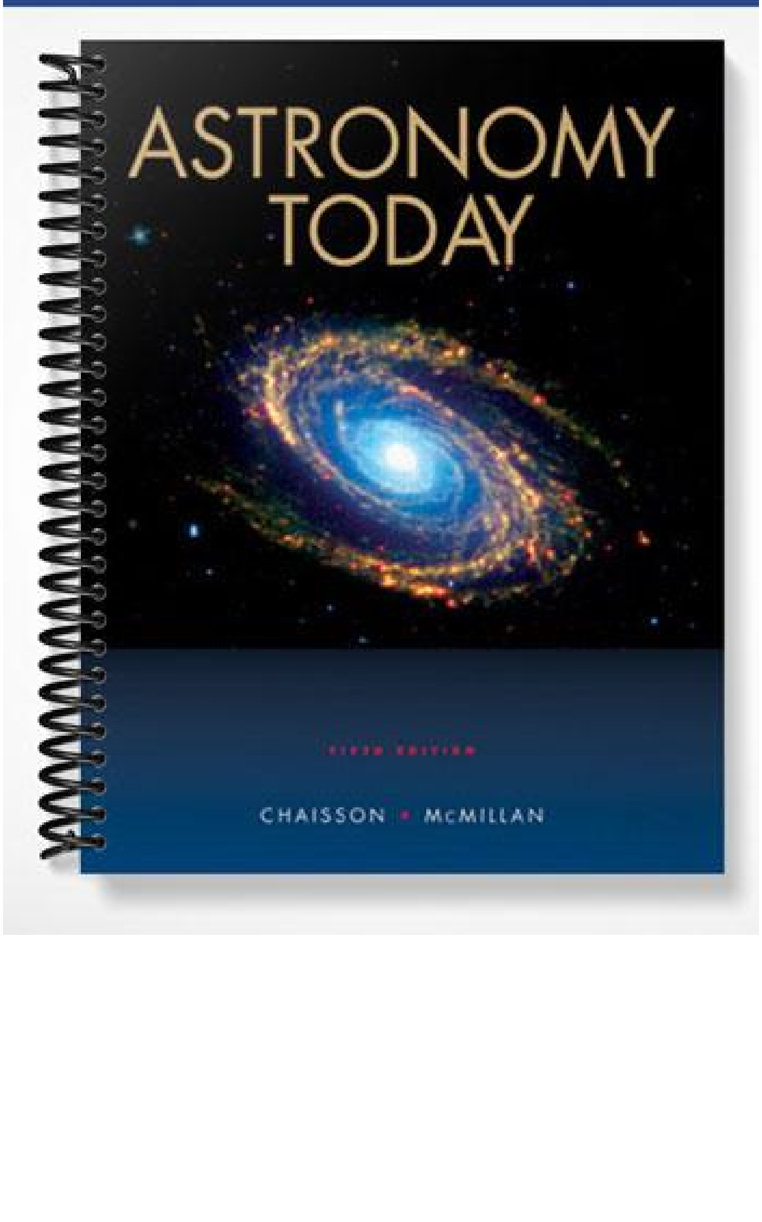
SOLUTIONS MANUAL



Chapter 2: The Copernican Revolution

The Birth of Modern Science

Outline

2.1 Ancient Astronomy
2.2 The Geocentric Universe
2.3 The Heliocentric Model of the Solar System
2.4 The Birth of Modern Astronomy
2.5 The Laws of Planetary Motion
2.6 The Dimensions of the Solar System
2.7 Newton's Laws

Summary

Chapter 2 continues the view from Earth begun in the previous chapter by discussing the apparent motions of the planets, which leads into two very important concepts that are introduced in this chapter: the history of astronomy and the laws of planetary motion and gravity. The historical context in which these concepts are couched provides a framework for the development of ideas relating to understanding the universe with one concept building upon the next. The fact that science and astronomy are human endeavors is most clearly seen here. Although the chapter takes a mostly western view, as is traditional, it does speak to the larger issue of contributions from various cultures. The latter often lead to dead ends whereas the western contributions lead directly to modern astronomy. But modern astronomy is anything but limited to western contributions; it is a truly international science as will be seen in later chapters.

The entire foundation for gravity and the laws of orbital motion are set forth in this chapter and there is hardly a chapter that follows that does not make reference to this material and build upon it. It is imperative for the student to understand this material. Without this understanding, very little of the following 26 chapters will make sense. The material is also highly relevant to issues of technology and modern life. There are many satellites in orbit that are taken for granted and about which little is understood by the students in our classes. These students have been exposed to the process of launches into orbit yet generally do not understand the process and often have many misconceptions about it. Everything from television cartoons to most movie and television science fiction promote these misconceptions that become the reality of our students.

Major Concepts

- Motions of the Planets
  - Wanderers among the stars
  - Retrograde motion
- Geocentric models of the universe
  - Aristotle
  - Ptolemy
- History of modern astronomy and heliocentric models
  - Copernicus
  - Brahe
  - Galileo
  - Kepler
- Keplers' laws of planetary motion

- Isaac Newton
    - Laws of motion
    - Gravity

Teaching Suggestions and Demonstrations

Section 2.1

Point out to the students that in ancient times astronomical observations were tightly intertwined with the mythological/spiritual aspects of human life as well as agricultural factors important to the well being of ancient cultures. Food sources, whether animal or vegetable, were found to be dependent on the annual seasonal cycles. Ask the students if they can come up with examples of things in their own lives that are dependent on celestial phenomena, including the Earth's rotation and the cyclical revolution period as we move around the Sun. When modern farmers plan, they simply look at the modern calendar and consult with technologically advanced prediction tools such as Doppler Radar and weather satellites. Ancient cultures lacked these tools and therefore relied on other instruments like *Stonehenge* or the *Caracol Temple* as described in the text.

Students may be surprised that even today, the spiritual components of society are still intermingled with astronomical phenomenon. One example is the date determined for the Christian holiday of Easter. This date is defined as the first Sunday following the first Full Moon after the Vernal Equinox.

Section 2.2

Ancient astronomers relied primarily on appearances. They could not "feel" the Earth rotating, for example, so believed that it was stationary beneath a rotating sky. Aristotle himself said that if the Earth were spinning, then we should feel the wind from its motion. Concerning models to describe the Universe, discuss the idea of "Saving the Appearance." Early astronomers were concerned with creating models of the Universe which were capable of providing accurate predictions of stellar motion without a deep regard for physical explanation or justification.

The scientific process is most easily demonstrated in a historical context and the evolution of our understanding of the structure of the universe is a remarkable story of the **scientific process**, where each successive model took care of some problem of the previous model. This chapter provides a catalyst for examples of the scientific method.

One common example of the scientific process at work is Ptolemy's **geocentric** model of the Universe with its epicycles and deferents being ultimately overthrown by the conceptually simpler Copernican **heliocentric** model. Students are often surprised to learn that aesthetics (simplicity, elegance, etc.) is one metric by which a scientific theory is measured. Although the early Copernican heliocentric model made no significant improvements with regard to predictive power, it was nonetheless accepted by the scientific community of its day. However, since accuracy of predictions is indeed a feature of scientific theories, even the Copernican model had to be modified as observations revealed more subtle details including the shapes of planetary orbits, which were discovered by Kepler to be ellipses rather than perfect circles.

Section 2.3

Retrograde motion is never obvious to students, and it needs demonstration. First, explain that the larger the orbit, the slower the planet moves. ➲ DEMO Draw some stars across the entire blackboard. Ask for a student volunteer to play the role of an outer planet. Have the student walk slowly from the right to the left (as seen by the class). You play the role of the observer on Earth. Without moving, note that the outer planet appears to move from west (right) to east (left). However, if you now walk parallel to the student (letting the student start first) and you move at a faster pace, you will appear to overtake and pass the student. This will be obvious. Now try it again, but stop both of your motions before you pass and several times while passing and note the position of the student relative to the background stars on the board. If the student walks slowly enough and you walk fast enough, you should get a good retrograde effect. (Try this out first before going into the classroom in order to find an effective pace to use.)

Expand on this idea, showing roughly circular orbits for the planets and how retrograde motion only occurs during the "passing" of the Earth relative to the outer planet. This will always occur when the outer planet is near opposition. Ask students which planets would have retrograde motion if they were standing on Mercury or Venus. Would other objects appear in retrograde motion or only outer planets? Emphasize that the effect is not unique to viewing from the Earth, nor does it only occur for planets.

Section 2.4

Before discussing **Galileo's observations with the telescope**, go over the prevailing worldview of his time and emphasize some of its major characteristics. This background will help students understand just how dramatic Galileo's discoveries were. The Aristotelian view maintained not only that all astronomical objects orbited Earth, but that they did so in perfect circles. Earth was flawed, but heavenly objects were perfect, unblemished, and unchanging. Further, Aristotle's view had been inextricably linked with Christianity through "medieval scholasticism," so contradicting Aristotle was extremely serious as it was equivalent to contradicting the Roman Catholic Church. Galileo's discoveries gave evidence that objects not only orbited something other than Earth (Jupiter's moons, phases of Venus) but also that heavenly bodies were not unblemished (sunspots, mountains on the Moon). Galileo's experiments with falling bodies also directly contradicted the Aristotelian view, which maintained that heavier objects fall faster than do lighter ones.

If Jupiter is visible at night when you are teaching the course, encourage your students to view Jupiter through binoculars from a reasonably dark site. The four **Galilean moons** are visible in binoculars, and students can follow their motions over the course of a week or so to re-create Galileo's observations.

Section 2.5

It will probably surprise students that Galileo and **Kepler** were contemporaries. In terms of conceptual development, it seems that Galileo built upon and provided evidence for Copernicus' heliocentric model, and then Kepler refined the heliocentric theory with details about the orbits of the planets. In fact, Galileo and Kepler were working at the same time. Galileo was placed under house arrest for promoting the heliocentric model and was forced to declare that it was useful as a mathematical tool only, not as a description of reality. Meanwhile, at the same time, Kepler was not only assuming that the planets orbit the Sun, but he was describing their actual paths and speeds in those orbits. Point out to students the differences in societies at the time that resulted is these very different climates for scientific research and discussion.

Throughout your discussion of the **historical development** and final acceptance of the Copernican system, sprinkle in interesting details of the lives of the people involved. Copernicus' theory was not even published until he lay on his deathbed. Brahe wore metal noses after he had his nose cut off in a duel. Galileo was a flamboyant character who loved to engage in debate. He published in Italian and often expressed his ideas in dialogue form, to make them accessible to both the "common man" and the scholar.

Begin your discussion of **Kepler's laws of planetary motion** by drawing an ellipse on the board or overhead, using the method shown in Figure 2.16. Define the various parts of an ellipse and show how a circle is the special case of an ellipse with an eccentricity of 0. Have students draw ellipses with the same eccentricities as the planets and point out that most of the planetary orbits are nearly circular. (See Table 2.1 for data.) Extend Kepler's second law to comets, and ask students to describe the relative speeds of a comet with a very elliptical orbit when it is close to the Sun and when it is far away.

Finally, for Kepler's third law, pick one or two planets and use the semi-major axes given in Table 2.1 to calculate the periods. Compare to the periods given in the Appendix on planetary orbital properties. Review the mathematical meaning of "squaring" and "cubing." Many students will confuse a^3 with $3a$. The more mathematically-aware students are often concerned that the units of the third law do not work out correctly.

Section 2.6

Students will find it helpful if you review something as basic as similar triangles here. Draw two triangles with one being perhaps twice as big as the other but having the same angles. Show that if you know the angles and the length of one of the sides, then you can easily calculate the lengths of the remaining sides. The ratio of lengths for the known side of the similar triangles will be the same as the ratios of the sides where the length is to be determined.

Section 2.7

Newton's laws of motion are extremely important and not necessarily intuitive. Give plenty of examples of each. For instance, ask students to imagine an airplane trip on a beautiful day with no turbulence. If you throw a peanut up in the air, does it hit the person behind you or fall back in your lap? Also consider the motion of Earth. If you jump up in the air, does the wall of the classroom slam into you? (Galileo already had a pretty good idea of the notion of inertia when he argued against the geocentric view and used ships at sea as an example.) Emphasize to students that Newton's laws divide objects into the two categories of *accelerating* and *non-accelerating*, instead of *moving* and *not moving*. An object moving at a constant velocity (that is, in a straight line and at a constant speed) is like an object at rest in that both have no net force acting on them.

Define **acceleration** carefully and calculate an acceleration with which students are familiar, such as the acceleration of a car merging onto the highway. You can use first units that make sense, such as miles per hour per second, and then convert to the more standard meters per second squared to help students gain a feel for the acceleration due to Earth's gravity. Students often confuse acceleration and velocity, so be sure to distinguish between the two carefully. ➲ **DEMO** You can demonstrate Newton's third law and the role of mass by attaching a rope to a rolling chair and asking a student to pull it across the floor. Then sit in the chair and repeat. Ask the student to compare (qualitatively) the force used to accelerate the empty chair with the force applied to the chair with occupant.

➲ **DEMO** Use an air track with carts or an air hockey table with pucks to demonstrate Newton's laws, if possible. Seeing the behavior of objects in a nearly frictionless environment will help students overcome Aristotelian misconceptions about motion.

Newton's law of gravitation is explained in *More Precisely 2-2*. To examine the significance of the various terms, ask students what would happen to the force of gravity between Earth and the Sun if the mass of Earth doubled or if the distance between them doubled. Students often confuse the force of gravity with acceleration due to gravity. Derive the expression for acceleration due to gravity and show that it is consistent with Galileo's experiments regarding the motion of falling bodies. Also emphasize that Earth alone does not "have" gravity; gravity is a force *between* two objects. For instance, the weight of an object is the force between it and Earth. Calculate the weight of a 70 kg person on Earth and on the Moon and compare. Use Figure 2.26 to help explain how gravity is responsible for objects falling as well as objects orbiting. Ask your students to picture the Moon as constantly falling towards the Earth and missing!

➲ **DEMO** To demonstrate **orbital motion**, whirl around a ball on a string in a horizontal circle. In the demonstration, the tension in the string provides the centripetal force. In the case of a planet, gravity is the centripetal force. Ask students to predict what would happen if the force suddenly "turned off;" demonstrate by letting go of the string. This is also a good time to discuss the fact that an object in a circular orbit is constantly accelerating. Although moving at a constant speed, the object is always changing its direction. Reiterate: the speed may remain constant, but the direction change means a change in velocity nonetheless. Any change in velocity means that the acceleration is not zero.

➲ **DEMO** Ask your students whether it is possible to throw an object into orbit around the Earth. If they have read the text before coming to lecture they will probably answer "no." (Orbital velocity is about 18,000 mph around the Earth.) Next, bet them that you can actually throw an object into orbit and will even demonstrate it in class (brag a little about your fast pitch!). After they express their doubts, throw an object up and across the room so they can easily see the curve of the projectile path. Tell them that the object was in orbit but ran into the Earth! Objects orbit around the center of mass; for all practical purposes this is the center of the Earth in this case. Draw on the chalk board what the orbit would have been if the object had not run into the Earth. By throwing the object harder and harder it goes further. If thrown fast enough (orbital velocity) it will curve (fall) around the Earth at the same rate the Earth's surface curves.

Student Writing Questions

1. Look up one of the historical figures mentioned in this chapter. Find out as much as you can about their life and the period of time in which they lived. Describe what their daily life must have been like. In what ways was astronomy a part of their life?

2. Describe what it would be like to live without any gravity. What would be easier? Harder? Impossible? Fun? Annoying? Do you think you would like to live like this for an extended period of time?

3. What if Kepler had been prevented from gaining access to Tycho Brahe's observations? Speculate how this might have affected Newton's work on gravity. Would he still have been successful and proved his law of gravity? Would he even have worked on this problem? Do you think someone would have if Newton had not worked on it? Would our science today be affected by such a small change in historical events 400 years ago?

Answers to End of Chapter Exercises

Review and Discussion

1. Islamic astronomers preserved the discoveries of the ancient Greeks. They developed many methods in trigonometry. Most common stars have names given to them by Islamic astronomers. Chinese astrologers kept careful records of comets and "new" stars, extending back many centuries.

2. The geocentric model of Aristotle has the objects of the solar system revolving around the Earth. (See Figure 2.6.) The planets moved in small circles called epicycles and the center of these circles moved around the Earth in circles called deferents. Ptolemy needed 80 circles, however, to fully describe the motions of the 5 visible planets, the Moon, and the Sun.

3. The basic flaw in the Ptolemaic model is the Earth is not at the center of the solar system, let alone the entire universe. Another flaw, which is equally valid, is that the Ptolemaic model did not attempt to explain why the motions are the way they are observed to be. There was no physical reason given for the complex model of Ptolemy. Today we would require any such explanation to be based on fundamental physical laws.

4. Copernicus re-introduced the heliocentric model for explaining the motions of the visible bodies of the solar system. In so doing he realized that the rather complex observed motions of these bodies could be explained in a simpler way.

5. A theory is a framework of ideas and assumptions used to explain some set of observations and make predictions about the real world. A theory can never be proved to be true, but it can be proven to be false. As long as a theory survives attempts at disproving it, it may remain accepted.

6. Copernicus's ideas were finally published in the year of his death, 1543. By the beginning of the next century, around 1600, both Galileo Galilei and Johannes Kepler had fully embraced the Copernican heliocentric theory. It was not until the 19th and 20th centuries that the heliocentric theory could actually be proved.

7. The Copernican principle states that the Earth does not have a central position with respect to the solar system or any other part of the universe. It has been expanded upon to include the Sun not having a central position in the Galaxy and the Galaxy not having a central position in the universe.

8. Galileo discovered the phases and size changes of Venus. He also found the sizes and phases were related and could be explained using the heliocentric model. Other discoveries, such as the moons of Jupiter, showed that objects could move around a body other than the Earth.

9. First Law: the orbits of planets are in the shape of an ellipse with the Sun at one focus. Second Law: a line connecting the Sun and a planet sweeps out equal areas in equal intervals of time. Third Law: the square of the orbital period is proportional to the cube of the semi-major axis.

10. Tycho made observations of the planets' positions over many years. With this data, Kepler was able to determine the true motions of the planets around the Sun.

11. The Astronomical Unit, defined as the semi-major axis of the Earth's orbit, was used to describe the distances to other planets but the size of the A.U. was not known. Using radar, which allows distances to be determined directly in units such as kilometers, the distance to Venus could be measured. With the distance to Venus known in both A.U. and kilometers, the length of the Astronomical Unit could be determined, and, thus, the distance between the Earth and the Sun.

12. Astronomers used triangulation of the inner planets, Mercury and Venus, when they transited the Sun. Timings of these transits from various positions on Earth allowed their distances to be calculated.

13. Kepler's three laws resulted from the analysis of observational data. Kepler's laws describe the motions of planets around the Sun but they do not explain why the planets move as they do. Newton's laws were derived from a mathematical model. They represent a deeper understanding of the way in which all objects move and interact with one another.

14. First law of motion: Every body continues in a state of rest or in a state of uniform motion in a straight line unless it is compelled to change that state by a force acting on it.
    Second law of motion: When a force F acts on a body of mass m, it produces in it an acceleration a equal to the force divided by the mass. Thus, $a = F/m$, or $F = ma$.
    Third law of motion: To every action there is an equal and opposite reaction.
    Law of gravity: Every particle of matter in the universe attracts every other particle with a force that is directly proportional to the product of the masses of the particles and inversely propotional to the square of the distance between them.

15. The first modification was to Kepler's first law. The planet and Sun move in elliptical orbits around a common center of mass, located at the focus of the ellipse. The second modification was to Kepler's third law. The period squared is not only proportional to the semi-major axis cubed, it is also inversely proportional to the sum of the masses.

16. In fact, the Earth also moves in response to the baseball but its motion is not noticeable because it is so slight. Newton's second law states that the acceleration, produced by a force, is inversely proportional to the mass of the object being moved. The baseball has little mass and displays a large acceleration. The Earth is very massive and has so little acceleration in response to the baseball that it cannot be measured. If the baseball were as massive as the Moon, the motion of the Earth would be obvious, as indeed it is to astronomers who can measure the motion of the Earth due to the Moon.

17. The height to which a baseball can be thrown is dependent on the force of gravity pulling it back down (and also on how fast you initially throw it). All else being equal, because the Moon's gravity is about one sixth of the Earth's, the ball can be thrown much higher. Note also that the lack of air friction on the surface of the Moon (it has no atmosphere) also contributes significantly to the increased height to which the ball can be thrown.

18. The force of gravity between the Moon and Earth must pull the Moon towards the Earth, i.e., it must fall. Its motion tangential to that motion results in the Moon falling around the Earth.

19. Escape velocity is the velocity necessary to escape the gravitational pull of a body. A velocity less than this will result in an object eventually falling back to the body. A velocity greater than the escape velocity will result in an object never returning to the body.

20. If the Sun's gravity suddenly stopped, Earth would continue to move at its current velocity but in a straight line path. The gravitational pull between the Earth and Sun accelerates the Earth in the direction of the Sun, changing this straight-line path to one that is curved.

Conceptual Self-Test

1. F
2. T
3. F
4. F
5. F
6. F
7. F
8. T
9. F
10. T
11. A
12. D
13. B
14. C
15. C
16. A
17. C
18. B
19. C
20. A

Problems

1. Use the equation at the end of section 1.5 for this problem.
   (a) The distance, *d*, to the Moon is 384,000 km and a minute of arc is 1/60 of a degree.

$$\frac{d}{2\pi \times 384,000\text{km}} = \frac{1/60^\circ}{360^\circ}$$

$$d = 112 \text{ km}$$

   (b) The distance, *d*, to the Sun is 150,000,000 km.

$$\frac{d}{2\pi \times 150,000,000\text{km}} = \frac{1/60^\circ}{360^\circ}$$

$$d = 43,600 \text{ km}$$

   (c) Saturn is 9.5 A.U. from the Sun; 8.5 A.U. at its closest distance, *d*, to the Earth.

$$\frac{d}{2\pi \times 8.5 \times 150,000,000\text{km}} = \frac{1/60^\circ}{360^\circ}$$

$$d = 372,000 \text{ km}$$

2. In one day, the Earth moves 1/365 of its circumference or $2\pi \times 1$ A.U. / 365 = 0.0172 A.U. Mars has an orbital period of 687 days and will move $2\pi \times 1.5$ A.U. / 687 = 0.0137 A.U. Use the formulas as in the last problem but solve for the angle. First, assume Mars does not move; what angle, α, will it appear to have moved through?

$$\frac{0.0172 \text{ A.U.}}{2\pi \times 0.5 \text{ A.U.}} = \frac{\alpha}{360^\circ}$$

$$\alpha = 2^\circ \text{ retrograde}$$

Now assume the Earth does not move and Mars alone moves. Through what angle will it move?

$$\frac{0.0137 \text{ A.U.}}{2\pi \times 0.5 \text{ A.U.}} = \frac{\alpha}{360^\circ}$$

$$\alpha = 1.6^\circ \text{ prograde}$$

The net angle moved will be 0.4° retrograde. That is about 24 arc minutes or one minute per hour.

3. From *More Precisely 2-1* we have for the perihelion of Pluto

$$a(1-e) = 39.48(1-.249) = 29.6 \text{ AU},$$

while for Neptune's perihelion we get

$$a(1-e) = 30.07(1-.009) = 29.8 \text{ AU},$$

which is further than Pluto's perihelion. Therefore, Pluto is closer to the Sun than Neptune when Pluto is at perihelion, no matter where Neptune is in its orbit.

4. The sum of perihelion and aphelion distances is the major axis; 6.0 A.U. The semi-major axis is therefore 3.0 A.U. The eccentricity can be calculated from the focus-center distance, which is aphelion distance minus perihelion distance or 2.0 A.U., divided by the semi-major axis, giving 0.67. Using Kepler's third law to calculate the period gives $P^2 = 3.0^3$. The period equals 5.2 years.

5. The perihelion will be 0.72 AU and the aphelion will be 1 AU, so the semimajor axis will be $\frac{0.72+1}{2} = 0.86 \text{ AU}$. Using Kepler's 3rd law, $P^2=a^3$, gives an orbital period of $P = \sqrt{a^3} = .798 \text{ Earth years} = 290 \text{ days}$. Therefore, the spacecraft can make the one-way trip from Venus's orbit to Earth's orbit in half that time or 145 days.

6. Use Kepler's third law to calculate the semi-major axis from the period. $76^2 = a^3$; $a = 17.9$ A.U. Twice this is the major axis or 35.9 A.U. Subtracting the perihelion distance will give the aphelion distance, or 35.9 - 0.6 = 35.3 A.U. This places it beyond Neptune at aphelion.

7. Mercury's distance from the Sun is 0.39 A.U. (assuming its average distance). This is equivalent to 59 million km. Using the equation for parallax from *More Precisely 1-4* gives parallax = 3000 × 57.3° / 59 million km, parallax = 0.0029° = 8.1".

8. 1 AU is about 150 million kilometers. 0.7 AU is 105 million kilometers. Since the speed of light and radar is 300,000 kilometers per second, and a round trip to Mars is 1.4 AU, or 210 million kilometers, 210,000,000 km / 300,000 km/sec = 700 seconds (which equals about 12 minutes).

9. The modified version of Kepler's Third Law is in Earth and solar units; P must be in years, a must be in AU, and the mass will be in units of the mass of the Sun. 1.88 million km = 0.0126 A.U., 16.7 days = 0.0457 year. Solving the Third Law for the mass gives $M = a^3/P^2$. Using these values for a and P gives M = 0.000957 solar masses. The Sun's mass is 1.99×10^{30} kg, so the mass of Jupiter should be about 1.9×10^{27}kg.

10. Convert 26,000 light years to km; $26{,}000 \times 9.5{\times}10^{12} = 2.5{\times}10^{17}$ km. Calculate the circumference of the orbit around the Galaxy. $2\pi \times 2.5{\times}10^{17}$ km gives $1.6{\times}10^{18}$ km. Dividing this by the speed 220 km/s gives the period of the orbit in seconds. $P = 7 \times 10^{15}$ s = $2.2{\times}10^8$ yr. Convert 26,000 light-years to A.U. = $1.6{\times}10^9$ A.U. Using Kepler's third law gives a mass of: mass = $(1.6{\times}10^9 \text{ A.U.})^3/ (2.2{\times}10^8 \text{ yr})^2$. Mass = $4.5{\times}10^{12}$ solar masses.

11. Using Kepler's third law, $a = ((10^6)^2)^{1/3}$. Distance = 10,000 A.U. One light-year is 63,200 A.U. Calculating the period gives $P = ((63{,}200)^3)^{1/2}$. P = 16 million years.

12. The acceleration due to gravity is $a = GM/R^2$. If the acceleration is 9.80 m/s^2 at the surface, at any other distance from the surface, d, the acceleration will be $a = 9.80\, R^2/(R+d)^2$.
(a) for d = 100 km, a = 9.50 m/s^2, (b) for d = 1000 km, a = 7.33 m/s^2, (c) for d = 10,000 km, a = 1.49 m/s^2.

13. Choose the case for d = 1000 km. From *More Precisely 2-3*, calculate the orbital speed = $((6.67{\times}10^{-11} \times 6{\times}10^{24}) / 7.4{\times}10^6)^{1/2}$ = 7350 m/s. Calculating the centripetal acceleration gives $a = (7350)^2 / 7.4{\times}10^6 = 7.3$ m/s^2. This is the same as the acceleration due to gravity for part (b) of question 12. This will be the case for parts (a) and (c); the two accelerations will be the same.

14. <u>Assume</u> your mass is 55 kg. Using Newton's law of gravity;

$$F = \frac{6.67\times10^{-11}\times5.97\times10^{24}\times55}{\left(6.378\times10^{6}\right)^{2}}$$

$$F = 538 \text{ N}$$

F = 121 lbs, that is, your **weight**!

15. The speed in a circular orbit is given in Chapter 2. Putting in the appropriate information for the Moon gives:

$$v = \sqrt{\frac{6.67\times10^{-11}\times7.4\times10^{22}}{1.7\times10^{6}}}$$

v = 1700 m/s or 1.7 km/s

Escape velocity = 1.4 times the circular velocity

Escape velocity = 1.4 × 1.7 = 2.4 km/s

Resource Information

Student CD Media

Movies/Animations
None

Interactive Student Tutorials
None

Physlet Illustrations
Kepler's 3 Laws
Universal Gravitation
Escape Speed

Transparencies

T-12	Figure 2.4	Planetary Motion	p. 36
T-13	Figure 2.5	Inferior and Superior Orbits	p. 37
T-14	Figure 2.6/7	Ptolemy's Geocentric Model	p. 38/39
T-15	Figure 2.9	Retrograde Motion	p. 40
T-16	Figure 2.12	Venus Phases	p. 43
T-17	Figure 2.16/17	Ellipse and Kepler's 2nd law	p. 46/47
T-18	Figure 2.21	Newton's 1st Law	p. 51
T-19	Figure 2.22/26	Gravity and Escape Speed	p. 52/56
T-20	Figure MP 2-2	The Falling Moon	p. 53
T-21	Figure 2.23	Gravitational Force	p. 54

Suggested Readings

Berman, B. "The Outsider." *Astronomy* (October 2003). p. 48. Illuminating article about a modern astronomer. Helpful when discussing the scientific method with students and a good reminder that science is a human endeavor/activity. Relevant to this chapter and to Chapter 1.

Brown, Jeanette. "Its just a phase." *Astronomy* (Apr 1999). p. 76. Describes an activity designed to demonstrate the phases of the Moon.

Falk, D. "The Rise and Fall of Tycho Brahe." *Astronomy*, (December 2003). p. 52. A nice overview of Tycho Brahe, his observatories and details of his eccentric life.

Gettrust, E. "An Extraordinary Demonstration of Newton's Third Law." *The Physics Teacher* (October 2001). p. 392. A description of an apparatus using magnets and force probes to demonstrate that the action and reaction forces are equal in magnitude.

Gould, Stephen Jay. "The sharp-eyed lynx, outfoxed by nature. Part one: Galileo Galilei and the three globes of Saturn." *Natural History* (May 1998). p. 16. Discusses the life and work of Galileo.

Kemp, Martin. "Kepler's cosmos." *Nature* (May 14, 1998). p. 123. Describes ancient cultures image of the cosmos.

Kemp, Martin. "Maculate moons: Galileo and the lunar mountains." *Nature* (Sept 9, 1999). p. 116. Discusses Galileo's observations of features on the Moon.

Krupp, E. C. "Designated authority." *Sky & Telescope* (May 1997). p. 66. Discusses the role of the "official" astronomer in ancient cultures.

Krupp, E. C. "From here to eternity: Egyptian astronomy and monuments." *Sky & Telescope* (Feb 2000). p. 87. Discusses the depiction of the stars and sky in ancient Egyptian monuments.

Krupp, E. C. "Stairway to the stars: the Jantar Mantar, or 'House of Instruments,' in Jaipur, India." *Sky & Telescope* (Sept 1995). p. 56. Describes an 18th century Indian monument which was used to track the motions of the Sun.

Livio, M. "Is God a Mathematician?" *Mercury* (January/February 2003). p. 26. Historically based discussion of mathematics in the development of scientific theories.

Morris, R. *Dismantling the Universe: The Nature of Scientific Discovery*, Simon and Schuster, New York, 1983. Chapter 4 covers the story of Brahe, Kepler, and Galileo.

Nadis, S. "Big Science." *Astronomy* (May 2003). p. 46. Explores the trend toward fewer, but larger research projects and the hope for a trend reversal. This is a good contrast when discussing the projects that occupied Brahe/Kepler and Galileo, etc.

Olson, Donald W., Sinnott, Roger W. "Blue-moon mystery solved." *Sky and Telescope* (3 Mar 1999). p. 55. Discussion of the meaning of the term "blue moon."

Olson, Donald W. and Fienberg, Richard Tresch; Sinnott, Roger W. "What's a blue moon?" *Sky and Telescope* (5 May 1999). p. 36. Even more discussion about the interesting history of the term "blue moon."

Panek, Richard. "Venusian testimony." *Natural History* (June 1999). p. 68. Discusses Galileo's observations of the phases of Venus.

Stephenson, F. Richard. "Early Chinese observations and modern astronomy." *Sky & Telescope* (Feb 1999). p. 48. Discusses ancient Chinese astronomical observations, and how they can be connected to modern science.

Sullivant, Rosemary. "An unlikely revolutionary: Nicolas Copernicus." *Astronomy* (Oct 1999). p. 52. Discusses the life and scientific works of Copernicus.

Sullivant, Rosemary. "When the apple falls: Sir Isaac Newton." *Astronomy* (Apr 1998). p. 54. Discusses Newton, his life and his scientific works.

Toepker, T.,"Babies and the Moon." *The Physics Teacher* (April 2000). p. 242. Contains a graph of birth data to dispel the popular myth that more babies are born under a full moon.

Trefil, James. "Rounding the Earth." *Astronomy* (Aug. 2000). p. 40. Describes some of the astronomical knowledge of ancient Egyptian, Greek, and Near Eastern cultures.

Vogt, E. "Elementary Derivation of Kepler's Laws." *American Journal of Physics* (April 1996). p. 392. For your more advanced students, here is a proof of Kepler's laws that follows from conservation of energy and angular momentum, with further discussion.

Williams, K. "Inexpensive Demonstrator of Newton's First Law." *The Physics Teacher* (February 2000). p. 80. Uses a Downy® Ball fabric-softener dispenser!

Notes and Ideas

*Class time spent on material: Estimated:*_______ *Actual:*______________

Demonstration and activity materials:

Notes for next time: