictions.
26. A *hypothesis* is an idea that might explain some physical occurrence. A *theory* is a hypothesis that has been rigorously tested.
27. This suggests to me that one of the fields has an incorrect theory, basis, or understanding, and the two fields need to be carefully considered to reconcile this discrepancy.
28. (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.
29. 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 grows.
30. Answers will vary. Depending upon 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 of 12 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 horoscope would match the person's astrological sign; and 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.
31. Taken at face value, this is a ridiculous statement; but there are several items to consider critically before we apply a label of "nonreputable." 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.
32. Some scientific fields rely heavily on math while others hardly use it at all. The use of mathematics is not the hallmark of good science. Rather, good science involves following the scientific method, which astrology does not employ.
33. The cosmological principle essentially states that the universe will look the same to every observer inside it.
34. Answers will vary. Almost everyone has a set of routines that can be listed here. As creatures of habit, humans tend to find comfort in routines; and they can often be disturbed to some degree by changes or interruptions in those patterns. Patterns of your own making are habits, both good and bad. Patterns imposed by others might be the daily routine of work, laws that must be obeyed, and monthly bills that must be paid. Patterns imposed by nature might include your circadian rhythm, seasonal changes in the weather, and annual cycles in agriculture.
35. Answers will vary considerably. A few arguments for the reclassification are that Pluto's size and mass were not known when it was discovered, that our understanding of "planethood" has changed as we have discovered extra-solar systems, that Pluto is just one example of a larger class of objects that we are finally now observing. A few arguments against are that Pluto has been a planet for so much of our history that we should not change it, that it is much closer to the sun than many other trans-neptunian

objects (TNOs), or that we do not want to confuse children who are just learning this material. It is pretty clear that the pro reasons are scientific in merit and the con reasons are emotional.

36. Einstein did not prove Newton wrong; he simply developed a theory that is more generally complete than Newton's. Science proceeds through discovering ever better approximations to nature's behavior. Newton's theories work in the part of nature we can experience with our senses. Einstein's theories work in a part of nature that is more difficult for us to experience. All of Einstein's predictions reduce to Newton's predictions in the regime of low mass and low speeds.
37. Answers will vary and must be considered on an individual basis.
38. My cartoon would be a stick figure with a huge gaping wide mouth and a text blurb that only says "Wow . . .!"
39. Answers will vary.
40. (a) This claim does not make sense to me. (b) It is certainly falsifiable. (c) It took a few hours more for the hot tray to freeze.

Problems

41. **Setup:** Come up with an estimate for how many galaxies are in the Local Group, and how many stars are in our galaxy. The book says there are several hundred billion stars in our galaxy, and our Local Group is dominated by the Milky Way.
Solve: There are two main galaxies, each containing some 300 to 500 billion stars, so the total is about 600 billion to 1 trillion stars.
Review: Carl Sagan would always say there are "billions and billions of stars" so we seem to be on the right path.
42. **Setup:** Let's choose Smallville and Metropolis, separated by 60 miles, and Clark and Lois's houses, separated by about 10 blocks. Then we will convert between distance, rate, and time with distance = rate times time or $d = vt$.
Solve: If I travel 60 miles per hour, then the distance from Smallville to Metropolis is 60 miles or 1 hour. I walk a block in about 2 minutes, so since there are 10 blocks from Clark Street to Lois Street, it will take about 20 minutes to walk. Or if I call the time to walk a block a "timeblock," then it takes me 10 timeblocks.
Review: One timeblock is 2 minutes, so 10 timeblocks are 20 minutes, which I originally found.
43. **Setup:** We need our assumptions of speed. Let's say a car goes 50 miles per hour if we include filling up with gas, eating, and restroom breaks. On foot, a person walks about 2 miles per hour with these same stops. 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, $t = 2{,}444\text{ mi}/50\text{ mph} = 48.9$ hours and by foot, it will take 25 times longer or 1,222 hours. Since there are 24 hours in a day, the car takes $48.9/24 = 2.04$ days, while by foot it takes 50.9 days. Note these assume you travel around the clock, which we don't usually do!
Review: In car hours, it would take 48.9 hours or 48.9 car hours. This is close to 48 hours or 2 car-days. By foot, it would take 1,222 foot-hours or 51 foot-days. There are 30 days in a month so this is $51/30 = 1.70$ foot-months. There are 12 months in a year so this would take $1.70/12 = 0.14$ foot-years.
44. **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 minutes to reach earth, then it takes $8 \times 2 = 16$ minutes to go twice as far. Pluto is 40 times further from the sun so light takes $8 \times 40 = 320$ minutes, or $320/60 = 5.33$ hours. (b) This means that sharing two sentences will take half a day, so it would take a few days just to say hello and talk about the weather.
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. Since Pluto is much farther than Jupiter, it stands to reason that it would take light and communication a lot longer still!
45. **Setup:** First we need the numeric values, then we need to count the digits. Figure 1.2 gives 100,000 years for the galaxy and 2.5 million years for the Milky Way to Andromeda.
Solve: There are 5 zeroes in 100,000, so it would take 10^5 years for light to cross the galaxy. There are 6 zeroes in a million (1,000,000), so it would take 2.5×10^6 years for light to reach the Andromeda Galaxy from here.
Review: If you compare these to Working It Out 1.1 you will see that we followed the right procedure.
46. **Setup:** We need to know the distance to Andromeda in light-years, and how many kilometers and miles are in a light-year. Using this chapter, there are 2.5 million light-years to Andromeda, and using the

Appendix, I know there are 9.5 trillion kilometers in a light-year, and 1.6 kilometers in a mile.

Solve: $2.5 \times 10^6\text{ ly} \times \frac{9.5 \times 10^{12}\text{ km}}{\text{ly}} = 2.4 \times 10^{19}\text{ km}$ or 240,000,000,000,000,000,000 km. To convert to miles, $2.4 \times 10^{19}\text{ km} \times \frac{\text{mile}}{1.6\text{ km}} = 1.5 \times 10^{19}$ miles.

Review: We can see why we use scientific notation and light-years, since there are a *lot* of zeroes there. Does this make sense? The distance to the sun is 93 million miles or 8 light-minutes. So a light-year is much larger, and the distance to Andromeda is many millions, therefore we expect the distance to be huge!

47. **Setup:** We need to know the size of the galaxy in light-years (100,000 from Figure 1.2) and the number of miles in a light-year (5.9 trillion miles).
Solve: Convert $10^5\text{ ly} \times \frac{5.9 \times 10^{12}\text{ mi}}{\text{ly}} = 5.9 \times 10^{17}$ miles.
Review: This is 590 quadrillion miles. Honestly, that is too big for me to imagine!

48. **Setup:** This is all about unit conversion so let's make sure we know our conversion factors. There are 60 seconds in a minute and 60 minutes in an hour. The distance to the Moon is about 1.25 light-seconds, to the Sun is 8.3 light-minutes, and 8.3 light-hours to Neptune, using Figure 1.2.
Solve: If 10 millimeters (mm) equals 1 light-minute and there are 60 seconds in a minute, then using ratios, we can find how many millimeters are in a light-second. 1 light-second $= \frac{10\text{ mm}}{60} = \frac{1}{6}$ mm. There are 60 minutes in an hour so 1 light-hour $=$ 10 mm $\times 60 = 600$ mm or 0.6 meters. The Moon is 1.25 light-seconds away, or $1.25 \times \frac{1}{6}\text{ mm} =$ 0.288 mm away. Neptune is 8.3 light-hours from Earth, or $8.3 \times 0.6 = 4.98$ away.
Review: The Moon would be about the width of a hair away, while Neptune would be about 15 feet away. It just shows how close the Moon is and how much empty space there is in our Solar System!

49. **Setup:** This is another exercise in unit conversion. There are 60 minutes in an hour, 24 hours in a day and 365 days in a year. The nearest star is about 3 light-years away and Andromeda is 2.5 million light-years.
Solve: The number of minutes in a year is $1\text{ yr} \times \frac{365\text{ days}}{\text{yr}} \times \frac{24\text{ hrs}}{\text{day}} \times \frac{60\text{ min}}{\text{hr}} = 5.25 \times 10^5$ min. The scale in Problem 48 is 1 light-minute equals 10 millimeters so in this case, 1 light-year equals 5.25×10^6 mm or, using the conversion factors provided in the problem, 5.25 kilometers. This means that on this scale, the nearest star would be about $5.25 \times 3 = 15.75$ km, and Andromeda would be $2.5 \times 10^6\text{ ly} \times \frac{5.25\text{ km}}{\text{ly}} = 1.3 \times 10^7$ km.
Review: If 5.25 kilometers is about 3.3 miles, the nearest star would be about 10 miles away and Andromeda would be about 8 million miles away (over 20 times farther than the moon!).

50. **Setup:** In this problem we will convert between distance, rate and time with $d = vt$ or, solving for time, $t = d/v$. The problem is straightforward since the units of distance are already the same.
Solve: $t = \frac{d}{v} = \frac{384{,}000\text{ km}}{800\text{ km/hr}} = 480$ hr. There are 24 hours in a day, so this would take 480 hr $\times \frac{\text{day}}{24\text{ hr}} = 20$ days or about 2/3 of a month (a typical month is 30 days).
Review: A typical flight from New York to London takes about 7 hours and covers a distance of about 6,000 kilometers. The moon is 64 times farther away, so it would take about $64 \times 7 = 448$ hours to reach the moon using these estimates. This is about the same amount of time as we found by exactly solving the problem.

51. **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 since the units of distance are already the same.
Solve: $v = \frac{d}{t} = \frac{384{,}000\text{ km}}{3\text{ days}} \times \frac{\text{day}}{24\text{ hrs}} = 5{,}333$ km/hr. This is about $\frac{5{,}333}{800} \approx 6.7$ times faster than a jet plane.
Review: Using the result from Problem 51, we have to travel $20/3 \approx 6.7$ times faster than a jet plane, which agrees with our solution.

52. **Setup:** As a rough estimate, 1 meter is 1 yard or, since there are 3 feet in 1 yard, 1 foot is about 0.33 meters.
Solve: Example: Someone who is 5′6″ is 5.5 feet or $5.5\text{ ft} \times \frac{0.33\text{ m}}{\text{ft}} \approx 1.8$ m.
Review: The height of an average person is 5 to 6 feet or about 1.5 to 2 meters.

53. **Setup:** This is an exercise in metric conversion. Note that 1 micrometer is 10^{-6} m and 1 nanometer is 10^{-9} m.
Solve: $1\ \mu\text{m} \times \frac{10^{-6}\text{ m}}{1\ \mu\text{m}} \times \frac{\text{nm}}{10^{-9}\text{ m}} = 1000$ nm.
Review: The solution is done longhand, but comparing the metric values in the setup, one sees there are 10^3 nm in a micron.

54. **Setup:** This is a longer exercise in unit conversion. There are 100 centimeters in a meter, 1,000 meters in a kilometer, and 1.6 kilometers in 1 mile.
Solve: $1\text{ mi} \times \frac{1.6\text{ km}}{\text{mi}} \times \frac{1{,}000\text{ m}}{\text{km}} \times \frac{100\text{ cm}}{\text{m}} =$ 160,000 cm.
Review: Using metric values, there are 10^5 centimeters in a kilometer, so there are 1.6×10^5 cm in a mile, as found above.

55. **Setup:** Remember that scientific notation counts how far the decimal has to move to the right or left so there is one non-zero digit left of the decimal.
Solve: 86,400 → 8.64×10^4 and 0.0123 → 1.23×10^{-2}
Review: A student can try typing these into a calculator where "×10" is replaced by the "E" or "EE" button, to verify the conversion.
56. **Setup:** Remember that scientific notation counts how far the decimal has to move to the right or left so there is one non-zero digit to the left of the decimal.
Solve: 1.60934×10^3 → 1609.34 and 9.154×10^{-3} → 0.009154
Review: A student can try typing these into a calculator where "×10" is replaced by the "E" or "EE" button, to verify the conversion.
57. **Setup:** We will use the equation $d = vt$, where the distance is $2 \cdot 3.6 \times 10^7$ m and light travels at $v = c = 3 \times 10^8$ m/s.
Solve: $t = \frac{d}{c} = \frac{2 \times 3.6 \times 10^7 \text{ m}}{3 \times 10^8 \text{ m/s}} = 0.24$ s or about ¼ a second.
Review: If we are receiving information by 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).

Exploration

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

CHAPTER TWO

Patterns in the Sky—Motions of Earth

SUMMARY

For thousands of years humans ignored the fact that they are moving at incredibly fast speeds through the vastness of space. The geocentric model came to an abrupt end when the telescope was invented and careful observations led to the modern view of our place in the universe. Scientific knowledge is often counterintuitive, and traditional beliefs cling to our daily lives even long after they are shown not to be well founded. We still talk about sunrise and sunset as if they were caused by the Sun moving and not us. Our clocks still turn in the opposite direction of Earth's rotation as if they were tracking the motion of the heavens instead of our own. The contents of this chapter are fundamental to orient ourselves by linking common phenomena to our place in the universe. It paves the way to understanding how the basic laws of physics are pulling the strings of the play that we see in the heavens, and it helps to make us feel how we are connected with the cosmos. Because this chapter is so fundamental, the instructor should allow for sufficient time to make sure that the concepts are cemented in the minds of the students. This chapter could easily be the one that requires the longest amount of time so that it can be covered at a pace so slow that students feel comfortable with these basic astronomical concepts. Other chapters can be covered at a faster pace, but out of everything that students will learn in the whole course that can be of practical use for the rest of their lives the contents of this chapter are most relevant.

Since Earth has sufficient mass to have a shape close to a sphere, it is useful to introduce the concept of the celestial sphere to locate the objects in the sky and to visualize their motions. In this imaginary sphere, the celestial poles and the celestial equator are defined as infinite projections of Earth's poles and equator. Associated with this spherical frame of reference are the meridian line, the zenith point, and the altitude of celestial objects, which are very useful astronomical concepts to orient ourselves with respect to the sky. The first applications of the celestial sphere are the descriptions of what happens if we watch the sky from the North or South Poles. More generally, the understanding of how the view of the sky changes with the position of the observer on Earth calls for examples of the interplay between latitude and the directions of the celestial equator and poles. Numerous figures and pictures are provided to show different perspectives from a variety of viewpoints. They are necessary because this is a fundamental topic for the students to grasp.

Another connection between us and the sky is the astronomical explanation of the seasonal changes in climate at different locations on Earth. Students will be thrilled to learn about the ecliptic plane and the zodiac in a way that also provides them with a deep understanding of why the weather is always chilly in winter in Chicago, but at the same time it is hot in Buenos Aires because it is summertime over there. Four special days in the calendar, namely the equinoxes and the solstices, mark the transitions from one season to another, and they are connected with festivities in many countries, indicating that those days have been identified to be important by ancient cultures. In fact, our whole calendar is a system that is precisely tuned to keep the months of the years and the seasons well synchronized. After the two main motions of Earth, rotation around its axis, which is tilted with respect to its revolution around the Sun, have been described and the students have become familiar with their effects on our views of the sky, it will be time to talk about a secondary motion of our planet, that is, the wobble that causes long-term periodic shifts of the celestial poles, a phenomenon known as the precession of the equinoxes.

When the motions of our home planet across interplanetary space have thoroughly been explained, it is time to look at our only natural satellite, the Moon. Most students will have noticed from their own experience that the shape of the illuminated portion of the Moon changes with a regular pattern. They are likely to eagerly learn the elegant explanation for the lunar phases in terms of the relative positions of the Moon, Earth, and the Sun. Sometimes these three objects align themselves to produce a variety of spectacular shadows that are classified as different types of eclipses. Ask if any of the students has witnessed some sort of eclipse (and almost certainly some of them have because lunar eclipses are easier to see than solar ones). They will want to understand why the Moon does not completely vanish during a total lunar eclipse.

Going beyond the Moon takes the students to look at the motions of the main planets in the Solar System, which are governed by Kepler's laws in a heliocentric framework. The beauty of these laws lies in the fact that they are simple and

yet have a wide range of applicability. These laws are still used in modern studies for stellar binaries and exoplanetary systems. They indicate that we live in a planetary system that is in equilibrium, which is very likely a necessary condition for us to be here.

DISCUSSION POINTS

- Apply the dependence of the perspective on the sky shown in Figure 2.6 to the location of the classroom. Engage students coming from other countries or states to discuss the perspective on the sky from their birthplaces. Make them realize that these perspectives are similar for places with similar latitudes even though they may be very far apart because the perspective does not change with longitude. 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? Discuss how it all depends on the altitude of the Sun.
- Focus on the equations on page 32 where the rotation speed of Earth is worked out. Ask the students to convert it to miles per hour. How does it compare with the speed of commercial air jets? How long would it take to travel from London to New York if we could just lift ourselves from Earth's attraction and let it rotate below us before coming back down?
- Manipulate the equations to find out the speed at which the Moon revolves around Earth and the speed at which Earth revolves around the Sun. Discuss how is it possible that even though those velocities are very high, we do not feel them at all.
- Figure 2.14 shows the brightest stars around the north ecliptic pole. The current celestial north pole is marked, and it lies very close to the North Pole star, Polaris. To familiarize the students with the night sky discuss how to identify Polaris from the location of your classroom. Have the students determine the maximum southern latitude from which Polaris can still be seen. Have them identify for themselves the star or asterism that can play a similar role for finding the celestial south pole.
- Figures 2.19 through 2.23 provide spectacular pictures and pedagogical graphics of eclipses. To test that students have mastered the understanding of eclipses, discuss a limiting case: What would happen if Earth's rotation rate and the Moon's revolution rate were perfectly synchronized? What about if the apparent size of the Moon were double that of the Sun? Half that of the Sun?
- Figures 2.26 through 2.29 illustrate Kepler's three laws of planetary motion. Demonstrate that Kepler's laws are universal by applying them to other solar systems where several exoplanets have been found. Use the data from http://exoplanet.eu.

ASTROTOUR ANIMATIONS

The following AstroTour animations are referenced in Chapter 2 and are available from the free StudySpace student website (http://wwnorton.com/studyspace). These animations are also integrated into assignable Smartwork online homework exercises (http://wwnorton.com/smartwork).

THE EARTH SPINS AND REVOLVES

This animation shows Earth as it is positioned with respect to the Sun, including motion along its orbit, spin axis tilt, and discussion of the causes for the seasonal variation in climate in terms of latitude and angle of incident sunlight.

- 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: Section 2.1

THE CELESTIAL SPHERE AND THE ECLIPTIC

This animation shows side-by-side perspectives of (1) the view of the sky (day and night) from a backyard and (2) an "outside" view of Earth embedded in a concentric celestial sphere. The point of view moves with Earth as it rotates on its axis. The content of the animation focuses on the ecliptic, showing the motion of the Sun, Moon, and constellations in relation to one another.

- Text reference: Section 2.1

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 Earth Spins and Revolves" and "The Celestial Sphere and the Ecliptic"). 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 showing the relative configurations of Earth, Moon, and Sun.

- Text reference: Sections 2.3 and 2.4

KEPLER'S LAWS

This animation of Kepler's three laws contrasts Earth's orbit with that of other bodies in the Solar System. Using slightly eccentric (Mars) and extremely eccentric (Comet Halley) orbits for comparison, the three laws are illustrated showing (1) the difference between an elliptical and

near-circular orbit, (2) changes in speed as an object moves along its orbit, and (3) how period changes with larger semimajor axes.
► Text reference: Section 2.5

INTERACTIVE SIMULATIONS

Developed at the University of Nebraska–Lincoln, these Interactive Simulations enable students to manipulate variables and work toward understanding physical concepts presented in Chapter 2. All simulations are available on the free StudySpace student website (http://wwnorton.com/studyspace) and offline versions can be found on the Instructor's Resource Disc.

CELESTIAL AND HORIZONS SYSTEMS COMPARISON

This simulation demonstrates how the celestial sphere and horizon diagram are related.
► Text reference: Section 2.1

MERIDIONAL ALTITUDE SIMULATOR

This simulation shows helpful diagrams for finding the meridional altitude of an object.
► Text reference: Section 2.1

PATH OF THE SUN DEMONSTRATOR

This simulation shows how the declination of the Sun varies over the course of a year using a horizon diagram.
► Text reference: Section 2.2

SUN'S RAYS SIMULATOR

This simulation shows the angles at which the Sun's rays hit different parts of Earth at different times of the year.
► Text reference: Section 2.2

ZODIAC SIMULATOR

This simulation shows the position of the Sun in the zodiac in different months of the year.
► Text reference: Section 2.2

LUNAR PHASE SIMULATOR

This simulation shows how the Moon's orbit around Earth results in the different phases.
► Text reference: Section 2.3

MOON PHASES AND THE HORIZON DIAGRAM

This simulation correlates the phases of the Moon with its positions in the sky.
► Text reference: Section 2.3

ECLIPSE SHADOW DEMONSTRATOR

This simulation shows the shadows cast by the Moon and Earth due to the Sun and how they can produce the visual effect of an eclipse.
► Text reference: Section 2.4

ECCENTRICITY DEMONSTRATOR

This simulation demonstrates the parameters that define the eccentricity of an ellipse.
► Text reference: Section 2.5

KEPLER'S THIRD LAW

This simulation shows how to calculate the period of a planet from its semimajor axis, and vice versa.
► Text reference: Section 2.5

PLANETARY ORBIT SIMULATOR

This simulation demonstrates the behavior of planetary orbits and Kepler's laws.
► Text reference: Section 2.5

TEACHING READING ASTRONOMY NEWS

NOTE TO INSTRUCTORS

If you spend time showing the difference between astronomy and astrology, this alternate article may help start a discussion while reinforcing the students' understanding of the scientific method and Earth's seasonal motion and precession.

The Evaluating the News questions that follow the article try to help students discover for themselves the distinction between astronomy and astrology (science and psuedoscience) while still maintaining respect for people's beliefs.

ALTERNATE NEWS STORY

"New Zodiac Signs 2011: Can One Guy Just Change the Zodiac Like That?" Mark Sappenfield, *The Christian Science Monitor*, Jan. 14, 2011. www.csmonitor.com/Science/2011/0114/New-zodiac-signs-2011-Can-one-guy-just-change-the-zodiac-like-that

EVALUATING THE NEWS

1. What makes a constellation a *zodiac constellation*? How many are there? Has this number changed over time?
2. Why are the astronomical dates of the zodiac constellations no longer the same as the ones in the newspaper horoscopes? What caused this change?
3. How is astrology different from astronomy? If you met an astrologer and an astronomer at a party and

asked each about what they did at their jobs, what do you think each would say?

4. Does astrology, which is based on the movements of the Sun, Moon, and planets through the zodiac constellations, follow the scientific method? You may want to refer back to Figure 1.7 from Chapter 1 to answer this question. Come up with several specific attributes of astrology and decide whether these are compatible or incompatible with the scientific method.
5. The news presented in this article severely shook the astrological community. Were astronomers similarly impacted? Explain.

TEACHING EXPLORATION

NOTE TO INSTRUCTORS

Two optional extensions are given for this Exploration. Extension 1 explores the (lack of) effect that mass has on a planet's orbital period. Exploration 2 uses cometary orbits to further explore Kepler's second law. Additionally, an alternate version of the Exploration for Kepler's second law is given that adds in the equal *times* aspect of Kepler's second law to accompany the measurement and comparison of swept areas.

GOALS

- Give students hands-on experience with Kepler's laws
- Debunk misconceptions about what parameters determine a planet's orbital period

REQUIRED MATERIALS

- Computer with Internet access

PRE/POSTASSESSMENT QUESTIONS

Use the information in the table to answer the following questions.

Planet	Orbital Semimajor Axis (AU)	Orbital Eccentricity
Mercury	0.39	0.21
Jupiter	5.20	0.05

1. Which planet has a more circular orbit?
   a. Mercury
   b. Jupiter
   c. They both have circular orbits.
2. Which planet takes longer to orbit the Sun?
   a. Mercury
   b. Jupiter
   c. They both take the same amount of time to orbit the Sun.
3. If Jupiter's eccentricity were 0.30 instead of 0.05, Jupiter would orbit the Sun in
   a. less time than it does now.
   b. more time than it does now.
   c. the same amount of time as it does now.

POSTACTIVITY DEBRIEFING

The "Kepler's Laws" AstroTour found at the *Understanding Our Universe* StudySpace (http://wwnorton.com/studyspace) makes an excellent accompaniment to this exercise, whether shown before the Exploration or after as a way to review students' answers.

Kepler's Second Law: Alternate Version

Click the "reset" button near the top of the control panel, set parameters for Mercury, and then click on the "Kepler's 2nd Law" tab at the bottom of the control panel. Slide the "adjust size" slider to the right, until the fractional sweep size is $\frac{1}{8}$ (or 12.5 percent).

Click "start sweeping." The planet moves around its orbit, and the simulation fills in the area for one-eighth of the orbital period of Mercury (0.0301 years). Click "start sweeping" again as the planet arrives at the right-most point in its orbit (that is, at the point in its orbit farthest from the Sun). You may need to slow the animation rate using the slider under "Animation Controls." Click "show grid" under the visualization options. (If the moving planet annoys you, you can pause the animation.) One easy way to estimate an area is to count the number of squares.

4. Count the number of squares in the yellow area and in the red area. You will need to decide what to do with fractional squares. Are the areas the same? Should they be?
5. When is Mercury going faster: at the left-most portion of its orbit, the right-most portion, or somewhere in between? How do you know?

Extension 1: Does Mass Affect a Planet's Orbit?

10. Which is more massive: Mercury or Jupiter? Which takes longer to orbit the Sun? You can look this information up in the back of the textbook if needed.

Click the "reset" button near the top of the control panel, set parameters for Jupiter, and then click on the "Kepler's 2nd Law" tab at the bottom of the control panel. Jupiter's semimajor axis is 5.20 AU. If Jupiter were to orbit the Sun at the same distance as Mercury, would it go faster, slower, or the same speed as Mercury? To find out, change the "semimajor axis" for Jupiter to 0.387 AU (the value for Mercury's semimajor axis). Adjust the "fractional sweep size" to $\frac{1}{2}$ (or 50.0 percent). This is the amount of time it takes the simulated Jupiter to go halfway around its orbit. Multiply this by 2 to get the total amount of time it would take this simulated Jupiter to orbit.

11. How long would it take Jupiter to orbit the Sun if it were at Mercury's orbital distance?
12. How does this orbital period compare to Mercury's orbital period?
13. How does a planet's mass affect the length of its orbital period?

Extension 2: Comets

Now we will simulate the orbit of a comet. Click the "reset" button near the top of the control panel, set the parameters for Pluto, and change the semimajor axis to 5 AU and the eccentricity to 0.70. Click on the "Kepler's 2nd Law" tab at the bottom of the control panel. Watch one orbit of the comet.

Comets, icy bodies formed in the outer solar system, are most visible when they are less than 2 AU from the Sun and are warmed enough to form a large, bright tail of debris. When comets are cold, they lose their tails and become dark.

14. Where in the comet's orbit is it most visible? Explain your reasoning.
15. The simulated comet takes 11.2 years to orbit the Sun. How much of the time do you think the comet spends being visible? Explain.
16. Sketch the comet's orbit on your paper and indicate the portion of the orbit where the comet is visible.

DEMONSTRATIONS AND ACTIVITIES

Activity 1: Celestial Motion

NOTE TO INSTRUCTORS

This kinesthetic activity makes an excellent interactive demonstration in class. Students each become "Earth" and orbit the "Sun" to see how the constellations that are visible change throughout the year. You will in essence be building the world's cheapest and most fun planetarium in your classroom for exploring celestial motion.

GOALS

- For students to model the motion of Earth around the Sun
- For students to be able to relate Earth's rotation and revolution to the day and year of Earth
- For students to connect Earth's motion to the diurnal and annual motions of constellations
- For students to be able to understand how Earth's tilt causes the seasons

REQUIRED MATERIALS

- A space large enough for students to stand in a circle with arms stretched out to their sides
- A large ball to represent the Sun
- Signs that say "Summer Solstice," "Spring Equinox," "Winter Solstice," and "Fall Equinox" and have the corresponding dates on them.
- Flashlight (optional)

INSTRUCTIONS

1. Have students (or a subset of them if you are teaching more than 30 students) arrange themselves in a circle around the ball representing the Sun. Students should have enough room to rotate with their arms stretched out. Tell them to imagine they are each representing Earth, with the tops of their heads as the North Pole. A line from head-to-toe represents the rotation axis of Earth. Their waists are the equator. Above the waist represents the Northern Hemisphere, below the waist represents the Southern Hemisphere.
2. Have students face directly toward the "Sun" with their arms outstretched to the sides. Ask students,
   "What time is it at your nose?"
3. Have students face directly away from the Sun with their arms outstretched to the sides. Ask them,
   "What time is it at your nose?"
   "What time is it at your back?"
   "Where on Earth would your back represent?"
4. Have all students again face toward the Sun with arms outstretched. Remind them that the top of their head is the North Pole and ask them to imagine that they have a standard globe wrapped around their belly so that the United States is on the part of the globe facing forward. Ask students to think and discuss with neighbors,
   "Which of your hands represents eastward (toward New York on a map of the United States) and which hand represents westward (toward California on the map)?"
   Tell them to raise the thumb of their eastward hand.
5. Reinforce that what is visible in the sky at any given time is out in front of their arms and what is behind their arms is not visible at that time. Tell them that a person located at their noses looking out in a direction parallel to their arms would see whatever is low on the eastern and western horizons. Ask students,
   "Which way does Earth rotate?"
6. Once students see this, ask them to continue rotating around and confirm that the Sun is rising in the east and setting in the west. Ask students,
   "Does the Earth rotate toward the east or toward the west?"

7. Guide everyone in rotating through a complete day. Start with noses-at-noon position. Tell students to rotate to "sunset," "midnight," and "sunrise." Ask students,
   "What time is it at your nose?"
8. Ask students the following questions, giving them time to work out answers using their rotation relative to the Sun:
   - "At what time of day do you see stars other than the Sun? Why?"
   - "In general, will these constellations appear to rise and set like the Sun? Why?"
9. Have each person choose a major object that can be readily observed in the classroom and that would be visible during the nighttime part of his or her daily rotation. Have them give this object a name (like naming a constellation). Have each student rotate through a day and estimate the times when his or her constellation is visible in the night sky.
10. Define the term "rotation" as the spin of a body around an axis, just as they spin around the axis of their bodies with the top of their heads as the North Pole. Ask students,
    "How long does it take Earth to rotate around one time?"
    "What have we been ignoring so far about the Earth's rotation?" (The tilt)
11. Have all students face the Sun (noses-at-noon). Have everyone tilt their bodies at the waist about 23.5° in the same direction (for example, north or toward a distant object). Students should be bent toward north at an angle halfway between vertical and 45° from the vertical. All of the tops of the students' heads should be pointing at the same distant object.
12. Now ask all students to try to rotate their bodies in the appropriate direction around their *tilted* axis (i.e., while their heads and upper torsos remain pointed in the same direction in space).
13. Ask the class,
    "Who has a birthday closest to today?"
    Ask that student,
    "How many orbits around the Sun have you made in your life?"
    Ask the class,
    "How many times does Earth *rotate* on its axis during one *orbit* around the Sun?"
    Ask students,
    "How much does Earth move in its orbit of the Sun in one day?" (1/365th or about 1°)
14. Have students face in the same direction (say, north) and do their tilt forward at the waist until their head (North Pole) is tilted about 23.5° from the vertical. While tilted, ask students to look around and note that the time of day is different for each student. Select a few students around the circle and ask them to estimate the time of day at their noses.
15. Now ask the students to make an Earth year happen (one orbit of the Sun) while maintaining their tilt. *Tell students not to worry about the daily rotation for now, but to focus on their tilt.* Students should orbit in a counterclockwise direction around the Sun.
16. Have all students face the Sun (noses-at-noon) and assume the appropriate tilt toward North. Now ask the students,
    "Who has their upper body tilted most directly toward the Sun?"
    "Who has their upper body tilted most directly away from the Sun?"
    "What time of year is it when the Earth is in these positions in its orbit around the Sun?" (summer and winter for the Northern Hemisphere)
    Point out that both students are still tilted toward Polaris even though their orientation relative to the Sun changes depending on their orbital position.
17. Ask the students to all tilt their "North Poles" away from the sun as if in the Northern Hemisphere winter (back bends away from the Sun). Then ask
    "Do you have to look higher or lower in the sky to see the Sun?"
    Next ask all students to tilt toward the Sun as if in northern summer (forward bends toward the Sun). Then ask the same question again.
18. Use a sphere to show students that the opposite tilts are happening in the Southern Hemisphere compared to the Northern Hemisphere. When there is a summer tilt in the Northern Hemisphere, there is a winter tilt in the Southern Hemisphere.
19. Call on students' prior knowledge of what it is like in the summer: warmer, and the Sun is higher in the sky. Remind them that when the Sun is higher in the sky, the Sun's rays beat down more directly. Also, because the Sun is on a higher arc in the sky, it spends longer in the sky and sets later (more daylight hours). On the contrary, if the Sun is lower in the sky at noon (as in winter), then the Sun's rays come in at a lower angle and, because the Sun is on a lower arc across the sky, it sets sooner (fewer daylight hours).
20. You may want to use a flashlight to demonstrate the effect of the Sun's rays coming in at different angles. Compare the patch of light that results from shining the flashlight on the floor from directly overhead

to the patch resulting from shining the flashlight from an angle. At an angle, the light is less intense (dispersed over a greater area) and so would heat Earth's surface less. This idea can be further demonstrated by asking students to imagine holding the palms of their hands perpendicular to a heat source (like a campfire) versus holding their palms at an angle where their fingertips are pointed more toward the source. Your palm feels hotter when the light strikes the surface directly instead of in a glancing way.

21. Ask students for the dates of summer and winter solstice. Select students with birthdays on or near these dates, then have them move to the appropriate orbital position. Make sure all students are maintaining their proper tilt toward the North Star.
22. Ask students for the dates of the first days of spring and fall—the equinoxes.
23. Ask who has a birthday on or near spring equinox. Ask this student to go stand where he or she thinks Earth belongs on this date. Ask this student to explain why. Likewise, have someone who has a birthday on or near fall equinox to stand where he or she thinks the Earth belongs on this date.
24. Give the students representing the four seasons signs to hold, including the title and appropriate date of the two solstices and two equinoxes.
25. Have all students go to noses-at-noon and assume the appropriate tilt. Ask,

    "Do the equinox students tilt either toward or away from the Sun?"
26. Ask all students to go and stand in the approximate position of Earth's orbit around the Sun on their birthday. This helps confirm that students are making the connection between a personally significant time of the year and the position of Earth in its orbit around the Sun.
27. Check results by asking each student to report out the date of his or her birthday.
28. Have all students face the Sun (noses-at-noon) and assume the appropriate tilt on their birthday. Have them experience their birthday kinesthetically by rotating in the proper direction while maintaining the appropriate tilt.
29. Have students turn to represent midnight on their birthday (turning away from the Sun). In turn, ask students on opposite sides of Earth's orbit to identify a major object they see out in front of them. Have them imagine this object as a constellation and even give it a name.
30. Ask,

    "Why do people on the night side of Earth see different stars in their night sky at different times of year?"
31. Remind students that stars rise and set like the Sun and thus appear in different parts of the sky as the night progresses. Choose a "constellation" object that everyone in the learning environment can easily locate (for example, the "flagpole constellation"). This object should be as far away as the learning environment permits.
32. Ask all students to stretch out their arms and rotate as Earth does in order to determine whether they could see this "constellation" at some time during the night at the time of year represented by their orbital position. Ask them to estimate the times of night when it would be visible at their noses and where it would be in their "sky." Have students report out, either verbally or in writing. Students on the opposite side of the Sun from the constellation should only see it for a short time near sunrise or sunset or not at all because the Sun is up when they are facing in the direction of the constellation. Students on the same side of the Sun as the constellation should be able to see it for more of the night.
33. Have students complete and turn in the following worksheet.

Name: ____________________________

Section: ____________________________

CELESTIAL MOTION

Answer the following questions following the class activity on celestial motion.

1. Why does the Sun appear to rise in the east and set in the west?

2. Do we see the same stars at different times of night? Why or why not?

3. Why is the Sun higher at noon in the summer than it is in the winter?

4. Do we see the same stars at different times of year? Why or why not?

5. Will people in China see the same stars tonight as people in the United States? Assume the people in China and the United States are located at the same latitude.

6. The table at right shows the calendar dates for each of the constellations along the ecliptic. The dates listed are when the Sun appears to be in front of the constellation (i.e., Earth is opposite the Sun from the constellation). In what constellation is the Sun on your birthday?

Calendar Dates	Ecliptic Constellation
Feb. 16–Mar. 11	Aquarius
Mar. 12–Apr. 18	Pisces
Apr. 19–May 18	Aries
May 19–June 19	Taurus
June 20–Jul. 20	Gemini
Jul. 21–Aug. 10	Cancer
Aug. 11–Sep. 15	Leo
Sep. 15–Oct. 30	Virgo
Oct. 31–Nov. 22	Libra
Nov. 23–Nov. 28	Scorpio
Nov. 29–Dec. 17	Ophiuchus
Dec. 18–Jan. 17	Sagittarius
Jan. 18–Feb. 15	Capricorn

7. Determine when the constellation corresponding to your birthday can be seen throughout the year and put your answers in the table below. You may want to get into groups and use kinesthetic modeling to answer this question.

Month	Approximate Times Constellation Is Visible
Ecliptic constellation month	
Ecliptic constellation month plus two months	
Ecliptic constellation month plus three months	
Ecliptic constellation month plus six months	
Ecliptic constellation month plus nine months	
Ecliptic constellation month plus ten months	

Activity 2: Phases of the Moon

NOTE TO INSTRUCTORS

In this activity move the "Moon" (a Styrofoam ball) in its orbit around the "Earth" (the students' heads) to re-create all the observable lunar phases.

GOALS

- For students to understand the cause for lunar phases
- For students to use a simple model of the Sun, Earth, and Moon in order to predict rise, set, and transit times for the Moon for each phase

REQUIRED MATERIALS

Each student (or pair of students) will need:

- a white Styrofoam ball
- a pencil or stick to spear the ball and hold it up

You will need:

- a bare-bulb light source (incandescent or black light)

INSTRUCTIONS

1. The room should be dim and the light source should be positioned so that students can all have one half of their "Moon" illuminated. You will want to caution students to hold the ball at arm's length but slightly higher than head-height so that they don't make "eclipses".
2. Parts 1 and 2 have the students re-creating Figure 2.17 from the book, but in such a way that the diagram takes on real meaning and connects to observations. Part 3 extends the Sun-Earth-Moon model and has students determine approximate rise, set, and transit times for the Moon. Parts 1–3 make for a good in-class activity.
3. Part 4 and the Moon Observations chart (p. 28) can be assigned a few weeks in advance to extend the activity into an observational lab. If you choose to assign the observation portion, be sure to allow students to collect observations over at least two weeks. You will want to assign a specific minimum number of observations to be taken. If you live in a cloudy part of the world (such as the Pacific Northwest), you can typically make at least two observations per week. If you live in a place with clear skies, you should increase this to 4–5 observations per week. As a cautionary note, most people think the Moon is only visible at night, so you will have to let your students know to look during the day, too.
4. Part 5 contains extra questions to assess students' understanding of lunar phases. Some of these questions are meant to connect the content from the observation portion and the first three parts of the activity. The other questions are meant to be a conceptual challenge for students and can help them debunk some common misconceptions when done in pairs or reviewed as a class afterward.
5. Detailed instructions for performing this activity are contained on the following worksheet, which students can fill out and turn in.

Name: ____________________________

Section: ____________________________

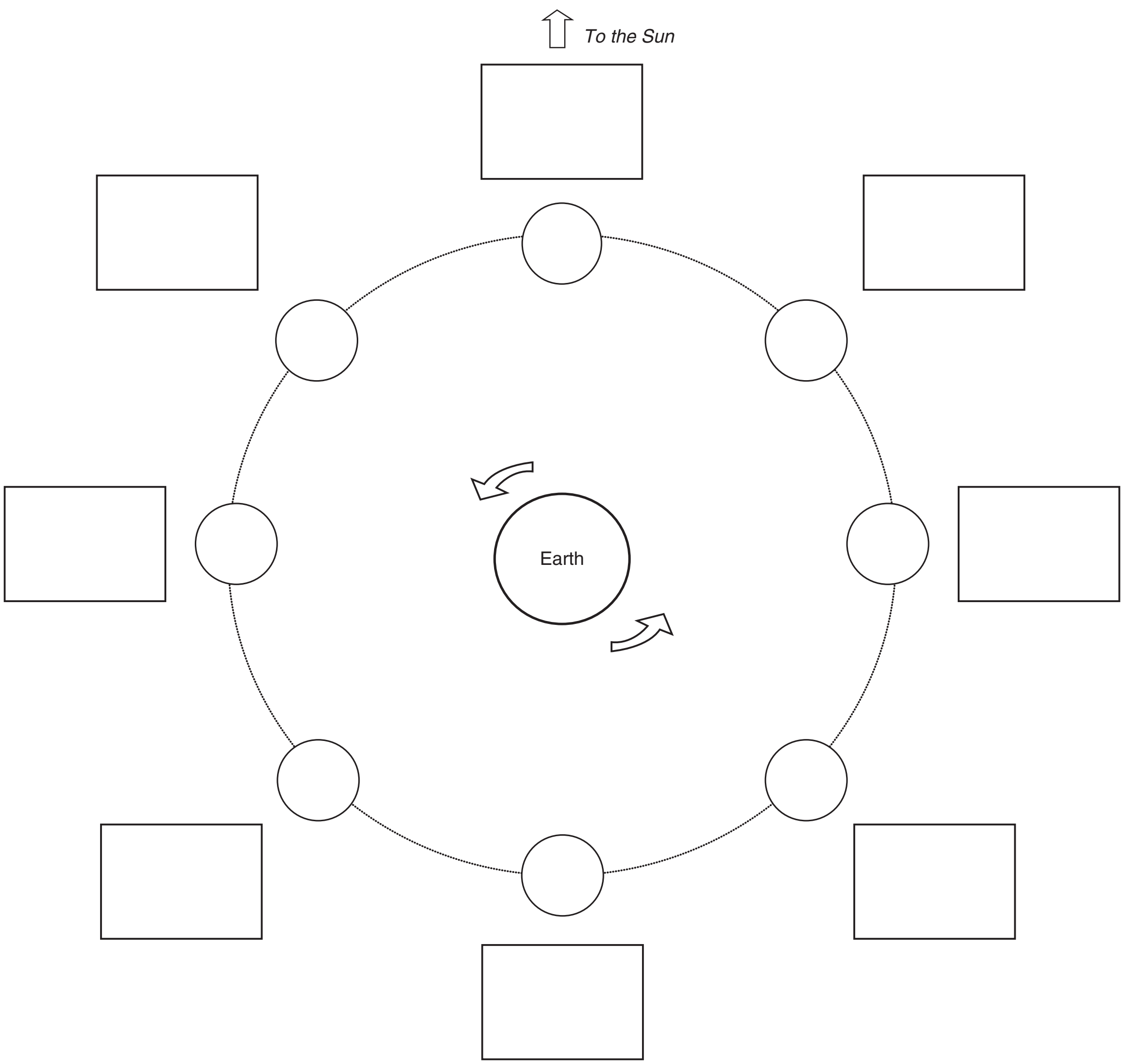
PHASES OF THE MOON

In this activity we will construct a model of the Earth-Moon system that explains the lunar phases and use our knowledge of how the lunar phases work to answer some questions.

PART 1: MODELING THE LUNAR PHASES FROM ABOVE THE MOON'S ORBIT

Below is a sketch of the Moon's orbit as viewed from far above Earth's North Pole. The eight circles represent the Moon at various positions in its orbit. The Sun (not shown here) is far away in the direction of the top of the page.

In the diagram below, based on the location of the Sun, shade in the portion of the Moon that is dark at each of the eight positions. Ignore the boxes for now.



PART 2: MODELING THE LUNAR PHASES FROM EARTH

Next we will model the lunar phases in a way that recreates what we see here on Earth.

- Get a Styrofoam ball on a stick from your instructor. This ball will be the Moon in our model. The light in the center of the room will be the Sun.
- Your head will be Earth. The top of your head will be the North Pole. Hold the Styrofoam ball at arm's length.
- Figure out which direction you, Earth, rotate according to the diagram on the previous page.
- Without the ball, rotate through one day's worth of motion, noting which positions represent noon, 6 P.M, midnight, and 6 A.M.
- With the ball at arm's length, position yourself so the Moon is close to the sun in the sky. Hold the Moon a bit higher than your head so you don't get any eclipses.

  What phase is the Moon in?

- Now put the Moon through one complete orbit while rotating your body along with it (don't worry about making your head spin). The Moon orbits in the same direction as Earth spins.

  If you could make your head spin, about how many times should it spin during one Moon orbit? (You may have to look this up in your textbook.)

- In your diagram from Part 1, sketch the way the Moon appears from the Earth at each of the eight positions you marked. Make these sketches in the box next to each orbital position.
- Label the phases as new, full, first quarter, third quarter, crescent, or gibbous. Specify waxing or waning for crescent and gibbous (refer to your textbook if you don't recall which is which).

PART 3: RISE AND SET TIMES

In addition to matching phases to the corresponding positions in the Moon's orbit, we can use this simple model with the Styrofoam ball to estimate what time the Moon is visible for any given phase.

- Grab a partner and have one person be the Earth while the other holds the Moon.
- Begin in the new phase.
- Have the person who is Earth go through one day's worth of rotation and determine at what time the Moon will rise and set and at what time the Moon will cross the meridian. During the course of one day the Moon doesn't move much in its orbit so the person holding the Moon can stand still. Record these times in the table below.

Rise Time	Crosses the Meridian	Set Time

- Have the Moon move in its orbit to the next position and go through the same procedure of determining the rise and set times. Note that these will be approximations.

► Continue on through all the eight positions on your diagram, determining the rise and set times and the time the Moon crosses the meridian for each one. Fill in the table below with these times.

Phase	Rise Time	Crosses Meridian	Set Time

► Now have the person holding the Moon be Earth and go through the same exercise so both people can verify that their answers match.

1. Where in the sky should the Moon be when it is rising as viewed from your location on Earth (both direction and altitude)?

2. Where in the sky should the Moon be when it is crossing the meridian as viewed from your location on Earth (both direction and altitude)?

3. Where in the sky should the Moon be when it is setting as viewed from your location on Earth (both direction and altitude)?

PART 4: MATCHING YOUR OBSERVATIONS TO THIS MODEL

For this part you will need to refer to the Moon Observations chart that you've been filling in for the past 2 weeks. We will be matching the model we have been presently manipulation to your observations.

► On the diagram in Part 1, mark the position of the Moon in its orbit for each of your observations. Label them with the dates on which they occurred.

► Compare the times you observed the Moon to the times you listed in the table above.

4. Do all of your observations fall within the predicted range of time that the Moon should have been visible? (Note: you may have to allow +/−4 hours to account for our latitude's effect on the rise and set times and Daylight Savings Time.)

► Now compare *where* in the sky you observed the Moon with where the Moon should be according to our model.

5. Was the Moon always roughly where this model predicts it should be? If not, give an example of an observation you made of the Moon's position and the corresponding unmatched model prediction.

6. Is it possible that there are aspects of the Earth-Moon system that were not accounted for in this simple Styrofoam model?

7. Before continuing on, use the Styrofoam ball, the light, and your head to show your partner the position of the Sun, Moon, and Earth at the time of your first lunar observation for this lab.

MOON OBSERVATIONS

For each lunar observation, write the date, time, and position in the sky (e.g., low in the west, high in the south, halfway up toward the southeast, etc). Shade the circle to show the Moon's appearance. Use dark shading to represent the part of the Moon you can't see and white for the visible part.

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________
Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________	Date ______ Time ______ Position __________ __________

PART 5: ADDITIONAL QUESTIONS

8. Are the Sun and Moon ever in the sky at the same time?

9. How much of the Moon is dark at any given time?

10. Assuming the Moon's orbit is fairly circular, how long is it between the new Moon and first quarter?

11. If you wanted to see the Moon just before you walk into astronomy class on the date this assignment is due, where in the sky should you look to see it? What phase will it be in?

12. Suppose you are in North America. One day you look up and notice that there's a crescent Moon in the sky and the right side is lit. Is it waxing or waning?

13. Which side of a crescent is lit: the side closer to the sun or the side farther from the sun?

14. On the same day that you see a waxing crescent Moon, what phase will someone in the Southern Hemisphere see? Draw a picture and explain. (Note: *waxing* and *waning* do not refer to the side that is illuminated. They simply mean "increasing" and "decreasing."

15. Your friend thinks the phases of the Moon are caused by the Earth's shadow falling on the Moon. What observations could you make to prove to your friend that this is not true?

16. For each lunar phase, fill in the table below with what phase the Earth would appear to be in if you were an astronaut standing on the Moon during that lunar phase.

Lunar Phase	Earth's Phase as Viewed from the Moon

Activity 3: Introduction to Observational Astronomy

NOTE TO INSTRUCTORS

This activity is meant to get students out and looking at astronomical objects and to connect what they see to the concept of a celestial sphere.

GOALS

- For students to observe celestial objects
- For students to learn how to use some basic observational tools: a star wheel and a quadrant
- For students to observe and explain celestial motions
- For students to relate observations to the concept of a celestial sphere

REQUIRED MATERIALS

- A star wheel (http://lawrencehallofscience.org/starclock/skywheel.html)
- A quadrant/astrolabe (www.experiment-resources.com/astrolabe.html)

INSTRUCTIONS

1. Use the directions at the links above to have students print out and construct a star wheel and quadrant. The last page of this activity has directions on how to use these two tools.
2. Part 1 has students using their quadrants to measure the heights of various objects. Do not let students sight the Sun through the quadrant. Have them use the method outlined in the instructions. Some of the objects listed for observation (the astronomy building, a nearby statue) may need to be modified to suit your teaching environment. If students give the distance they are from the base of the object and you know roughly what the height is, you will be able to grade their answers very approximately with no problem.
3. Part 2 must be done on a clear night over the course of four hours. Students observe the motions of two stars—one circumpolar and one non-circumpolar—and the Moon and answer questions about them in Part 3. Depending on the time of month, the Moon observations may need to be made at a separate time from the star observations.
4. Detailed instructions for performing this activity are provided on the following worksheet, which students can fill out and turn in.

Name: ____________________________

Section: ____________________________

INTRODUCTION TO OBSERVATIONAL ASTRONOMY

Before you begin this activity you will need to construct some very simple, basic equipment: a sky wheel and a quadrant (also known as an astrolabe). To construct the sky wheel, follow the instructions found at http://lawrencehallofscience.org/starclock/skywheel.html. To construct a quadrant, follow the instructions found at www.experiment-resources.com/build-an-astrolabe.html. Instructions for how to use the sky wheel and quadrant, should have been provided to you by your instructor.

Once you have constructed your sky wheel and quadrant, you are ready to use them to answer the questions below.

PART 1: USING A QUADRANT

Measure the altitude of the following objects around campus:

1. The altitude of the sun. **Caution:** Be sure to use the method outlined in the directions for your quadrant! (If the weather is bad, do this on your own after class.)
   Altitude of the sun: ____________________
   Time of observation: ____________________
2. The altitude of the top of a flagpole at a distance of 20 paces.
   Altitude of the flagpole: ____________________
3. The altitude of the top of the building in which this class is held as viewed from the nearest parking lot.
   Altitude of building: ____________________
4. The altitude of the top of a statue of your choice as viewed from 20 paces away.
   Altitude of statue: ____________________
   Description of statue: ____________________

PART 2: TAKE-HOME OBSERVATION

Take your two new tools home and use them to find and measure the following:

5. The altitude of Polaris: ____________________
6. The altitude of one other circumpolar star
   Constellation: ____________________ Altitude: ____________________
   Same star, observed two hours later: Altitude: ____________________
   Same star, observed four hours later: Altitude: ____________________
7. The altitude of one noncircumpolar star
   Constellation: ____________________ Altitude: ____________________
   Same star, observed two hours later: Altitude: ____________________
   Same star, observed four hours later: Altitude: ____________________
8. The altitude of the Moon
   Observing time: ____________________ Altitude: ____________________
   Altitude of Moon two hours later: ____________________

PART 3: ADDITIONAL QUESTIONS

9. Describe the motion of the star you observed in Question 6 over the course of four hours. Did it move higher, lower, eastward, westward, etc.?

10. Describe the motion of the star you observed in Question 7 over the course of four hours. Did it move higher, lower, eastward, westward, etc.?

11. Describe the motion of the Moon over the course of two hours. Did it move higher, lower, eastward, westward, etc.?

12. Do all stars move east to west over the course of a night? If not, give the name of a star or constellation that did not.

13. Polaris is directly above the Earth's North Pole. What is one star or constellation, visible on the night you do your observations, that is directly above the Earth's equator? You might find the declination markings ("celestial latitude") on the star wheel useful for this.

14. Where in the sky should you look to find a star or constellation that is at the same "celestial latitude" as your latitude on Earth?

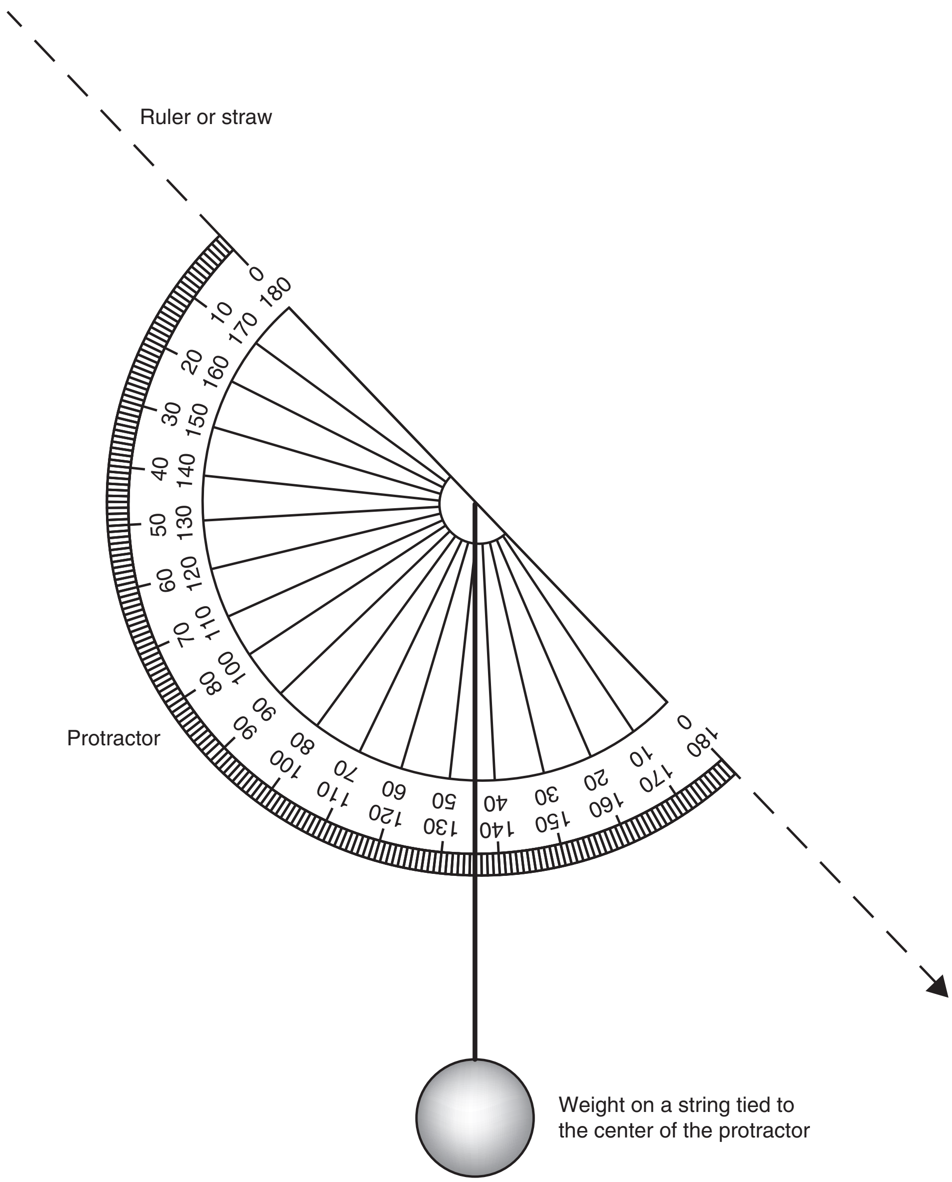
15. What is one star or constellation, visible on the night you do your observations, that is at the same declination ("celestial latitude") as your latitude on Earth?

HOW TO USE A QUADRANT

To measure objects that are NOT THE SUN, look through the straw at the object. Wait for the weight on the string to stop swinging and then pinch it against the protractor. Read off the angle that the string crosses.

NEVER, EVER LOOK DIRECTLY AT THE SUN. To measure the sun's height, you will hold the straw at waist level and tilt it until sunlight shines all the way through the straw and produces a circle of light on your shirt. When the light is able to make it all the way through the straw, the sun is in line with your quadrant. Pinch the string against the protractor and read off the angle.

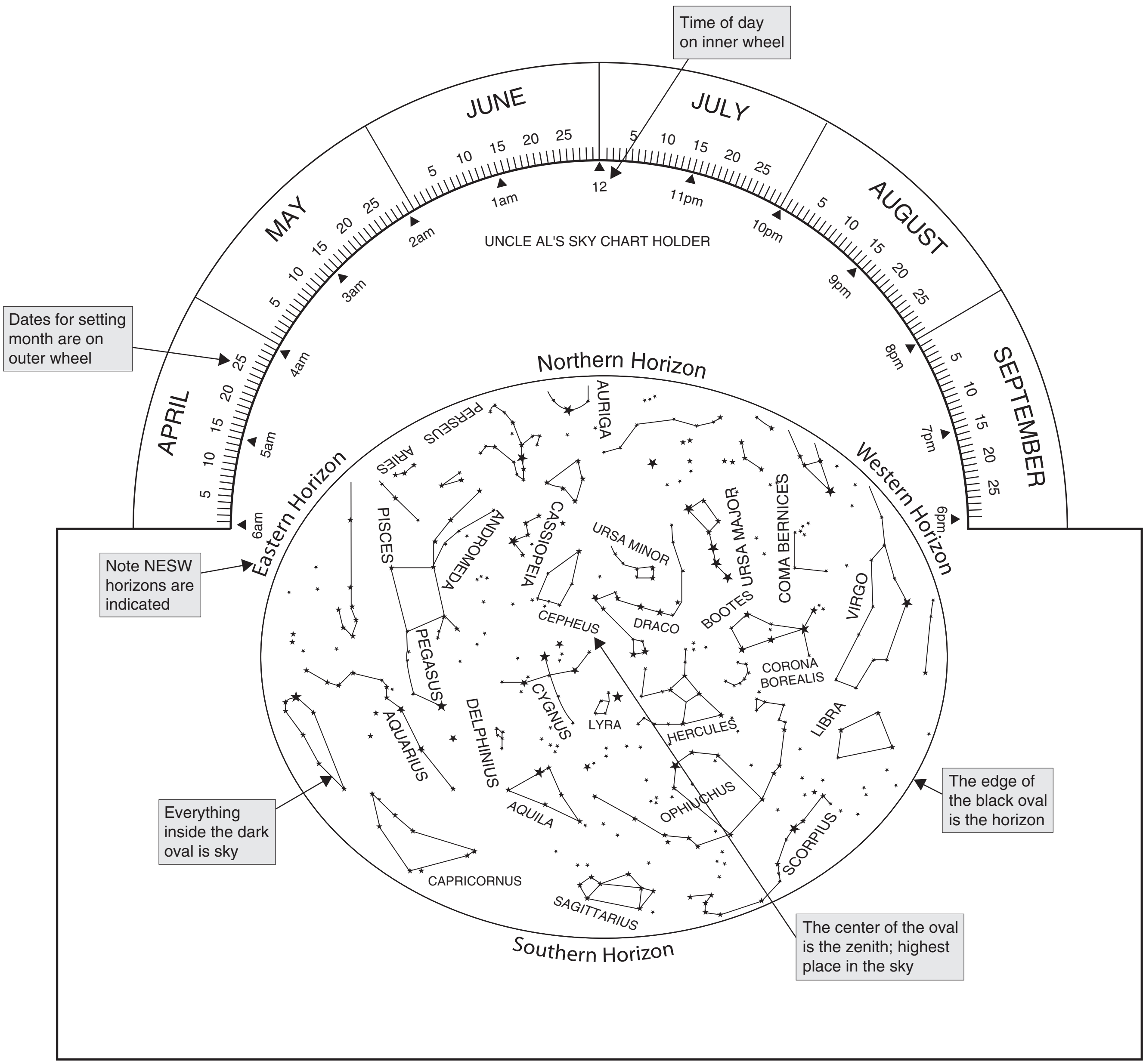
NOTE: It is difficult to use a quadrant to measure angles close to 90° (your face gets in the way). Try to avoid having to measure the heights of stars that are near the zenith.



HOW TO USE A SKY WHEEL

To find a constellation in the sky using the star wheel, follow these steps:

1. Rotate the star wheel in the star holder until your desired time of night lines up with the desired date.
2. Find the constellation on the star wheel and note which horizon it is closest to.
3. Orient the star holder so that the horizon nearest to the constellation is near the bottom. This will allow that part of the sky to look right-side up to you. For example, if your constellation is closest to the northern horizon, flip the star holder upside down so that you are reading the northern horizon at the bottom of the oval.
4. To figure out how high the constellation is in the sky, look at whether it is closer to the zenith (center of the map) or closer to the horizon.



LECTURE NOTES

SLIDE 2: MOTIONS IN THE SKY

- Since humans first looked up at the sky, they have noticed the behaviors of the objects they could see. These behaviors were analyzed at first all from the perspective of a stationary Earth and a moving sky. It is important that the students understand that and are able to visualize the ideas in this chapter both from the vantage point of a stationary Earth and that of a rotating Earth.
- This chapter will focus on the motion of Earth, the Moon, and the other planets:
  - Daily rotation of Earth
  - Annual orbit (or revolution) of Earth around the Sun
  - Monthly orbit of the Moon around Earth
  - Behavior of the planets as they orbit the Sun
- The patterns people noted in the sky were clues to understanding these motions and other phenomena.

SLIDE 3: EARTH ROTATES ON ITS AXIS

- The apparent motion of the stars across the sky is a direct result of Earth's rotation on its axis.
- If you were looking down at the **North Pole**, you would see Earth rotating in a counterclockwise direction. The opposite would be true for viewing the rotation from the South Pole.
- One complete rotation takes about 24 hours, or 1 day.

SLIDES 4–5: THE CELESTIAL SPHERE

- It is sometimes convenient to think of the sky as a large sphere centered on Earth. This is called the **celestial sphere**.
- This is a fiction. The planets and the stars are all at very different distances from Earth.
- However, the points on the sphere correspond to directions instead of distance. It is a useful way to map positions of stars and objects in the sky.
- Each day, the celestial sphere appears to rotate around two poles. These are called the **north celestial pole** and the **south celestial pole**.
- Midway between the two poles is the **celestial equator**. In fact, the celestial equator is an extension of Earth's equator.
- The path of the Sun across the sky is called the **ecliptic**, and it appears on the celestial sphere as a circle inclined 23.5° from the celestial equator. This is because Earth's axis is tilted 23.5° from the plane of its orbit around the Sun (the ecliptic). Earth maintains this tilt as it orbits the Sun, such that at some points the North Pole is tilted towards the Sun and sometimes away.
- It is very important for the students to be able to visualize the celestial sphere as an extension of Earth's coordinate system of latitude and longitude (though measured slightly differently). The text suggests the use of an orange, a physical example that the students can manipulate.

SLIDES 6–7: AT EARTH'S NORTH POLE

- An observer at Earth's North Pole would see half the celestial sphere. This is called the north celestial hemisphere. The south celestial hemisphere would always be below the **horizon**.
- The north celestial pole would be overhead.
- The stars rotate counterclockwise around the north celestial pole in about 24 hours. The period of rotation is 23 hours, 56 minutes, 4 seconds. This is the rotation period of Earth. They do so precisely because of Earth's rotation.
- No star rises or sets. All are constantly above the horizon. Such stars are called **circumpolar** stars.
- From the South Pole, things would be the same except that the south celestial pole would be overhead and the stars would rotate clockwise around that pole.

SLIDE 8: AT EARTH'S EQUATOR

- At Earth's equator, an observer with an unobstructed view would see all stars rise and set. No stars are circumpolar.
- The celestial poles are located at the observer's north and south horizons.
- At any one instant, half the celestial sphere is above the horizon. Observers at the equator can see the entire celestial sphere as it rotates each day.
- Note that the celestial sphere must be imagined as being much larger than Earth. This is indicated by the greatly reduced version of the left panel of this figure just visible in the center of the celestial sphere in the right panel.

SLIDES 9–10: BETWEEN THE POLES AND EQUATOR

- Between the poles and the equator, at an intermediate **latitude**, one celestial pole is above the horizon but not straight overhead. The North Pole is above the horizon for northern observers, and the South Pole is above the horizon for southern observers.
- The angle between the pole and the horizon equals the observer's latitude on Earth. As an example, an observer in Los Angeles would see the pole 32° above the north horizon. The pole would be about 44° above the horizon for an observer in Toronto.
- Some stars are circumpolar, while others rise and set. The further north an observer is, the more stars will be circumpolar.
- Some of the celestial sphere is always below the horizon and is never visible.

SLIDE 11: THE SIZE OF EARTH'S ORBIT

- Earth's orbit is nearly circular, so the distance from Earth to the Sun does not change much during the year.
- We define the **astronomical unit** to be the average distance between Earth and the Sun (i.e., about equal to the radius of Earth's orbit). The abbreviation for astronomical unit is AU.
- The AU is a unit of length. It is about 150 million kilometers, or 1.5×10^8 km. The minimum and maximum distances to the Sun are 147.5 and 152.6 million kilometers.
- The orientation of the orbit defines the ecliptic plane. This is a plane centered on Earth that passes through the ecliptic (on the celestial sphere.) We will see later that each planet has an orbital plane.

SLIDE 12: EARTH ORBITS THE SUN

- Imagining a stationary Earth, we can see the Sun move on the ecliptic of the celestial sphere. This movement is a consequence of Earth orbiting the Sun.
- As the Earth orbits the Sun, it moves among (relatively) fixed stars. Therefore, at different times of the year we see different background stars behind the Sun.
- These background stars were given special significance—the constellations of the **zodiac**.
- It is important to stress to the students that the only reason those constellations are significant is because of the Sun appearing to pass through them, due to Earth's orbit.

SLIDES 13–14: EARTH'S AXIS AND THE SEASONS

- The rotation axis of Earth is not perpendicular to the ecliptic plane.
- It is at an angle of 23.5° to the ecliptic plane.
- As a result, the Sun (which moves along the ecliptic) is alternately north and south of the equator during the year.
- The angle between the rotation axis and the ecliptic causes us to have seasons because the illumination from the Sun is not uniform.
- In the summer, sunlight arrives at a steeper angle to the ground (more direct sunlight). Therefore more energy arrives each second on a patch of Earth. In the winter, the angle is shallower, and less energy arrives each second.
- Furthermore, the Sun is above the horizon for more hours each day in the summer than in the winter. Therefore in the summer, there is more energy given to the land on any given day than in the winter.
- Many surveys show that students—even university graduates—cannot correctly explain the origin of the seasons. The seasons have nothing to do with the distance between Earth and the Sun. The distance is nearly constant. Earth is actually closest to the Sun in early January.
- Be careful with the word "tilt," as in the phrase "the tilt of Earth's axis." Since *tilt* is also a verb, some students will think that the axis of Earth moves during the year, swinging up and down with respect to the Sun.

SLIDES 15–16: SPECIAL DAYS OF THE YEAR

- Note that these days are from the perspective of Northern Hemisphere observers. The equivalent dates are 6 months later for observers in the Southern Hemisphere.
- **Summer solstice**: The Sun is farthest north of the equator. This happens about June 21. Days are longest and nights are shortest.
- **Autumnal equinox**: The Sun is on the equator, moving southward. (Reminder: The Sun is always on the ecliptic, so on this day the Sun is at the place where the ecliptic crosses the equator). Day and night are of equal length. This happens about September 23.
- **Winter solstice**: The Sun is farthest south. This happens about December 22.
- **Vernal equinox**: The Sun is on the equator, moving northward. This happens about March 21.

SLIDE 17: PRECESSION OF THE POLES

- The location of the celestial pole slowly shifts.
- Currently the north celestial pole is near the bright star Polaris. This is the star at the end of the handle of the Little Dipper (for North American students—other countries have different names for this constellation).
- **Precession** happens because the orientation of Earth's rotation axis slowly changes its direction, tracing out a large circle on the celestial sphere. After 26,000 years, the pole returns to its original position. Earth is spinning like a top that is not quite straight up and down, and so its poles slowly change which way they are pointing.
- Since the rotation axis shifts, the celestial equator shifts as well, meaning that the equinoxes will precess as well.
- This has resulted in some complicated calendar issues throughout human history.
- The length of a year has its own complications. The addition of a day every 4 years is needed because the length of a year (one full Earth orbit around the Sun) is not exactly 365 days, but instead is 365.24 days. Such a year with an additional day is a **leap year**.

SLIDE 18: THE MOON

- The Moon is the next prominent object in the sky after the Sun.
- The Moon shines only because of sunlight reflecting off its surface.
- As it orbits around Earth, it only shows us one face. It is locked in a synchronous rotation. This means that it completes one full rotation on its axis in one full orbit around Earth.

- It is important to stress to the students that the Moon does indeed rotate fully on its axis. It just appears not to rotate since it only shows us one face in the sky. Half of the Moon is always lit by the Sun; it just may not be the half we see. Rather than saying "light" and "dark" sides of the Moon, it is more useful, and more correct, to say the "near" and "far" sides of the Moon.

SLIDES 19–20: PHASES OF THE MOON

- The phases of the Moon reflect the angle between the Sun and the Moon. As the Moon orbits Earth each month, this angle is constantly changing. The Sun shines on one half of the Moon, always. From Earth, we can see part, all, or none of this half during each month.
- The students might have some preconceived notions that the shadow of Earth is what causes the phases of the Moon. It is very important to stress that the phases are a result of the angle between the fully illuminated half of the Moon and Earth.
- The **new Moon** is when the Sun and the Moon are nearly in the same direction in the sky. In direction, the Moon is between Earth and the Sun, so the fully illuminated side faces away from Earth.
- **Quarter** moons occur when the Sun and the Moon are at right angles, so the view from Earth is half of the fully illuminated side. **Crescent** moons are between the new and quarter phases.
- The **full Moon** takes place when the Sun and the Moon are in opposite directions, so the view from Earth is of all of the fully illuminated side. **Gibbous** moons take place between the quarter moons and the full Moon.
- **Waxing** refers to a phase that is part of an increase in size, while **waning** is the opposite.
- It is helpful to tell the students that the Moon fills in from right to left as it progresses from new Moon to full Moon.

SLIDES 21–22: SOLAR ECLIPSES

- **Eclipses** are caused by one object passing in front of another, thereby blocking its light.
- **Solar eclipses** happen when the Moon passes in front of the Sun. The shadow of the Moon touches part of Earth. Due to the small size of the Moon's shadow, only a small portion of Earth can view each solar eclipse.
- Solar eclipses happen when the Moon is new. The Sun and the Moon are in close proximity in the sky.
- There are three types of solar eclipses:
  - **Total**: The Moon completely blocks the Sun's light. Total eclipses occur because the sizes of the Moon and the Sun in the sky appear the same.
  - **Partial**: Only a part of the Sun is seen as blocked.
  - **Annular**: The Sun appears as a bright ring surrounding the Moon. Due to the fact that the Moon's orbit is not a perfect circle, sometimes it is farther from Earth during an eclipse. This results in the Moon appearing smaller than the Sun in the sky.

SLIDE 23: LUNAR ECLIPSES

- **Lunar eclipses** happen when the Moon passes through the shadow of Earth.
- Lunar eclipses happen at full Moon. The Sun and the Moon are on opposite sides of Earth.
- Since Earth's shadow is much bigger than the Moon's, these eclipses are visible for a wider area of Earth, and also have a much longer duration.

SLIDE 24: ECLIPSE FREQUENCY

- Eclipses do not take place each month because the Moon's orbital plane is at a 5.2° angle to the ecliptic. For example, the Moon usually passes above or below Earth's shadow each month. Eclipses happen about twice every 11 months.
- If the Moon's orbital plane and the ecliptic were exactly aligned, eclipses would happen every month because the configuration would be correct.

SLIDE 25: A HELIOCENTRIC SOLAR SYSTEM

- Prior to Nicolaus Copernicus, humans believed in a **geocentric** (Earth-centered) universe. This resulted in some very complicated models of the Solar System in order to explain the observed behaviors of the Sun, Moon, and other planets.
- Copernicus (while not the first person to suggest the Sun was at the center of the Solar System) was able to develop the first **heliocentric** model that people took seriously.
- This greatly aided in simplifying the explanations of the motions of the planets. A behavior observed of the planets is their **apparent retrograde motion**, where they appear to backtrack across the sky, and then reverse direction again to continue on in their orbit. Understanding that Earth is the third planet from the Sun allowed for this to make sense—sometimes the planets would overtake each other in their respective orbits for a time.
- This revolutionized astronomy, although Copernicus believed the planets orbited in circles. Johannes Kepler used data from observations to show this was not the case, as exemplified in **Kepler's laws**.

SLIDES 26–27: KEPLER'S FIRST LAW

- Kepler's first law states that each orbit has a particular shape called an **ellipse**. Ellipses look like squashed circles. Ellipses can be very flattened or circular.

- An ellipse has two points called the **foci**. The singular of foci is **focus**.
- The Sun is located at one focus of each ellipse. There is nothing at the other focus. As a result, each planet has a minimum and a maximum distance from the Sun.
- There are two numbers that describe an ellipse. These tell us the shape of the ellipse (whether it is squashed or nearly circular) and the size of the ellipse (whether it is large or small). We can describe the orientation of an ellipse in space, but Kepler's laws apply for any orientation.
- The first important number is the size of the orbit, given by the length of the **semimajor axis**. In this context, the prefix *semi-* means "half."
- The largest width of the ellipse (its length along its longest axis) is *twice* the length of the semimajor axis. For the Earth, the semimajor axis has a length of 1 AU. The full length of the orbit from one side to the other is 2 AU.

SLIDE 28: ELLIPSE ECCENTRICITY

- The second important number concerning ellipses is the separation between the foci. This determines the shape of the orbit. If the foci are close together, the ellipse is almost circular. If the foci are far apart, the ellipse is very elongated. A circle is a special case of an ellipse, in which the two foci are on top of one another.
- The shape of the ellipse is described by a number called the **eccentricity**. If the eccentricity is nearly 0.0, the ellipse is nearly circular. Very elongated ellipses have a larger eccentricity.

SLIDES 29–30: KEPLER'S SECOND LAW

- Kepler's second law describes the speed that an individual planet has at different times in its orbit. It is often called the **Law of Equal Areas**.
- The rule is "the line between the Sun and the planet sweeps out, or creates, equal areas in equal times."
- Consequences of the Law of Equal Areas:
  - A planet will travel at its highest speed when it is closest to the Sun.
  - It will travel at its slowest speed when it is farthest from the Sun.
- In describing this picture, a useful analogy is to cut an elliptical pizza into slices of equal area. Each slice has a point at the focus of the ellipse. There will be short, fat slices and long, skinny slices.
- It is important to stress to students that this law can only be applied to each planet individually, during the course of its own orbit. It is not used to compare the orbital speeds of two different planets.

SLIDE 31: KEPLER'S THIRD LAW

- Kepler's third law describes the orbital speeds for planets at different distances from the Sun. It relates the size of the orbit to the orbital period.
- Consequences:
  - Distant planets take longer to orbit the Sun.
  - Distant planets travel at slower speeds than inner planets.
- Unlike Kepler's second law, this law does involve comparing the orbits of two different planets.

SLIDE 32: CONCEPT QUIZ—EARTH'S ROTATION

- The point of this question is to get the students to realize that the apparent motion of the sky is opposite from the actual motion of Earth.
- The correct answer is C, toward the east. Choices B and D don't make sense.

SLIDE 33: CONCEPT QUIZ—A FASTER SPIN

- This quiz tests whether the students can separate the various motions discussed in this chapter.
- The correct answer is A. Earth would still take the same amount of time (i.e., the same number of seconds) to orbit the Sun, so the seasons would still occur as they do now. We would not get two winters in each orbit around the Sun.
- Choices B and C are incorrect because the Moon's orbit would be unaffected. We only see one hemisphere of the Moon because its orbital and rotation periods are the same. The cycle of lunar phases would take the same amount of time as it does now.
- Choice D is incorrect because an observer at the North Pole would have the same view as now.

SLIDE 34: CONCEPT QUIZ—ECLIPTIC AND EQUATOR

- Here the students are to imagine the Sun staying on the celestial equator during the year.
- The correct answer is C. The Sun would always be on the equator and therefore would deliver the same amount of sunlight to each point of Earth all year long.

END-OF-CHAPTER SOLUTIONS

Evaluating the News

1. The Earth's rate of rotation increased, or sped up, by a tiny amount, which shortened the length of a day (again by a tiny amount). This was caused by large amounts of rock being moved up or down by the Earthquake.
2. The "ice-skater effect" describes how an ice skater spins faster or slower depending on where his or her

arms are: when the arms are outstretched, one spins slowly, and one speeds up as the arms are pulled in toward the body. This is also called *conservation of spin* or *angular momentum*. For this reader, it makes the idea of the Earth's spin easier to understand *and* more convincing: large amounts of rock moving in or away from the center of the Earth are like the skater's arms moving in or out a little bit, since both cause the rate of rotation to change. However this reader thinks that if the article specified that rock moved *in* toward the earth or made the average size of the earth a little *smaller*, then the analogy would have been more clear as to why the length of the day increased.

3. 1.26 microseconds is 1.26×10^{-6} since "micro" means 10^{-6}. This is a *very* small number: for example we would have to wait one million days (over 2,700 years!) to detect a change in the length of a day by one second. This amount certainly does not change the time it took to complete a homework or to write this solution.
4. The Chilean earthquake is by no means unique. A similar occurrence took place during the 2004 Earthquake in Sumatra, and probably happens during any large earthquake.
5. That "an earthquake changes the length of a day and/or shifts the Earth's spin axis" is a testable and falsifiable statement. We can try to make hyper-accurate measurements of star positions and time (using very sensitive telescopes or atomic clocks, for example) over a few years to see if these changes have occurred. So yes, this is a hypothesis.
6. This reader does not believe the article has anything to do with business, per se, but it is a story of global interest (and business is global these days) and it is important to remember that we must all keep ourselves well-rounded and not focus on one single interest or field.
7. If the moon is moving away from us, then using the analogy of an ice-skater, the skater's arms are moving away from the body (i.e., the skater will slow down). Thus we expect the Earth's rate of rotation to be decreasing *and* the rate at which the Moon orbits the earth (i.e., its *period*) will be increasing. The result is that the length of the day is getting longer and the Moon is orbiting more slowly around the Earth.

Summary Self-Test

1. **(d)** The Sun, Moon and stars do all of the listed changes.
2. **(d)** The stars that we see at night depend on all of the options listed.
3. The seasons are caused by *the tilt of the Earth's axis*.
4. **(a)** If the moon is rising just as the sun is setting, it is full.
5. **(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 using Figure 2.17, it is sunset, or on the western horizon.
6. **(b)** We do not see eclipses every month because the Sun, Moon and Earth only line up about twice a year.
7. A frame of reference is a coordinate system within which an observer measures *positions* (space) and *motion* (time).
8. **c, b, d, a** The semimajor axis, or average distance from the Sun, is larger if the period is larger.
9. A planet moves fastest when it is *closest* to the Sun and slowest when it is *farthest* from the Sun. This is a restatement of Kepler's second law.

Questions and Problems: True/False and Multiple Choice

10. **False:** Kepler's laws describe *how* the planets orbit the Sun, not *why*.
11. **True:** The celestial sphere is the imaginary sphere of the sky.
12. **False:** Eclipses only happen two times a year.
13. **True:** The phases of the Moon depend on the relative positions of the Moon to the Sun (what part of the Moon is lit) and the Moon to the Earth (how much of that lit half we can see).
14. **False:** If a star rises north of east, it will set north of west.
15. **True:** All stars as viewed from the North Pole are circumpolar.
16. **(e)** Seasons happen because both (b) days are longer in the summer and (c) light is more direct in the summer.
17. **(d)** On an equinox, the ecliptic crosses the celestial equator, the sun rises due east, and one has exactly 12 hours of daylight.
18. **(b)** The moon is in a "tidal lock" with the Earth so it spins at the same rate as it orbits.
19. **(e)** Using Figure 2.17, the Moon must be in the third-quarter phase.
20. **(a)** A lunar eclipse happens when the *Earth's* shadow falls on the *Moon*.
21. **(d)** Kepler's second law says that planets move fastest when they are closest to the Sun.
22. **(d)** This claim violates Kepler's second law, since the planet is said to be moving *slowest* when it is *closest* to the Sun.

Conceptual Questions

23. It is not possible for the phases of the moon to be caused by shadows, since the full Moon phase would have to appear as a new Moon, as in this position the Earth's shadow could block it.
24. The north and south celestial poles are extensions of the north and south poles of the Earth. There are no "eastern" or "western" poles on Earth, so by extension, there are no such celestial poles. Another way to think about this is that the celestial sphere revolves around its poles (north and south) so there can't be another axis about which it revolves.
25. The analog of the North Pole is the north celestial pole, the South Pole is the south celestial pole, and the equator is the celestial equator.
26. Magellan could not use the North Star (Polaris) for navigation since he was in the Southern Hemisphere, thus Polaris was never above the horizon. Rather he might have discovered that the Southern Cross constellation points approximately south.
27. Since 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 right overhead, that is, at your zenith.
28. If you are standing at either of Earth's Poles, you will see no stars rise or set since they are all circumpolar.
29. The only place on Earth where you can, over the course of 1 year, see all stars is at the Equator.
30. The constellations through which the Sun appears to move through the year are called the *ecliptic*.
31. If Gemini is high in the night sky in the winter, then it is high in the daytime sky in the summer, which we can't see. Thus during the night it is behind the Earth. This is why we can't see Gemini in the summer or Sagittarius in the winter.
32. If I am flying in a jetliner, (a) my frame of reference can be the Earth or the plane itself. (b) I use the Earth if I want to talk about where I am relative to my point of departure or my destination or the speed at which the plane is flying. I would use the jetliner itself if I wanted to discuss where I am located on the plane, that is, my seat number or my position with respect to the wings.
33. If the Earth had an axis of rotation of only 3° there would be almost imperceptible seasons since the height of the Sun and the length of the day would change over the course of a year by very small amounts.
34. (a) At the vernal equinox, the Sun rises due east, sets due west and its maximum height in the sky will be equal to $90° - L$ where L is the observers' latitude. (b) At the summer solstice, the Sun will rise north of east, set north of west, and its maximum height in the sky will be $90° - L + 23.5°$.
35. The average temperatures on Earth lag a bit behind the formal change in seasons since it takes time for the Earth to heat up or cool down. Thus while the winter starts officially in December, it takes 1 to 2 months for the Earth to cool down, making the coldest months January and February.
36. If one wants to observe the Sun at the zenith at some point during the year, one must be located at or between the two tropics.
37. (a) On east-west streets near the equinoxes, the Sun is rising and setting in a direct line with the street, meaning drivers are receiving a lot of Sun glare, which always causes traffic jams. (b) If we assume that the Sun rises before I go to work, then I would rather live east of the city, so my afternoon drive home is *away* from the Sun.
38. (a) The Earth takes 24 hours to complete one rotation (about its axis) with respect to the Sun. (b) The Earth takes 26,000 years to complete one "wobble."
39. We always see the same side of the Moon because it is in a "tidal lock" with the Earth, that is, it takes the same amount of time for it to orbit the Earth as to rotate once about its own axis.
40. 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 like 2.17.
41. (a) Over the course of one orbit, the Earth will stay in a fixed position in the observer's sky, since the same side of the moon always faces the Earth. (b) The phases of the 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.
42. The "horns" of the crescent Moon always point away from the Sun. A waxing crescent Moon rises after sunrise so a waxing crescent Moon on the eastern horizon would have its horns pointed toward the horizon.
43. 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 doesn't 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, while at midnight the Moon will be at the meridian. For most observers this is relatively high in the sky, which

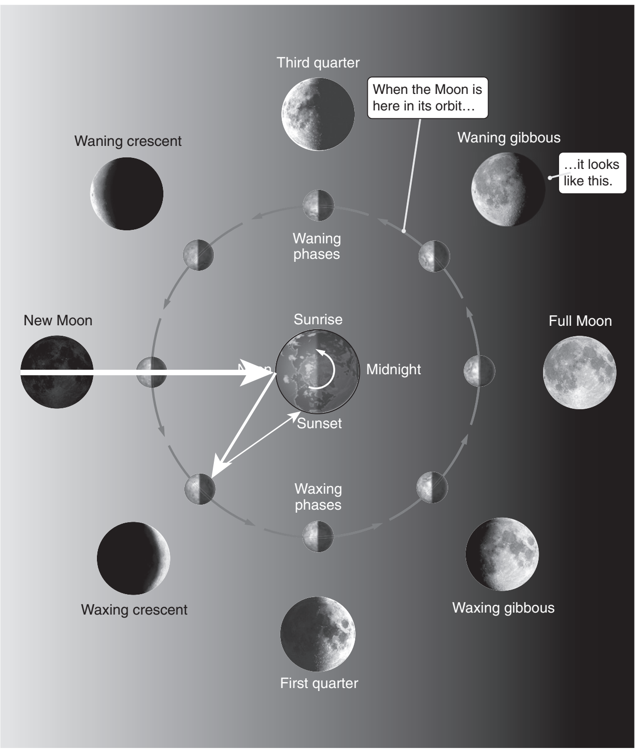
negates the defendant's claim. However, if one were living around the Arctic Circle then this argument might have some credibility since the Moon would never rise to be very high in the sky.

44. A total eclipse of the Sun casts a very small shadow on Earth and thus can only be seen from very narrow strips of the Earth, while the partial shadow covers a much larger area and can thus be seen by many more observers.
45. To see an eclipse at each full or new Moon requires that the Moon's orbit be in the same plane as the Earth's orbit around the Sun. Since this is not the case, we only see eclipses on those occasions when the two planes line up, about twice a year.
46. A full lunar eclipse is caused by the solid part of the Earth blocking the Sun's light. However the Earth's atmosphere is larger, and dust and gas particles in our atmosphere can still reflect some sunlight toward the Moon. Since most of the blue light is scattered out of its path to the Moon, what arrives at the Moon is mostly red, causing the reddish tinge. However, this color and brightness is dependent on how much dust, pollution or water vapor is in the air thus the color of a total eclipse doesn't always appear the same.
47. For 3 years, we ignore the extra $\frac{1}{4}$ of a day, but we add in the accumulated $\frac{4}{4} = 1$ day as an extra day in February (Feb. 29) every 4 years, calling this a "leap day" and the year a "leap year." Interestingly the year is not exactly 365.25 days, so we account for that extra difference by not having leap years at the turn of the century, unless it is also the turn of a millennium.
48. As long as the Moon is closer to the Earth than the Sun, then eclipses can be explained equally well by the Earth orbiting the Sun or the Sun orbiting the Earth. Thus eclipses do not prove or disprove the geocentric or heliocentric models.
49. Moonlight is merely reflected sunlight, so to argue that a vampire is killed by sunlight but not moonlight only makes sense if one uses the same suspension of disbelief to believe that (1) vampires exist, and (2) that reflected sunlight off of the Moon does not harm them.
50. If I experience the longest day of the year in the Northern Hemisphere then I am flying on the summer solstice, June 21. This also happens to be the shortest day of the year in the Southern Hemisphere since it is the winter solstice there. If this reader were going to explain it to the person next to me on the plane, I would probably have to ask for a napkin from the flight attendant and draw a picture or two like those in Figures 2.12 and 2.13 since I have found it hard to explain the changing lengths of a day by just "waving my hands."
51. While the Sun is at one focus of a planetary-orbit ellipse, there is nothing at the other focus.
52. By Kepler's third law, the semimajor axis a of an orbit is related to the orbital period P by $P^2 = a^3$.
53. *Eccentricity* of an orbit or ellipse describes how oval or elongated it is. *Zero eccentricity* means the orbit is a circle, while *high eccentricity* (close to one) is extremely elongated, like a hot dog or cigar.
54. (a) By Kepler's second law a planet is always moving the fastest when it is closest to the Sun. (b) By the same law a planet moves the slowest when it is furthest away from the Sun.
55. By Kepler's third law, period P and distance a of an orbit are not linearly related (i.e., 2 times further away equals 2 times longer) but are related by the $\frac{3}{2}$ power, that is, 30 times further away is $30^{3/2} = 165$ times longer.

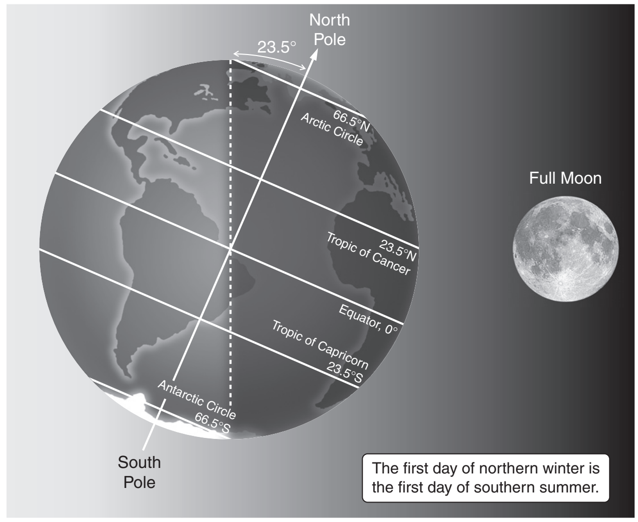
Problems

56. **Setup:** We know that it takes 24 hours for the Earth to make one revolution, so using $d = vt$ we can find the circumference of the Earth. To find the diameter we will use $C = 2\pi r$ where r is the radius and the diameter is twice that value.
    Solve: If the speed $v = 1{,}674$ km/h at the equator then the total distance traveled in 24 hours is $1{,}674\,\frac{\text{km}}{\text{h}} \times 24\text{ h} = 40{,}176$ km. The Earth's radius is then $r = \frac{C}{2\pi} = \frac{40{,}176\text{ km}}{2 \times 3.14} = 6{,}397$ km, so the diameter is twice that, or 12,790 kilometers.
    Review: I can think of two ways to check this answer. First, look in Appendix 2 of the book. Second, it is about 3,000 miles from NYC to LA and there are 3 time zones, which means there are about 1,000 miles or 1,600 kilometers per time zone. There are 24 time zones so the circumference of the Earth is about 24,000 miles or 38,000 kilometers. This is close to what we found so it is a reasonable sanity check.
57. **Setup:** To solve this problem, use Figure 2.17.
    Solve: If the waxing crescent is rising in the east, the time is mid-morning. If the Moon moves in its orbit over a few days, then it will be close to the first quarter, which will rise around noon. So we see that the Moon rises a little later each day. It takes about 29 days to complete a lunar month, and there are 24 hours in a day, so the Moon rises about $\frac{24}{29} = 0.8$ hour, or $0.8\text{ hr} \times \frac{60\text{ min}}{\text{hr}} = 48$ min later each day.
    Review: This reader thinks the best way to check this is to go out and see for yourself! It is a perfect naked-eye observing project that works from anywhere, whether a dark rural town or a bright city.

58. **Setup:** To solve this problem, use Figure 2.17.
Solve: According to our figure, the full Moon is opposite the Sun. So if the Sun is setting then the full Moon is rising, meaning the full Moon is *not* anywhere near overhead.
Review: This reader thinks the best way to check this is to go out and see for yourself! It is a perfect naked-eye observing project that works from anywhere, whether a dark rural town or a bright city.
59. **Setup:** To solve this problem, use Figure 2.17.



Solve: The white arrows show light bouncing off the Earth, then the Moon, and returning to Earth. Notice the thickness of the line shows how much light is returned, showing that Earthshine is fairly faint.
Review: An easy way to test this is to conduct an experiment like the visual analogy in Figure 2.16, but use a very dark room, and hold a mirror against your chest to reflect some of the light back toward your Moon.
60. **Setup:** Use Figure 2.15 and imagine being the person shown.
Solve: Since the Earth never changes the angle it makes with the person drawn in Figure 2.15, we can conclude that the Earth stays in a fixed position in the sky for a lunar observer.
Review: Try the experiment with an orange suggested in the section "We Always See the Same Face of the Moon." As you rotate around, ask a friend to observe where your head is with respect to the little person you drew on the Moon.
61. **Setup:** Remember that the full Moon is opposite the Sun, and use Figure 2.12.



Solve: Notice that if we are in Antarctica during northern-hemisphere winter, we are pointed toward the Sun for almost the whole day while the Moon will be opposite us, making it very unlikely it will rise above the horizon. At most you might see a tiny sliver of it rising if you are at the highest latitude of Antarctica.
Review: Recall that the full Moon is always opposite the Sun so if it is daylight for 24 hours then you can never see the full Moon!
62. **Setup:** This problem is solved with a little algebra. If we lose 1.26 microseconds in 1 day, then how many days do we need to combine for the total time change to equal 1 second? In other words, what number n times 1.26 microseconds equals 1 second?
Solve: $n \times 1.26 \times 10^{-6} = 1$ or $n = \frac{1}{1.26 \times 10^{-6}} = 7.94 \times 10^5$ days.
Review: Since the change in time is roughly 1 millionth of a second, it will take roughly 1 million days to change by 1 second. Our answer, 794,000 is close to 1 million, as expected.
63. **Setup:** We are relating distance (d), speed (v) and time (t) so use $d = vt$.
Solve: $t = \frac{d}{v} = \frac{15\text{ mi}}{60\text{ mi/hr}} = \frac{1}{4}$ hr or 15 min. If we speed up to 65 miles per hour (mph) then it takes $t = \frac{d}{v} = \frac{15\text{ mi}}{65\text{ mi/hr}} = 0.23$ hr or about 13.8 minutes. We save 1.8 minutes by speeding up.
Review: One could spend 30 minutes trying this out on the freeway, or recognize that at 60 mph, one travels a mile per minute, so 15 miles equals 15 minutes. If you speed up by a small amount then you cut your trip a little shorter, as we found.
64. **Setup:** For this problem, use Figure 2.8.
Solve: The tropic is always 23.5° from the equator, and since I am in Australia, I am at −23.5° latitude.

Figure 2.8 shows us that if you are at latitude L, then stars within L degrees of the celestial pole are circumpolar. Thus all stars within 23.5° of the Southern Cross will be circumpolar.
Review: One can verify this trend by looking at Figure 2.9.

65. **Setup:** For this problem, use Figure 2.13.
Solve: On the equinox the highest the Sun will be in your sky will be L degrees below the zenith or $90° - L$ degrees above the horizon, where L is your latitude. So 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: Figure 2.23 shows this situation as described.

66. **Setup:** For this problem, use Figure 2.12 and note that panel (b) corresponds to the summer solstice in the Southern Hemisphere.
Solve: As the 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. Using the same argument as in Problem 65, 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.
Review: One can also visualize this by combining Figures 2.10a and 2.13b, which shows the Sun 23.5° above the celestial equator and hence, your horizon.

67. **Setup:** For this problem, use Figures 2.8a, 2.10b, and 2.13b.
Solve: (a) Answers will vary with latitude but should look like Figure 2.8a. (b) Combining Figs. 2.10b and 2.13b, 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: 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.

68. **Setup:** For this problem, use Figure 2.10b.
Solve: If I am living in the U.S. (the Northern Hemisphere) then as shown in Figure 2.10b, I can see a star in the southern part of the celestial sphere if it is more than L degrees from the southern celestial pole. So if I want to see a star 65° from the celestial equator, that means it is within $90° - 65° = 25°$ of the south celestial pole. To see it in the Northern Hemisphere, I need to be at this latitude or below. The only state that reaches this low latitude is 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.

69. **Setup:** For this problem, use Figures 2.8 and 2.9.
Solve: If Polaris is D degrees from the zenith then your latitude is $L = 90° - D$. So in this problem, Polaris is 40° from the zenith therefore I am at latitude 50° which is in the southernmost part of Canada.
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.

70. **Setup:** For this problem, use Figures 2.12 and 2.13.
Solve: If the tilt of the Earth changed to D degrees, then the maximum height of the Sun above the celestial equator would also be D degrees. Since the tropics are D degrees above our equator, and the (ant)arctic circles are D degrees below the poles, we see that for this problem the tropics would be at latitudes $\pm 10°$ and the circles at $\pm 80°$.
Review: Imagine the Earth had no tilt; then where would the tropics and circles be? Now tilt the Earth by a tiny amount, and answer the question. One can easily derive the logic used in the solution in this way to verify that it is correct.

71. **Setup:** For this problem, use Figure 2.12a.
Solve: According to this figure, (a) if we 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: Reviewing the section Some Places on Earth Experience the Seasons Differently, we see that this is correct.

72. **Setup:** We need to know how much time it takes for the vernal equinox to move from one constellation to another. Let's 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 the Earth's wobble)?
Solve: There are 12 constellations, and if they are distributed roughly uniformly around in the zodiac (Figure 2.11) it takes roughly $\frac{26{,}000 \text{ yr}}{12} \approx 2{,}200$ yr for the equinox to move from one constellation to the

next. As extra credit, one might ask how long it will take to move from Pisces to Aquarius, since the student must figure out whether the equinox is moving from Pisces *toward* or *away from* Aquarius? The section Earth's Axis Wobbles, tells us that 2,000 years ago, the Sun was in Cancer on the first day of summer, while today it is in Taurus. Looking back at Figure 2.11, we see that this is a change in the direction of Pisces toward Aquarius, therefore the equinox need only move by one constellation or 2,200 years.
Review: 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!

73. **Setup:** Looking at Figure 2.14a, it took from 3000 BC to AD 2000 for the north celestial pole to move from Thuban to Polaris. The question is, how long will it take to move back to Thuban? We have all we need, as long as we remember that the full time to make a complete revolution is 26,000 years.
Solve: A full revolution is 26,000 years and it took 5,000 years to move from Thuban to Polaris. Therefore, only 21,000 years remain until the pole is back at Thuban.
Review: We could also estimate this from Figure 2.14c. It looks like the angle between Polaris and Thuban (as measured from the center of the image) is about 60°. That means there are 300° left until the pole is back at Thuban, or a total time to wait of $\frac{300}{360} \times 26{,}000 \approx 22{,}000$ years, which is close to what we found above.

74. **Setup:** To solve this problem, remember there are 360° in a circle and it takes about 29 days for the Moon to complete one orbit around the Earth, that is, to make one complete path through the fixed stars on the sky. We must find out how long it takes to move 1°.
Solve: If the Moon moves 360° in 29 days then it takes $\frac{29\text{ days}}{360°} = 0.08$ days to move 1°. $0.08\text{ day} \times \frac{24\text{ hr}}{\text{day}} \approx 1.9$ hr. We want the Moon to move half a degree, which will take half as long or about 1 hour, roughly.
Review: There are 720 half-degrees in one revolution, so $720 \times 1\text{ hr} = 720\text{ hr} \times \frac{\text{day}}{24\text{ hr}} = 30$ days, which is about 1 lunar month. Check!

75. **Setup:** If the Moon were moved further away from the Earth, it would look smaller and take longer to complete one orbit. Let's apply these to the questions.
Solve: (a) The phases of the Moon happen because of the Moon-Earth-Sun alignment, thus they would still occur. However, it would take longer to change from phase to phase, since the Moon's orbit is slower. Using Kepler's third law, the new orbit would be $2^{3/2} = 2.8$ times longer, so a lunar month would be 2.8 times longer as well. (b) A total eclipse of the Sun requires that the Moon fully block the disk of the Sun. Since the Moon will appear one-half its current size, it will not be able to fully block the Sun, therefore total solar eclipses will no longer happen. (c) For the Moon to be totally eclipsed it must pass completely inside the Earth's shadow, which is much larger than the size of the Moon. With the Moon smaller it would be a little easier for these to happen, so many partial eclipses would be seen as total.
Review: Interestingly, the Moon used to be closer to the Earth and has been drifting away over time. It is an unusual coincidence that the Moon and Sun currently have about the same size on the sky, because in the distant future, total solar eclipses will no longer be possible.

76. **Setup:** For this problem, use Figure 2.21c.
Solve: Note that in this figure, if the Earth observer sees a total lunar eclipse, the Moon observer is completely in the shadow of the Earth and thus will not see any of the Sun, that is, that the observer will see a total solar eclipse. Thus both are just as common.
Review: In questions such as these, it is very important to draw or use a figure. Remember, when in doubt, draw it out!

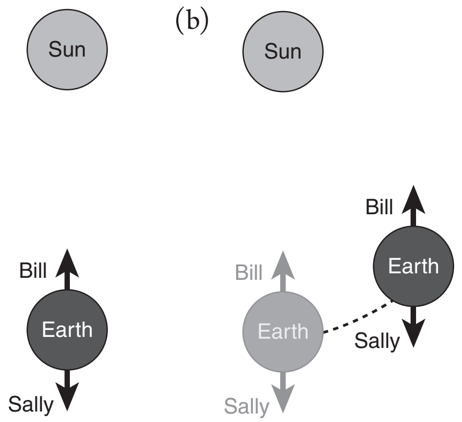
77. **Setup:** We are given a semimajor axis and asked for a period. This screams to us "Kepler's third law!"
Solve: $P^2 = A^3$ and we are given A (46.4 AU) so we must find P. $P = \sqrt{A^3} = \sqrt{46.4^3} = 316$ yr.
Review: Comparing our result with Appendix 2, we find that 46.4 AU is between Pluto and Eris, which have periods of 248 and 557 years.

78. **Setup:** For this problem, use Kepler's third law.
Solve: $P^2 = A^3$ and we are given P, so plugging into our formula we find $A^3 = P^2 = 12^2 = 144$ or $A = \sqrt[3]{144} = 5.25$ AU.
Review: Comparing our result with the Appendix, we find that a period of 12 years roughly corresponds to that of Jupiter, which has a distance right around 5.2 AU.

79. **Setup:** Kepler's third law tells us that $P^2 = A^3$. To test if this assertion is correct, we will figure out what distance corresponds to a period of 1 year.
Solve: $P^2 = A^3$ implies that $A^3 = 1^2$ or $A = 1$ AU, so this assertion is wrong.
Review: We can review this two ways. First, what period corresponds to a planet at a distance of 3 AU? Using Kepler's third law, we find $P^2 = 3^3$ or $P = \sqrt{27} \approx 5$ yr. Well that isn't 1 year as claimed. Another way is to recognize that the Earth is at 1 AU and has a period of 1 year, so this claim is obviously false.

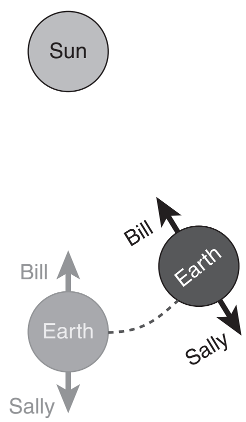
80. **Setup:** For this problem, make the figures as described in the text.
Solve:

(a) (b)



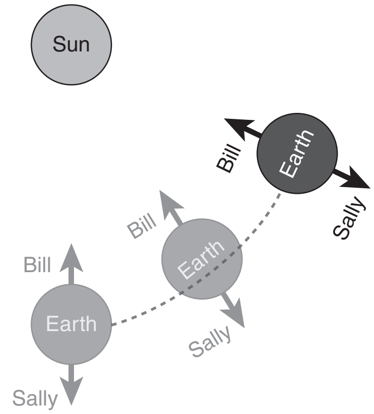
(c) In the second sketch, the Sun is not directly in front of Bill. (d) The Earth has to rotate more (about 1°) for the Sun to appear at the noon position for Bill. (e) This makes the solar day longer than the sidereal day.

(f)



Based on this figure, Sally will see the stars at a slightly different position at midnight as well.
Review: Looking up values online, the sidereal day is 23 hours, 56 minutes, while the solar day is 24 hours, confirming our findings.

81. **Setup:** It helps to think about this problem using figures as described in Problem 80a, b, and f.
Solve: (a) If the Earth revolves around the sun faster, it will travel further in its orbit in a given time. In this case, the Earth moves twice as fast so it travels twice as far. (b) The Earth will have to rotate further to bring the Sun back to the noon position. Since it takes about 1° to return the sun to noon at our current orbital speed, it will take about 2° in this hypothetical problem. (c) Based on our argument above, it will take another 4 minutes to return the sun to noon. (d) Since the solar day is longer than the sidereal day by 4 minutes, the solar day is currently 24 hours. In our hypothetical system, the solar day will be 24 hours, 4 minutes.
Review: A copy of the figure for Problem 80f confirms our finding:



Exploration

1. Mercury's orbit is definitely an ellipse, with the Sun noticeably far from the center of the orbit.
2. Using the grid provided, I estimate the semimajor axis is about 7.8 units and the semiminor axis is around 7.6, for a ratio of $\frac{7.6}{7.8} = 0.974$.
3. Using the eccentricity formula, $e = \sqrt{1 - r^2} = \sqrt{1 - 0.974^2} = 0.23$. Appendix 2 lists $e = 0.24$ so we are very close!
4. When I sweep the first time (i.e., closest to the Sun) the shade region is yellow. When I sweep the second time (i.e., furthest from the Sun) it is magenta. In the yellow region I count about 22.5 squares, and in the magenta region I also count about 22.5 squares. When I hit fractional squares I tried to find another one that was shaded with the amount needed to make a full square. I find about the same total area per region, as I should since Kepler's second law tells us that we should find equal area in equal time.
5. As I change the eccentricity, the orbit becomes very elongated if e is close to 1, and very circular when $e = 0$, as expected.
6. The position of the planet on the graph of axis versus period does not change, which confirms that these orbital characteristics do not depend on the eccentricity (or shape) of the orbit.
7. As I make the semimajor axis smaller, the period decreases.
8. As I make the semimajor axis larger, the period increases.
9. This confirms that the larger the semimajor axis, the longer the period of a planet.