CHAPTER 7 Summary

BIG IDEA Objects move in a circular path when there is a centrally directed force. The concept of circular motion helps to explain phenomena such as orbital motion or torque.

SECTION 1 Circular Motion

KEY TERM

- An object that revolves about a single axis undergoes circular motion.
- An object in circular motion has a centripetal acceleration and a centripetal force, which are both directed toward the center of the circular path.

centripetal acceleration

SECTION 2 Newton's Law of Universal Gravitation

KEY TERM

- Every particle in the universe is attracted to every other particle by a force that is directly proportional to the product of the particles' masses and inversely proportional to the square of the distance between the particles.
- Gravitational field strength is the gravitational force that would be exerted on a unit mass at any given point in space and is equal to free-fall acceleration.

gravitational force

SECTION 3 Motion in Space

- Kepler developed three laws of planetary motion.
- Both the period and speed of an object that is in a circular orbit around another object depend on two quantities: the mass of the central object and the distance between the centers of the objects.

SECTION 4 Torque and Simple Machines

KEY TERMS

- Torque is a measure of a force's tendency to rotate an object.
- The torque on an object depends on the magnitude of the applied force and on the lever arm.
- Simple machines provide a mechanical advantage.

torque

lever arm

VARIABLE SYMBOLS

Quantities		Units	
v_t	tangential speed	m/s	meters/second
a_c	centripetal acceleration	m/s^2	$meters/second^2$
F_c	centripetal force	N	newtons
F_g	gravitational force	N	newtons
g	gravitational field strength	N/kg	newtons/kilogram
T	orbital period	s	seconds
τ	torque	N•m	newton meter

Problem Solving

See **Appendix D: Equations** for a summary of the equations introduced in this chapter. If you need more problem-solving practice, see **Appendix I: Additional Problems.**

CHAPTER 7 Review

Circular Motion

REVIEWING MAIN IDEAS

1. When a solid wheel rotates about a fixed axis, do all of the points of the wheel have the same tangential speed?

2. Correct the following statement: The racing car rounds the turn at a constant velocity of 145 km/h.

3. Describe the path of a moving body whose acceleration is constant in magnitude at all times and is perpendicular to the velocity.

4. Give an example of a situation in which an automobile driver can have a centripetal acceleration but no tangential acceleration.

CONCEPTUAL QUESTIONS

5. The force exerted by a spring increases as the spring stretches. Imagine that you attach a heavy object to one end of a spring and then, while holding the spring's other end, whirl the spring and object in a horizontal circle. Does the spring stretch? Explain.

6. Can a car move around a circular racetrack so that the car has a tangential acceleration but no centripetal acceleration?

7. Why does mud fly off a rapidly turning wheel?

PRACTICE PROBLEMS

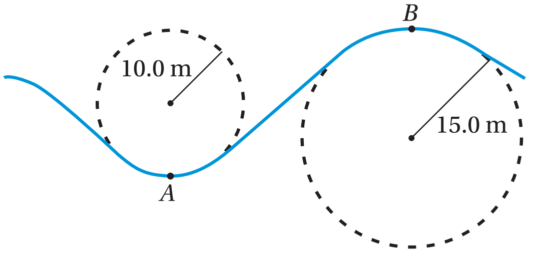
For problems 8–9, see Sample Problem A.

8. A building superintendent twirls a set of keys in a circle at the end of a cord. If the keys have a centripetal acceleration of 145 m/s^2 and the cord has a length of 0.34 m, what is the tangential speed of the keys?

9. A sock stuck to the side of a clothes-dryer barrel has a centripetal acceleration of 28 m/s^2. If the dryer barrel has a radius of 27 cm, what is the tangential speed of the sock?

For problems 10–11, see Sample Problem B.

10. A roller-coaster car speeds down a hill past point *A* and then rolls up a hill past point *B*, as shown below.
    a. The car has a speed of 20.0 m/s at point *A*. If the track exerts a normal force on the car of 2.06×10^4 N at this point, what is the mass of the car? (Be sure to account for gravitational force.)
    b. What is the maximum speed the car can have at point *B* for the gravitational force to hold it on the track?



11. Tarzan tries to cross a river by swinging from one bank to the other on a vine that is 10.0 m long. His speed at the bottom of the swing is 8.0 m/s. Tarzan does not know that the vine has a breaking strength of 1.0×10^3 N. What is the largest mass that Tarzan can have and still make it safely across the river?

Newton's Law of Universal Gravitation

REVIEWING MAIN IDEAS

12. Identify the influence of mass and distance on gravitational forces.

13. If a satellite orbiting Earth is in free fall, why does the satellite not fall and crash into Earth?

14. How does the gravitational force exerted by Earth on the sun compare with the gravitational force exerted by the sun on Earth?

15. Describe two situations in which Newton's laws are not completely accurate.

CONCEPTUAL QUESTIONS

16. Would you expect tides to be higher at the equator or at the North Pole? Why?

17. Given Earth's radius, how could you use the value of *G* to calculate Earth's mass?

PRACTICE PROBLEMS

For problems 18–19, see Sample Problem C.

18. The gravitational force of attraction between two students sitting at their desks in physics class is 3.20×10^{-8} N. If one student has a mass of 50.0 kg and the other has a mass of 60.0 kg, how far apart are the students sitting?

19. If the gravitational force between the electron (9.11×10^{-31} kg) and the proton (1.67×10^{-27} kg) in a hydrogen atom is 1.0×10^{-47} N, how far apart are the two particles?

Motion in Space

REVIEWING MAIN IDEAS

20. Compare and contrast Kepler's model of the solar system with Copernicus's model.

21. How do Kepler's laws help support Newton's theory of gravitation?

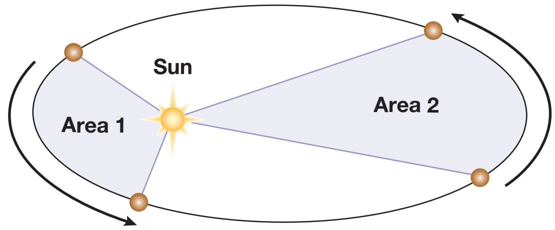
22. You are standing on a scale in an elevator. For a brief time, the elevator descends with free-fall acceleration. What does the scale show your weight to be during that time interval?

23. Astronauts floating around inside the space shuttle are not actually in a zero-gravity environment. What is the real reason astronauts seem weightless?

CONCEPTUAL QUESTIONS

24. A tiny alien spaceship ($m = 0.25$ kg) and the *International Space Station* are both orbiting Earth in circular orbits and at the same distance from Earth. Which one has a greater orbital speed?

25. The planet shown below sweeps out Area 1 in half the time that the planet sweeps out Area 2. How much bigger is Area 2 than Area 1?



26. Comment on the statement, "There is no gravity in outer space."

PRACTICE PROBLEMS

For problems 27–29, see Sample Problem D.

27. What would be the orbital speed and period of a satellite in orbit 1.44×10^{8} m above Earth?

28. A satellite with an orbital period of exactly 24.0 h is always positioned over the same spot on Earth. This is known as a *geosynchronous* orbit. Television, communication, and weather satellites use geosynchronous orbits. At what distance would a satellite have to orbit Earth in order to have a geosynchronous orbit?

29. The distance between the centers of a small moon and a planet in our solar system is 2.0×10^{8} m. If the moon's orbital period is 5.0×10^{4} s, what is the planet? (See **Figure 3.3** of the chapter for planet masses.)

Torque and Simple Machines

REVIEWING MAIN IDEAS

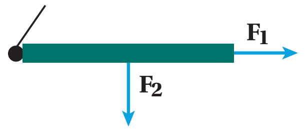
30. Why is it easier to loosen the lid from the top of a paint can with a long-handled screwdriver than with a short-handled screwdriver?

31. If a machine cannot multiply the amount of work, what is the advantage of using such a machine?

32. In the equation for the magnitude of a torque, what does the quantity $d \sin \theta$ represent?

CONCEPTUAL QUESTIONS

33. Which of the forces acting on the rod shown below will produce a torque about the axis at the left end of the rod?



34. Two forces equal in magnitude but opposite in direction act at the same point on an object. Is it possible for there to be a net torque on the object? Explain.

35. You are attempting to move a large rock by using a long lever. Is it more effective to place the lever's axis of rotation nearer to your hands or nearer to the rock? Explain.

36. A perpetual motion machine is a machine that, when set in motion, will never come to a halt. Why is such a machine not possible?

PRACTICE PROBLEMS

For problems 37–38, see Sample Problem E.

37. A bucket filled with water has a mass of 54 kg and is hanging from a rope that is wound around a 0.050 m radius stationary cylinder. If the cylinder does not rotate and the bucket hangs straight down, what is the magnitude of the torque the bucket produces around the center of the cylinder?

38. A mechanic jacks up the front of a car to an angle of 8.0° with the horizontal in order to change the front tires. The car is 3.05 m long and has a mass of 1130 kg. Gravitational force acts at the center of mass, which is located 1.12 m from the front end. The rear wheels are 0.40 m from the back end. Calculate the magnitude of the torque exerted by the jack.

Mixed Review

REVIEWING MAIN IDEAS

39. A 2.00×10^3 kg car rounds a circular turn of radius 20.0 m. If the road is flat and the coefficient of static friction between the tires and the road is 0.70, how fast can the car go without skidding?

40. During a solar eclipse, the moon, Earth, and the sun lie on the same line, with the moon between Earth and the sun. What force is exerted on

a. the moon by the sun?
b. the moon by Earth?
c. Earth by the sun?

(See the table in **Appendix F** for data on the sun, moon, and Earth.)

41. A wooden bucket filled with water has a mass of 75 kg and is attached to a rope that is wound around a cylinder with a radius of 0.075 m. A crank with a turning radius of 0.25 m is attached to the end of the cylinder. What minimum force directed perpendicularly to the crank handle is required to raise the bucket?

42. If the torque required to loosen a nut that holds a wheel on a car has a magnitude of 58 N•m, what force must be exerted at the end of a 0.35 m lug wrench to loosen the nut when the angle is 56°? (Hint: See **Figure 4.5** for an example, and assume that θ is 56°.)

43. In a canyon between two mountains, a spherical boulder with a radius of 1.4 m is just set in motion by a force of 1600 N. The force is applied at an angle of 53.5° measured with respect to the vertical radius of the boulder. What is the magnitude of the torque on the boulder?

44. The hands of the clock in the famous Parliament Clock Tower in London are 2.7 m and 4.5 m long and have masses of 60.0 kg and 100.0 kg, respectively. Calculate the torque around the center of the clock due to the weight of these hands at 5:20. The weight of each hand acts at the center of mass (the midpoint of the hand).

45. The efficiency of a pulley system is 64 percent. The pulleys are used to raise a mass of 78 kg to a height of 4.0 m. What force is exerted on the rope of the pulley system if the rope is pulled for 24 m in order to raise the mass to the required height?

46. A crate is pulled 2.0 m at constant velocity along a 15° incline. The coefficient of kinetic friction between the crate and the plane is 0.160. Calculate the efficiency of this procedure.

47. A pulley system is used to lift a piano 3.0 m. If a force of 2200 N is applied to the rope as the rope is pulled in 14 m, what is the efficiency of the machine? Assume the mass of the piano is 750 kg.

48. A pulley system has an efficiency of 87.5 percent. How much of the rope must be pulled in if a force of 648 N is needed to lift a 150 kg desk 2.46 m? (Disregard friction.)

49. Jupiter's four large moons—Io, Europa, Ganymede, and Callisto—were discovered by Galileo in 1610. Jupiter also has dozens of smaller moons. Jupiter's rocky, volcanically active moon Io is about the size of Earth's moon. Io has a radius of about 1.82×10^6 m, and the mean distance between Io and Jupiter is 4.22×10^8 m.

a. If Io's orbit were circular, how many days would it take for Io to complete one full revolution around Jupiter?

b. If Io's orbit were circular, what would its orbital speed be?

50. A 13 500 N car traveling at 50.0 km/h rounds a curve of radius 2.00×10^2 m. Find the following:

a. the centripetal acceleration of the car

b. the centripetal force

c. the minimum coefficient of static friction between the tires and the road that will allow the car to round the curve safely

51. The arm of a crane at a construction site is 15.0 m long, and it makes an angle of 20.0° with the horizontal. Assume that the maximum load the crane can handle is limited by the amount of torque the load produces around the base of the arm.

a. What is the magnitude of the maximum torque the crane can withstand if the maximum load the crane can handle is 450 N?

b. What is the maximum load for this crane at an angle of 40.0° with the horizontal?

52. At the sun's surface, the gravitational force between the sun and a 5.00 kg mass of hot gas has a magnitude of 1370 N. Assuming that the sun is spherical, what is the sun's mean radius?

53. An automobile with a tangential speed of 55.0 km/h follows a circular road that has a radius of 40.0 m. The automobile has a mass of 1350 kg. The pavement is wet and oily, so the coefficient of kinetic friction between the car's tires and the pavement is only 0.500. How large is the available frictional force? Is this frictional force large enough to maintain the automobile's circular motion?

GRAPHING CALCULATOR PRACTICE

Torque

Torque is a measure of the ability of a force to rotate an object around an axis. How does the angle and application distance of the applied force affect torque?

Torque is described by the following equation:

$$\tau = Fd \sin \theta$$

In this equation, F is the applied force, d is the distance from the axis of rotation, and θ is the angle at which the force is applied. A mechanic using a long wrench to loosen a "frozen" bolt is a common illustration of this equation.

In this graphing calculator activity, you will determine how torque relates to the angle of the applied force and to the distance of application.

Go online to HMHScience.com to find the skillsheet and program for this graphing calculator activity.

54. A force is applied to a door at an angle of 60.0° and 0.35 m from the hinge. The force exerts a torque with a magnitude of 2.0 N•m. What is the magnitude of the force? How large is the maximum torque this force can exert?

55. Imagine a balance with unequal arms. An earring placed in the left basket was balanced by 5.00 g of standard masses on the right. When placed in the right basket, the same earring required 15.00 g on the left to balance. Which was the longer arm? Do you need to know the exact length of each arm to determine the mass of the earring? Explain.

ALTERNATIVE ASSESSMENT

1. Research the historical development of the concept of gravitational force. Find out how scientists' ideas about gravity have changed over time. Identify the contributions of different scientists, such as Galileo, Kepler, Newton, and Einstein. How did each scientist's work build on the work of earlier scientists? What were the impacts of the scientific contributions of each of these scientists on scientific thought? Analyze, review, and critique the different scientific explanations of gravity. Focus on each scientist's hypotheses and theories. What are their strengths? What are their weaknesses? What do scientists think about gravity now? Use scientific evidence and other information to support your answers. Write a report or prepare an oral presentation to share your conclusions.

2. In the reduced gravity of space, called *microgravity*, astronauts lose bone and muscle mass, even after a short time. These effects happen more gradually on Earth as people age. Scientists are studying this phenomenon so that they can find ways to counteract it, in space and on Earth. Such studies are essential for future plans that involve astronauts spending significant time on space stations or for distant missions such as a trip to Mars. Research the causes of this phenomenon and possible methods of prevention, including NASA's current efforts to minimize bone density loss for astronauts on the *International Space Station*. Create a poster or brochure displaying the results of your research.

3. Research the life and scientific contributions of one of the astronomers discussed in the chapter: Claudius Ptolemy, Nicolaus Copernicus, Tycho Brahe, or Johannes Kepler. On a posterboard, create a visual timeline that summarizes key events in the atsronomer's life and work, including astronomical discoveries and other scientific advances or inventions. Add images to some of the events on the timeline. You may also want to include historical events on the timeline to provide context for the scientific works.

4. Describe exactly which measurements you would need to make in order to identify the torques at work during a ride on a specific bicycle. Your plans should include measurements you can make with equipment available to you. If others in the class analyzed different bicycle models, compare the models for efficiency and mechanical advantage.

5. Prepare a poster or a series of models of simple machines, explaining their use and how they work. Include a schematic diagram next to each sample or picture to identify the fulcrum, lever arm, and resistance. Add your own examples to the following list: nail clipper, wheelbarrow, can opener, nutcracker, electric drill, screwdriver, tweezers, and key in lock.