CHAPTER 5 Summary

BIG IDEA Work, energy, and power are related to each other. Although energy can change from one form to another, it is always conserved.

SECTION 1 Work

KEY TERM: work

- Work is done on an object only when a net force acts on the object to displace it in the direction of a component of the net force.
- The amount of work done on an object by a force is equal to the component of the force along the direction of motion times the distance the object moves.

SECTION 2 Energy

KEY TERMS: kinetic energy; work–kinetic energy theorem; potential energy; gravitational potential energy; elastic potential energy; spring constant

- Objects in motion have kinetic energy because of their mass and speed.
- The net work done on or by an object is equal to the change in the kinetic energy of the object.
- Potential energy is energy associated with an object's position. Two forms of potential energy discussed in this chapter are gravitational potential energy and elastic potential energy.

SECTION 3 Conservation of Energy

KEY TERM: mechanical energy

- Energy can change form but can never be created or destroyed.
- Mechanical energy is the sum of the kinetic energy and total potential energy associated with a system.
- In the absence of friction, mechanical energy is conserved, so the amount of mechanical energy remains constant.

SECTION 4 Power

KEY TERM: power

- Power is the rate at which work is done or the rate of energy transfer.
- Machines with different power ratings do the same amount of work in different time intervals.

VARIABLE SYMBOLS

Quantities		Units		Conversions
W	work	J	joule	$= \text{N}\bullet\text{m}$
KE	kinetic energy	J	joule	$= \text{kg}\bullet\text{m}^2/\text{s}^2$
PE_g	gravitational potential energy	J	joule	
$PE_{elastic}$	elastic potential energy	J	joule	
P	power	W	watt	$= \text{J/s}$

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.**

Work

REVIEWING MAIN IDEAS

1. Can the speed of an object change if the net work done on it is zero?

2. Discuss whether any work is being done by each of the following agents and, if so, whether the work is positive or negative.
   a. a chicken scratching the ground
   b. a person reading a sign
   c. a crane lifting a bucket of concrete
   d. the force of gravity on the bucket in **(c)**

3. Furniture movers wish to load a truck using a ramp from the ground to the rear of the truck. One of the movers claims that less work would be required if the ramp's length were increased, reducing its angle with the horizontal. Is this claim valid? Explain.

CONCEPTUAL QUESTIONS

4. A pendulum swings back and forth, as shown at right. Does the tension force in the string do work on the pendulum bob? Does the force of gravity do work on the bob? Explain your answers.

5. The drivers of two identical cars heading toward each other apply the brakes at the same instant. The skid marks of one of the cars are twice as long as the skid marks of the other vehicle. Assuming that the brakes of both cars apply the same force, what conclusions can you draw about the motion of the cars?

6. When a punter kicks a football, is he doing work on the ball while his toe is in contact with it? Is he doing work on the ball after the ball loses contact with his toe? Are any forces doing work on the ball while the ball is in flight?

PRACTICE PROBLEMS

For problems 7–10, see Sample Problem A.

7. A person lifts a 4.5 kg cement block a vertical distance of 1.2 m and then carries the block horizontally a distance of 7.3 m. Determine the work done by the person and by the force of gravity in this process.

8. A plane designed for vertical takeoff has a mass of 8.0×10^3 kg. Find the net work done by all forces on the plane as it accelerates upward at 1.0 m/s^2 through a distance of 30.0 m after starting from rest.

9. When catching a baseball, a catcher's glove moves by 10 cm along the line of motion of the ball. If the baseball exerts a force of 475 N on the glove, how much work is done by the ball?

10. A flight attendant pulls her 70.0 N flight bag a distance of 253 m along a level airport floor at a constant velocity. The force she exerts is 40.0 N at an angle of 52.0° above the horizontal. Find the following:
    a. the work she does on the flight bag
    b. the work done by the force of friction on the flight bag
    c. the coefficient of kinetic friction between the flight bag and the floor

Energy

REVIEWING MAIN IDEAS

11. A person drops a ball from the top of a building while another person on the ground observes the ball's motion. Each observer chooses his or her own location as the level for zero potential energy. Will they calculate the same values for:
    a. the potential energy associated with the ball?
    b. the change in potential energy associated with the ball?
    c. the ball's kinetic energy?

12. Can the kinetic energy of an object be negative? Explain your answer.

13. Can the gravitational potential energy associated with an object be negative? Explain your answer.

14. Two identical objects move with speeds of 5.0 m/s and 25.0 m/s. What is the ratio of their kinetic energies?

CONCEPTUAL QUESTIONS

15. A satellite is in a circular orbit above Earth's surface. Why is the work done on the satellite by the gravitational force zero? What does the work–kinetic energy theorem predict about the satellite's speed?

16. A car traveling at 50.0 km/h skids a distance of 35 m after its brakes lock. Predict how far it will skid if its brakes lock when its initial speed is 100.0 km/h. What happens to the car's kinetic energy as it comes to rest?

17. Explain why more energy is needed to walk up stairs than to walk horizontally at the same speed.

18. How can the work–kinetic energy theorem explain why the force of sliding friction reduces the kinetic energy of a particle?

PRACTICE PROBLEMS

For problems 19–20, see Sample Problem B.

19. What is the kinetic energy of an automobile with a mass of 1250 kg traveling at a speed of 11 m/s?

20. What speed would a fly with a mass of 0.55 g need in order to have the same kinetic energy as the automobile in item 19?

For problems 21–22, see Sample Problem C.

21. A 50.0 kg diver steps off a diving board and drops straight down into the water. The water provides an upward average net force of 1500 N. If the diver comes to rest 5.0 m below the water's surface, what is the total distance between the diving board and the diver's stopping point underwater?

22. In a circus performance, a monkey on a sled is given an initial speed of 4.0 m/s up a 25° incline. The combined mass of the monkey and the sled is 20.0 kg, and the coefficient of kinetic friction between the sled and the incline is 0.20. How far up the incline does the sled move?

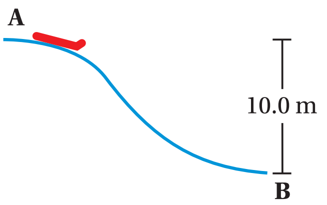
For problems 23–25, see Sample Problem D.

23. A 55 kg skier is at the top of a slope, as shown in the illustration below. At the initial point **A**, the skier is 10.0 m vertically above the final point **B**.

a. Set the zero level for gravitational potential energy at **B**, and find the gravitational potential energy associated with the skier at **A** and at **B**. Then find the difference in potential energy between these two points.

b. Repeat this problem with the zero level at point **A**.

c. Repeat this problem with the zero level midway down the slope, at a height of 5.0 m.



24. A 2.00 kg ball is attached to a ceiling by a string. The distance from the ceiling to the center of the ball is 1.00 m, and the height of the room is 3.00 m. What is the gravitational potential energy associated with the ball relative to each of the following?

a. the ceiling

b. the floor

c. a point at the same elevation as the ball

25. A spring has a force constant of 500.0 N/m. Show that the potential energy stored in the spring is as follows:

a. 0.400 J when the spring is stretched 4.00 cm from equilibrium

b. 0.225 J when the spring is compressed 3.00 cm from equilibrium

c. zero when the spring is unstretched

Conservation of Mechanical Energy

REVIEWING MAIN IDEAS

26. Each of the following objects possesses energy. Which forms of energy are mechanical, which are nonmechanical, and which are a combination?
- **a.** glowing embers in a campfire
- **b.** a strong wind
- **c.** a swinging pendulum
- **d.** a person sitting on a mattress
- **e.** a rocket being launched into space

27. Discuss the energy transformations that occur during the pole-vault event shown in the photograph below. Disregard rotational motion and air resistance.

28. A strong cord suspends a bowling ball from the center of a lecture hall's ceiling, forming a pendulum. The ball is pulled to the tip of a lecturer's nose at the front of the room and is then released. If the lecturer remains stationary, explain why the lecturer is not struck by the ball on its return swing. Would this person be safe if the ball were given a slight push from its starting position at the person's nose?

CONCEPTUAL QUESTIONS

29. Discuss the work done and change in mechanical energy as an athlete does the following:
- **a.** lifts a weight
- **b.** holds the weight up in a fixed position
- **c.** lowers the weight slowly

30. A ball is thrown straight up. At what position is its kinetic energy at its maximum? At what position is gravitational potential energy at its maximum?

31. Advertisements for a toy ball once stated that it would rebound to a height greater than the height from which it was dropped. Is this possible?

32. A weight is connected to a spring that is suspended vertically from the ceiling. If the weight is displaced downward from its equilibrium position and released, it will oscillate up and down. How many forms of potential energy are involved? If air resistance and friction are disregarded, will the total mechanical energy be conserved? Explain.

PRACTICE PROBLEMS

For problems 33–34, see Sample Problem E.

33. A child and sled with a combined mass of 50.0 kg slide down a frictionless hill that is 7.34 m high. If the sled starts from rest, what is the mechanical energy of the system, and what is the sled's speed at the bottom of the hill?

34. Tarzan swings on a 30.0 m long vine initially inclined at an angle of 37.0° with the vertical. What is his speed at the bottom of the swing if he does the following?
- **a.** starts from rest
- **b.** starts with an initial speed of 4.00 m/s

Power

REVIEWING MAIN IDEAS

PRACTICE PROBLEMS

For problems 35–36, see Sample Problem F.

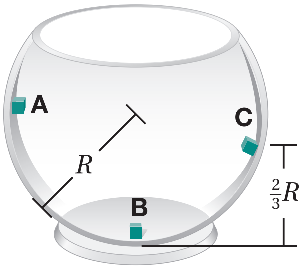
35. If an automobile engine delivers 50.0 hp of power, how much time will it take for the engine to do 6.40×10^5 J of work? (Hint: Note that one horsepower, 1 hp, is equal to 746 watts.)

36. Water flows over a section of Niagara Falls at the rate of 1.2×10^6 kg/s and falls 50.0 m. How much power is generated by the falling water?

Mixed Review

REVIEWING MAIN IDEAS

37. A 215 g particle is released from rest at point **A** inside a smooth hemispherical bowl of radius 30.0 cm, as shown at right. Calculate the following:



a. the gravitational potential energy at **A** relative to **B**

b. the particle's kinetic energy at **B**

c. the particle's speed at **B**

d. the potential energy and kinetic energy at **C**

38. A person doing a chin-up weighs 700.0 N, disregarding the weight of the arms. During the first 25.0 cm of the lift, each arm exerts an upward force of 355 N on the torso. If the upward movement starts from rest, what is the person's speed at this point?

39. A 50.0 kg pole vaulter running at 10.0 m/s vaults over the bar. If the vaulter's horizontal component of velocity over the bar is 1.0 m/s and air resistance is disregarded, how high was the jump?

40. An 80.0 N box of clothes is pulled 20.0 m up a 30.0° ramp by a force of 115 N that points along the ramp. If the coefficient of kinetic friction between the box and ramp is 0.22, calculate the change in the box's kinetic energy.

41. Tarzan and Jane, whose total mass is 130.0 kg, start their swing on a 5.0 m long vine when the vine is at an angle of 30.0° with the horizontal. At the bottom of the arc, Jane, whose mass is 50.0 kg, releases the vine. What is the maximum height at which Tarzan can land on a branch after his swing continues? (Hint: Treat Tarzan's and Jane's energies as separate quantities.)

42. A 0.250 kg block on a vertical spring with a spring constant of 5.00×10^3 N/m is pushed downward, compressing the spring 0.100 m. When released, the block leaves the spring and travels upward vertically. How high does it rise above the point of release?

43. Three identical balls, all with the same initial speed, are thrown by a juggling clown on a tightrope. The first ball is thrown horizontally, the second is thrown at some angle above the horizontal, and the third is thrown at some angle below the horizontal. Disregarding air resistance, describe the motions of the three balls and compare the speeds of the balls as they reach the ground.

44. A 0.60 kg rubber ball has a speed of 2.0 m/s at point A and kinetic energy of 7.5 J at point B. Determine the following:

a. the ball's kinetic energy at A

b. the ball's speed at B

c. the total work done on the ball from A to B

45. Starting from rest, a 5.0 kg block slides 2.5 m down a rough 30.0° incline in 2.0 s. Determine the following:

a. the work done by the force of gravity

b. the mechanical energy lost due to friction

c. the work done by the normal force between the block and the incline

46. A skier of mass 70.0 kg is pulled up a slope by a motor-driven cable. How much work is required to pull the skier 60.0 m up a 35° slope (assumed to be frictionless) at a constant speed of 2.0 m/s?

47. An acrobat on skis starts from rest 50.0 m above the ground on a frictionless track and flies off the track at a 45.0° angle above the horizontal and at a height of 10.0 m. Disregard air resistance.

a. What is the skier's speed when leaving the track?

b. What is the maximum height attained?

48. Starting from rest, a 10.0 kg suitcase slides 3.00 m down a frictionless ramp inclined at 30.0° from the floor. The suitcase then slides an additional 5.00 m along the floor before coming to a stop. Determine the following:

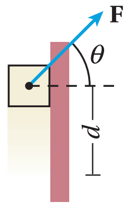
a. the suitcase's speed at the bottom of the ramp

b. the coefficient of kinetic friction between the suitcase and the floor

c. the change in mechanical energy due to friction

49. A light horizontal spring has a spring constant of 105 N/m. A 2.00 kg block is pressed against one end of the spring, compressing the spring 0.100 m. After the block is released, the block moves 0.250 m to the right before coming to rest. What is the coefficient of kinetic friction between the horizontal surface and the block?

50. A 5.0 kg block is pushed 3.0 m at a constant velocity up a vertical wall by a constant force applied at an angle of 30.0° with the horizontal, as shown at right. If the coefficient of kinetic friction between the block and the wall is 0.30, determine the following:



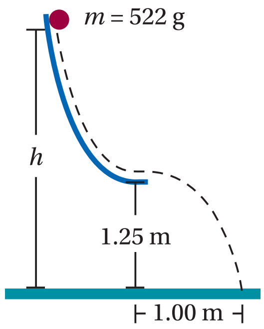
- **a.** the work done by the force on the block
- **b.** the work done by gravity on the block
- **c.** the magnitude of the normal force between the block and the wall

51. A 25 kg child on a 2.0 m long swing is released from rest when the swing supports make an angle of 30.0° with the vertical.

- **a.** What is the maximum potential energy associated with the child?
- **b.** Disregarding friction, find the child's speed at the lowest position.
- **c.** What is the child's total mechanical energy?
- **d.** If the speed of the child at the lowest position is 2.00 m/s, what is the change in mechanical energy due to friction?

52. A ball of mass 522 g starts at rest and slides down a frictionless track, as shown in the diagram. It leaves the track horizontally, striking the ground.

- **a.** At what height above the ground does the ball start to move?
- **b.** What is the speed of the ball when it leaves the track?
- **c.** What is the speed of the ball when it hits the ground?



GRAPHING CALCULATOR PRACTICE

Work of Displacement

Work done, as you learned earlier in this chapter, is a result of the net applied force, the distance of the displacement, and the angle of the applied force relative to the direction of displacement. Work done is described by the following equation:

$$W_{net} = F_{net} d \cos \theta$$

The equation for work done can be represented on a graphing calculator as follows:

$$Y_1 = FXCOS(\theta)$$

In this activity, you will use this equation and your graphing calculator to produce a table of results for various values of θ. Column one of the table will be the displacement (X) in meters, and column two will be the work done (Y_1) in joules.

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

ALTERNATIVE ASSESSMENT

1. Design experiments for measuring your power output when doing pushups, running up a flight of stairs, pushing a car, loading boxes onto a truck, throwing a baseball, or performing other energy-transferring activities. What data do you need to measure or calculate? What equipment and/or technology is needed to make these measurements or calculations? Form groups to present and discuss your plans. If your teacher approves your plans, perform the experiments.

2. Investigate the amount of kinetic energy involved when your car's speed is 60 km/h, 50 km/h, 40 km/h, 30 km/h, 20 km/h, and 10 km/h. (Hint: Find your car's mass in the owner's manual.) How much work does the brake system have to do to stop the car at each speed?

   If the owner's manual includes a table of braking distances at different speeds, determine the force the braking system must exert. Organize your findings in charts and graphs to study the questions and to present your conclusions.

3. Investigate the energy transformations of your body as you swing on a swing set. Working with a partner, measure the height of the swing at the high and low points of your motion. What points involve a maximum gravitational potential energy? What points involve a maximum kinetic energy? For three other points in the path of the swing, calculate the gravitational potential energy, the kinetic energy, and the velocity. Organize your findings in bar graphs.

4. Design an experiment to test the conservation of mechanical energy for a toy car rolling down a ramp. Use a board propped up on a stack of books as the ramp. To find the final speed of the car, use the equation:
   final speed = 2(average speed) = 2(length/time)
   Before beginning the experiment, formulate hypotheses about what you expect. Will the kinetic energy at the bottom equal the potential energy at the top? If not, which might be greater? Test your predictions with various ramp heights, and write a report describing your experiment and your results.

5. In order to save fuel, an airline executive recommended the following changes in the airline's largest jet flights:
   a. restrict the weight of personal luggage
   b. remove pillows, blankets, and magazines from the cabin
   c. lower flight altitudes by 5 percent
   d. reduce flying speeds by 5 percent

   Research the information necessary to calculate the approximate kinetic and potential energy of a large passenger aircraft. Which of the measures described above would result in significant savings? What might be their other consequences? Summarize your conclusions in a presentation or report.

6. Make a chart of the kinetic energies your body can have. First, measure your mass. Then, measure your speed when walking, running, sprinting, riding a bicycle, and driving a car. Make a poster graphically comparing these findings.

7. You are trying to find a way to bring electricity to a remote village in order to run a water-purifying device. A donor is willing to provide battery chargers that connect to bicycles. Assuming the water-purification device requires 18.6 kW•h daily, how many bicycles would a village need if a person can average 100 W while riding a bicycle? Is this a useful way to help the village? Evaluate your findings for strengths and weaknesses. Summarize your comments and suggestions in a letter to the donor.

8. Many scientific units are named after famous scientists or inventors. The SI unit of power, the watt, was named for the Scottish scientist James Watt. The SI unit of energy, the joule, was named for the English scientist James Prescott Joule. Use the Internet or library resources to learn about the contributions of these two scientists. Write a report to explain the impact of their scientific contributions on society, and then present your report to the class.