We mentioned in Example 6–14 that only part of the energy output of a car engine reaches the wheels. Not only is some energy wasted in getting from the engine to the wheels, in the engine itself most of the input energy (from the burning of gasoline or other fuel) does not do useful work. An important characteristic of all engines is their overall **efficiency** e, defined as the ratio of the useful power output of the engine, P_{out}, to the power input, P_{in} (provided by burning of gasoline, for example):

$$e = \frac{P_{out}}{P_{in}}.$$

The efficiency is always less than 1.0 because no engine can create energy, and no engine can even transform energy from one form to another without some energy going to friction, thermal energy, and other nonuseful forms of energy. For example, an automobile engine converts chemical energy released in the burning of gasoline into mechanical energy that moves the pistons and eventually the wheels. But nearly 85% of the input energy is "wasted" as thermal energy that goes into the cooling system or out the exhaust pipe, plus friction in the moving parts. Thus car engines are roughly only about 15% efficient. We will discuss efficiency in more detail in Chapter 15.

Summary

Work is done on an object by a force when the object moves through a distance d. If the direction of a constant force $\vec{\mathbf{F}}$ makes an angle θ with the direction of motion, the work done by this force is

$$W = Fd\cos\theta. \quad \textbf{(6–1)}$$

Energy can be defined as the ability to do work. In SI units, work and energy are measured in **joules** $(1\text{ J} = 1\text{ N}\cdot\text{m})$.

Kinetic energy (KE) is energy of motion. An object of mass m and speed v has **translational kinetic energy**

$$\text{KE} = \tfrac{1}{2}mv^2. \quad \textbf{(6–3)}$$

The **work-energy principle** states that the *net* work done on an object (by the *net* force) equals the change in kinetic energy of that object:

$$W_{net} = \Delta\text{KE} = \tfrac{1}{2}mv_2^2 - \tfrac{1}{2}mv_1^2. \quad \textbf{(6–4)}$$

Potential energy (PE) is energy associated with forces that depend on the position or configuration of objects. Gravitational potential energy is

$$\text{PE}_G = mgy, \quad \textbf{(6–6)}$$

where y is the height of the object of mass m above an arbitrary reference point. Elastic potential energy is given by

$$\text{PE}_{el} = \tfrac{1}{2}kx^2 \quad \textbf{(6–9)}$$

for a stretched or compressed spring, where x is the displacement from the unstretched position and k is the **spring stiffness constant**. Other potential energies include chemical, electrical, and nuclear energy. The *change in potential energy* when an object changes position *is equal to the external work* needed to take the object from one position to the other.

Potential energy is associated only with **conservative forces**, for which the work done by the force in moving an object from one position to another depends only on the two positions and not on the path taken. **Nonconservative forces** like friction are different—work done by them does depend on the path taken and potential energy cannot be defined for them.

The **law of conservation of energy** states that energy can be transformed from one type to another, but the total energy remains constant. It is valid even when friction is present, because the heat generated can be considered a form of energy transfer. When only *conservative forces* act, the **total mechanical energy** is conserved:

$$\text{KE} + \text{PE} = \text{constant}. \quad \textbf{(6–12)}$$

When nonconservative forces such as friction act, then

$$W_{NC} = \Delta\text{KE} + \Delta\text{PE}, \quad \textbf{(6–10, 6–15)}$$

where W_{NC} is the work done by nonconservative forces.

Power is defined as the rate at which work is done, or the rate at which energy is transformed. The SI unit of power is the **watt** $(1\text{ W} = 1\text{ J/s})$.

Questions

1. In what ways is the word "work" as used in everyday language the same as it is defined in physics? In what ways is it different? Give examples of both.
2. Can a centripetal force ever do work on an object? Explain.
3. Why is it tiring to push hard against a solid wall even though you are doing no work?
4. Can the normal force on an object ever do work? Explain.
5. You have two springs that are identical except that spring 1 is stiffer than spring 2 $(k_1 > k_2)$. On which spring is more work done: (a) if they are stretched using the same force; (b) if they are stretched the same distance?
6. If the speed of a particle triples, by what factor does its kinetic energy increase?
7. List some everyday forces that are not conservative, and explain why they aren't.

8. A hand exerts a constant horizontal force on a block that is free to slide on a frictionless surface (Fig. 6–30). The block starts from rest at point A, and by the time it has traveled a distance d to point B it is traveling with speed v_B. When the block has traveled another distance d to point C, will its speed be greater than, less than, or equal to $2v_B$? Explain your reasoning.

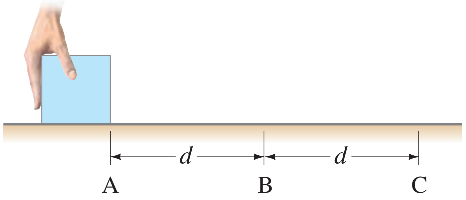


FIGURE 6–30 Question 8.

9. You lift a heavy book from a table to a high shelf. List the forces on the book during this process, and state whether each is conservative or nonconservative.

10. A hill has a height h. A child on a sled (total mass m) slides down starting from rest at the top. Does the speed at the bottom depend on the angle of the hill if (a) it is icy and there is no friction, and (b) there is friction (deep snow)? Explain your answers.

11. Analyze the motion of a simple swinging pendulum in terms of energy, (a) ignoring friction, and (b) taking friction into account. Explain why a grandfather clock has to be wound up.

12. In Fig. 6–31, water balloons are tossed from the roof of a building, all with the same speed but with different launch angles. Which one has the highest speed when it hits the ground? Ignore air resistance. Explain your answer.

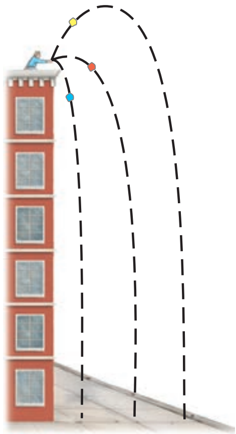


FIGURE 6–31 Question 12.

13. What happens to the gravitational potential energy when water at the top of a waterfall falls to the pool below?

14. Experienced hikers prefer to step over a fallen log in their path rather than stepping on top and stepping down on the other side. Explain.

15. The energy transformations in pole vaulting and archery are discussed in this Chapter. In a similar fashion, discuss the energy transformations related to: (a) hitting a golf ball; (b) serving a tennis ball; and (c) shooting a basket in basketball.

16. Describe precisely what is "wrong" physically in the famous Escher drawing shown in Fig. 6–32.

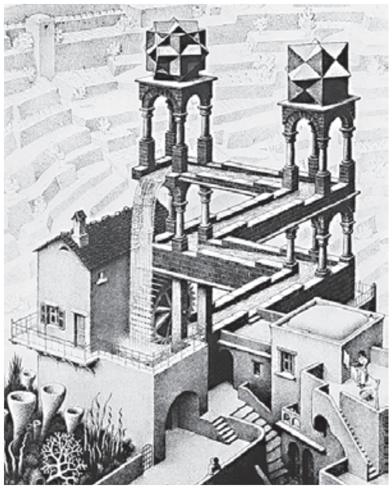


FIGURE 6–32 Question 16.

17. Two identical arrows, one with twice the speed of the other, are fired into a bale of hay. Assuming the hay exerts a constant "frictional" force on the arrows, the faster arrow will penetrate how much farther than the slower arrow? Explain.

18. A heavy ball is hung from the ceiling by a steel wire. The instructor pulls the ball back and stands against the wall with the ball against his chin. To avoid injury the instructor is supposed to release the ball without pushing it (Fig. 6–33). Why?

FIGURE 6–33 Question 18.

19. Describe the energy transformations when a child hops around on a pogo stick (there is a spring inside).

20. Describe the energy transformations that take place when a skier starts skiing down a hill, but after a time is brought to rest by striking a snowdrift.

21. Suppose you lift a suitcase from the floor to a table. The work you do on the suitcase depends on which of the following: (a) whether you lift it straight up or along a more complicated path, (b) the time the lifting takes, (c) the height of the table, and (d) the weight of the suitcase?

22. Repeat Question 21 for the *power* needed instead of the work.

23. Why is it easier to climb a mountain via a zigzag trail rather than to climb straight up?

MisConceptual Questions

1. You push very hard on a heavy desk, trying to move it. You do work on the desk:
(*a*) whether or not it moves, as long as you are exerting a force.
(*b*) only if it starts moving.
(*c*) only if it doesn't move.
(*d*) never—it does work on you.
(*e*) None of the above.

2. A satellite in circular orbit around the Earth moves at constant speed. This orbit is maintained by the force of gravity between the Earth and the satellite, yet no work is done on the satellite. How is this possible?
(*a*) No work is done if there is no contact between objects.
(*b*) No work is done because there is no gravity in space.
(*c*) No work is done if the direction of motion is perpendicular to the force.
(*d*) No work is done if objects move in a circle.

3. When the speed of your car is doubled, by what factor does its kinetic energy increase?
(*a*) $\sqrt{2}$. (*b*) 2. (*c*) 4. (*d*) 8.

4. A car traveling at a velocity v can stop in a minimum distance d. What would be the car's minimum stopping distance if it were traveling at a velocity of $2v$?
(*a*) d. (*b*) $\sqrt{2}\,d$. (*c*) $2d$. (*d*) $4d$. (*e*) $8d$.

5. A bowling ball is dropped from a height h onto the center of a trampoline, which launches the ball back up into the air. How high will the ball rise?
(*a*) Significantly less than h.
(*b*) More than h. The exact amount depends on the mass of the ball and the springiness of the trampoline.
(*c*) No more than h—probably a little less.
(*d*) Cannot tell without knowing the characteristics of the trampoline.

6. A ball is thrown straight up. At what point does the ball have the most energy? Ignore air resistance.
(*a*) At the highest point of its path.
(*b*) When it is first thrown.
(*c*) Just before it hits the ground.
(*d*) When the ball is halfway to the highest point of its path.
(*e*) Everywhere; the energy of the ball is the same at all of these points.

7. A car accelerates from rest to 30 km/h. Later, on a highway it accelerates from 30 km/h to 60 km/h. Which takes more energy, going from 0 to 30, or from 30 to 60?
(*a*) 0 to 30 km/h.
(*b*) 30 to 60 km/h.
(*c*) Both are the same.

8. Engines, including car engines, are rated in horsepower. What is horsepower?
(*a*) The force needed to start the engine.
(*b*) The force needed to keep the engine running at a steady rate.
(*c*) The energy the engine needs to obtain from gasoline or some other source.
(*d*) The rate at which the engine can do work.
(*e*) The amount of work the engine can perform.

9. Two balls are thrown off a building with the same speed, one straight up and one at a 45° angle. Which statement is true if air resistance can be ignored?
(*a*) Both hit the ground at the same time.
(*b*) Both hit the ground with the same speed.
(*c*) The one thrown at an angle hits the ground with a lower speed.
(*d*) The one thrown at an angle hits the ground with a higher speed.
(*e*) Both (*a*) and (*b*).

10. A skier starts from rest at the top of each of the hills shown in Fig. 6–34. On which hill will the skier have the highest speed at the bottom if we ignore friction:
(*a*), (*b*), (*c*), (*d*), or (*e*) *c* and *d* equally?

FIGURE 6–34
MisConceptual Questions 10 and 11.

11. Answer MisConceptual Question 10 assuming a small amount of friction.

12. A man pushes a block up an incline at a constant speed. As the block moves up the incline,
(*a*) its kinetic energy and potential energy both increase.
(*b*) its kinetic energy increases and its potential energy remains the same.
(*c*) its potential energy increases and its kinetic energy remains the same.
(*d*) its potential energy increases and its kinetic energy decreases by the same amount.

13. You push a heavy crate *down* a ramp at a constant velocity. Only four forces act on the crate. Which force does the greatest magnitude of work on the crate?
(*a*) The force of friction.
(*b*) The force of gravity.
(*c*) The normal force.
(*d*) The force of you pushing.
(*e*) The net force.

14. A ball is thrown straight up. Neglecting air resistance, which statement is *not* true regarding the energy of the ball?
(*a*) The potential energy decreases while the ball is going up.
(*b*) The kinetic energy decreases while the ball is going up.
(*c*) The sum of the kinetic energy and potential energy is constant.
(*d*) The potential energy decreases when the ball is coming down.
(*e*) The kinetic energy increases when the ball is coming down.

For assigned homework and other learning materials, go to the MasteringPhysics website.

Problems

6–1 Work, Constant Force

1. (I) A 75.0-kg firefighter climbs a flight of stairs 28.0 m high. How much work does he do?

2. (I) The head of a hammer with a mass of 1.2 kg is allowed to fall onto a nail from a height of 0.50 m. What is the maximum amount of work it could do on the nail? Why do people not just "let it fall" but add their own force to the hammer as it falls?

3. (II) How much work did the movers do (horizontally) pushing a 46.0-kg crate 10.3 m across a rough floor without acceleration, if the effective coefficient of friction was 0.50?

4. (II) A 1200-N crate rests on the floor. How much work is required to move it at constant speed (*a*) 5.0 m along the floor against a friction force of 230 N, and (*b*) 5.0 m vertically?

5. (II) What is the minimum work needed to push a 950-kg car 710 m up along a 9.0° incline? Ignore friction.

6. (II) Estimate the work you do to mow a lawn 10 m by 20 m with a 50-cm-wide mower. Assume you push with a force of about 15 N.

7. (II) In a certain library the first shelf is 15.0 cm off the ground, and the remaining four shelves are each spaced 38.0 cm above the previous one. If the average book has a mass of 1.40 kg with a height of 22.0 cm, and an average shelf holds 28 books (standing vertically), how much work is required to fill all the shelves, assuming the books are all laying flat on the floor to start?

8. (II) A **lever** such as that shown in Fig. 6–35 can be used to lift objects we might not otherwise be able to lift. Show that the ratio of output force, F_{O}, to input force, F_{I}, is related to the lengths ℓ_{I} and ℓ_{O} from the pivot by $F_{\mathrm{O}}/F_{\mathrm{I}} = \ell_{\mathrm{I}}/\ell_{\mathrm{O}}$. Ignore friction and the mass of the lever, and assume the work output equals the work input.

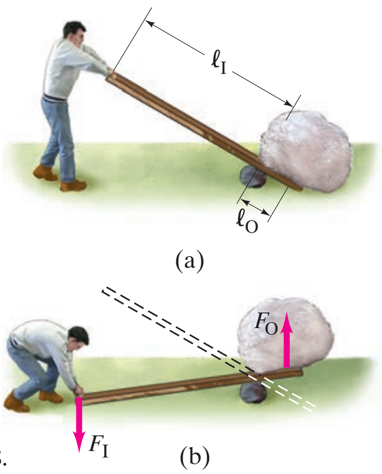


FIGURE 6–35
A lever. Problem 8.

9. (II) A box of mass 4.0 kg is accelerated from rest by a force across a floor at a rate of $2.0\ \mathrm{m/s^2}$ for 7.0 s. Find the net work done on the box.

10. (II) A 380-kg piano slides 2.9 m down a 25° incline and is kept from accelerating by a man who is pushing back on it *parallel to the incline* (Fig. 6–36). Determine: (*a*) the force exerted by the man, (*b*) the work done on the piano by the man, (*c*) the work done on the piano by the force of gravity, and (*d*) the net work done on the piano. Ignore friction.

FIGURE 6–36
Problem 10.

11. (II) Recall from Chapter 4, Example 4–14, that you can use a pulley and ropes to decrease the force needed to raise a heavy load (see Fig. 6–37). But for every meter the load is raised, how much rope must be pulled up? Account for this, using energy concepts.

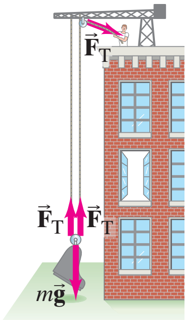


FIGURE 6–37
Problem 11.

12. (III) A grocery cart with mass of 16 kg is being pushed at constant speed up a 12° ramp by a force F_{P} which acts at an angle of 17° below the horizontal. Find the work done by each of the forces $(m\vec{\mathbf{g}}, \vec{\mathbf{F}}_{\mathrm{N}}, \vec{\mathbf{F}}_{\mathrm{P}})$ on the cart if the ramp is 7.5 m long.

*6–2 Work, Varying Force

*13. (II) The force on a particle, acting along the *x* axis, varies as shown in Fig. 6–38. Determine the work done by this force to move the particle along the *x* axis: (*a*) from $x = 0.0$ to $x = 10.0$ m; (*b*) from $x = 0.0$ to $x = 15.0$ m.

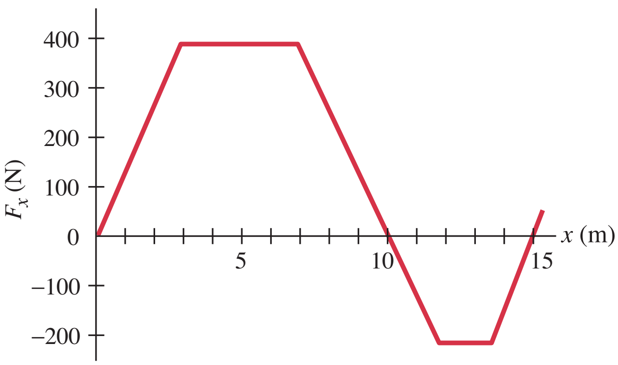
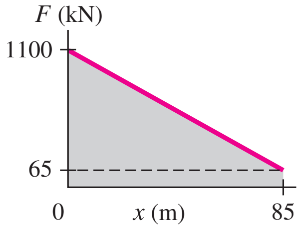


FIGURE 6–38 Problem 13.

*14. (III) A 17,000-kg jet takes off from an aircraft carrier via a catapult (Fig. 6–39a). The gases thrust out from the jet's engines exert a constant force of 130 kN on the jet; the force exerted on the jet by the catapult is plotted in Fig. 6–39b. Determine the work done on the jet: (*a*) by the gases expelled by its engines during launch of the jet; and (*b*) by the catapult during launch of the jet.

(a)



(b)

FIGURE 6–39 Problem 14.

6–3 Kinetic Energy; Work-Energy Principle

15. (I) At room temperature, an oxygen molecule, with mass of 5.31×10^{-26} kg, typically has a kinetic energy of about 6.21×10^{-21} J. How fast is it moving?

16. (I) (*a*) If the kinetic energy of a particle is tripled, by what factor has its speed increased? (*b*) If the speed of a particle is halved, by what factor does its kinetic energy change?

17. (I) How much work is required to stop an electron $(m = 9.11 \times 10^{-31}\ \text{kg})$ which is moving with a speed of 1.10×10^6 m/s?

18. (I) How much work must be done to stop a 925-kg car traveling at 95 km/h?

19. (II) Two bullets are fired at the same time with the same kinetic energy. If one bullet has twice the mass of the other, which has the greater speed and by what factor? Which can do the most work?

20. (II) A baseball $(m = 145\ \text{g})$ traveling 32 m/s moves a fielder's glove backward 25 cm when the ball is caught. What was the average force exerted by the ball on the glove?

21. (II) An 85-g arrow is fired from a bow whose string exerts an average force of 105 N on the arrow over a distance of 75 cm. What is the speed of the arrow as it leaves the bow?

22. (II) If the speed of a car is increased by 50%, by what factor will its minimum braking distance be increased, assuming all else is the same? Ignore the driver's reaction time.

23. (III) A 265-kg load is lifted 18.0 m vertically with an acceleration $a = 0.160\,g$ by a single cable. Determine (*a*) the tension in the cable; (*b*) the net work done on the load; (*c*) the work done by the cable on the load; (*d*) the work done by gravity on the load; (*e*) the final speed of the load assuming it started from rest.

6–4 and 6–5 Potential Energy

24. (I) By how much does the gravitational potential energy of a 54-kg pole vaulter change if her center of mass rises about 4.0 m during the jump?

25. (I) A spring has a spring constant *k* of 88.0 N/m. How much must this spring be compressed to store 45.0 J of potential energy?

26. (II) If it requires 6.0 J of work to stretch a particular spring by 2.0 cm from its equilibrium length, how much more work will be required to stretch it an additional 4.0 cm?

27. (II) A 66.5-kg hiker starts at an elevation of 1270 m and climbs to the top of a peak 2660 m high. (*a*) What is the hiker's change in potential energy? (*b*) What is the minimum work required of the hiker? (*c*) Can the actual work done be greater than this? Explain.

28. (II) A 1.60-m-tall person lifts a 1.65-kg book off the ground so it is 2.20 m above the ground. What is the potential energy of the book relative to (*a*) the ground, and (*b*) the top of the person's head? (*c*) How is the work done by the person related to the answers in parts (*a*) and (*b*)?

6–6 and 6–7 Conservation of Mechanical Energy

29. (I) A novice skier, starting from rest, slides down an icy frictionless 8.0° incline whose vertical height is 105 m. How fast is she going when she reaches the bottom?

30. (I) Jane, looking for Tarzan, is running at top speed (5.0 m/s) and grabs a vine hanging vertically from a tall tree in the jungle. How high can she swing upward? Does the length of the vine affect your answer?

31. (II) A sled is initially given a shove up a frictionless 23.0° incline. It reaches a maximum vertical height 1.22 m higher than where it started at the bottom. What was its initial speed?

32. (II) In the *high jump*, the kinetic energy of an athlete is transformed into gravitational potential energy without the aid of a pole. With what minimum speed must the athlete leave the ground in order to lift his center of mass 2.10 m and cross the bar with a speed of 0.50 m/s?

33. (II) A 1200-kg car moving on a horizontal surface has speed $v = 85$ km/h when it strikes a horizontal coiled spring and is brought to rest in a distance of 2.2 m. What is the spring stiffness constant of the spring?

34. (II) A 62-kg trampoline artist jumps upward from the top of a platform with a vertical speed of 4.5 m/s. (*a*) How fast is he going as he lands on the trampoline, 2.0 m below (Fig. 6–40)? (*b*) If the trampoline behaves like a spring of spring constant 5.8×10^4 N/m, how far down does he depress it?

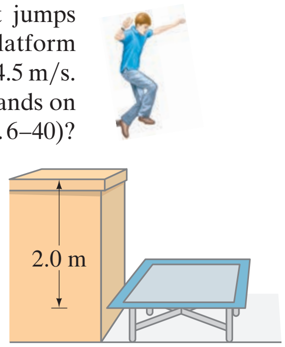


FIGURE 6–40 Problem 34.

35. (II) A vertical spring (ignore its mass), whose spring constant is 875 N/m, is attached to a table and is compressed down by 0.160 m. (*a*) What upward speed can it give to a 0.380-kg ball when released? (*b*) How high above its original position (spring compressed) will the ball fly?

36. (II) A roller-coaster car shown in Fig. 6–41 is pulled up to point 1 where it is released from rest. Assuming no friction, calculate the speed at points 2, 3, and 4.

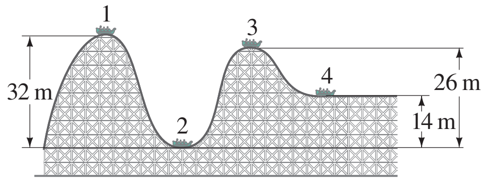


FIGURE 6–41 Problems 36.

37. (II) Chris jumps off a bridge with a bungee cord (a heavy stretchable cord) tied around his ankle, Fig. 6–42. He falls for 15 m before the bungee cord begins to stretch. Chris's mass is 75 kg and we assume the cord obeys Hooke's law, $F = -kx$, with $k = 55\ \text{N/m}$. If we neglect air resistance, estimate what distance d below the bridge Chris's foot will be before coming to a stop. Ignore the mass of the cord (not realistic, however) and treat Chris as a particle.

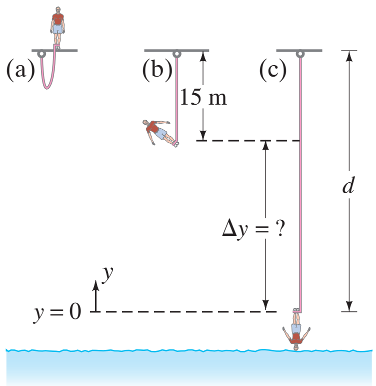


FIGURE 6–42 Problem 37. (a) Bungee jumper about to jump. (b) Bungee cord at its unstretched length. (c) Maximum stretch of cord.

38. (III) A block of mass m is attached to the end of a spring (spring stiffness constant k), Fig. 6–43. The mass is given an initial displacement x_0 from equilibrium, and an initial speed v_0. Ignoring friction and the mass of the spring, use energy methods to find (*a*) its maximum speed, and (*b*) its maximum stretch from equilibrium, in terms of the given quantities.

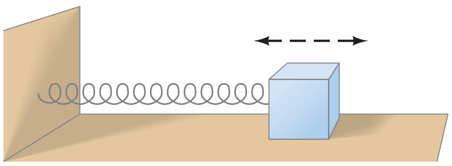


FIGURE 6–43 Problem 38.

39. (III) A cyclist intends to cycle up a 7.50° hill whose vertical height is 125 m. The pedals turn in a circle of diameter 36.0 cm. Assuming the mass of bicycle plus person is 75.0 kg, (*a*) calculate how much work must be done against gravity. (*b*) If each complete revolution of the pedals moves the bike 5.10 m along its path, calculate the average force that must be exerted on the pedals tangent to their circular path. Neglect work done by friction and other losses.

6–8 and 6–9 Law of Conservation of Energy

40. (I) Two railroad cars, each of mass 66,000 kg, are traveling 85 km/h toward each other. They collide head-on and come to rest. How much thermal energy is produced in this collision?

41. (I) A 16.0-kg child descends a slide 2.20 m high and, starting from rest, reaches the bottom with a speed of 1.25 m/s. How much thermal energy due to friction was generated in this process?

42. (II) A ski starts from rest and slides down a 28° incline 85 m long. (*a*) If the coefficient of friction is 0.090, what is the ski's speed at the base of the incline? (*b*) If the snow is level at the foot of the incline and has the same coefficient of friction, how far will the ski travel along the level? Use energy methods.

43. (II) A 145-g baseball is dropped from a tree 12.0 m above the ground. (*a*) With what speed would it hit the ground if air resistance could be ignored? (*b*) If it actually hits the ground with a speed of 8.00 m/s, what is the average force of air resistance exerted on it?

44. (II) A skier traveling 11.0 m/s reaches the foot of a steady upward 19° incline and glides 15 m up along this slope before coming to rest. What was the average coefficient of friction?

45. (II) You drop a ball from a height of 2.0 m, and it bounces back to a height of 1.6 m. (*a*) What fraction of its initial energy is lost during the bounce? (*b*) What is the ball's speed just before and just after the bounce? (*c*) Where did the energy go?

46. (II) A 66-kg skier starts from rest at the top of a 1200-m-long trail which drops a total of 230 m from top to bottom. At the bottom, the skier is moving 11.0 m/s. How much energy was dissipated by friction?

47. (II) The Lunar Module could make a safe landing if its vertical velocity at impact is 3.0 m/s or less. Suppose that you want to determine the greatest height h at which the pilot could shut off the engine if the velocity of the lander relative to the surface at that moment is (*a*) zero; (*b*) 2.0 m/s downward; (*c*) 2.0 m/s upward. Use conservation of energy to determine h in each case. The acceleration due to gravity at the surface of the Moon is $1.62\ \text{m/s}^2$.

48. (III) Early test flights for the space shuttle used a "glider" (mass of 980 kg including pilot). After a horizontal launch at 480 km/h at a height of 3500 m, the glider eventually landed at a speed of 210 km/h. (*a*) What would its landing speed have been in the absence of air resistance? (*b*) What was the average force of air resistance exerted on it if it came in at a constant glide angle of 12° to the Earth's surface?

6–10 Power

49. (I) How long will it take a 2750-W motor to lift a 385-kg piano to a sixth-story window 16.0 m above?

50. (I) (*a*) Show that one British horsepower (550 ft·lb/s) is equal to 746 W. (*b*) What is the horsepower rating of a 75-W lightbulb?

51. (II) If a car generates 18 hp when traveling at a steady 95 km/h, what must be the average force exerted on the car due to friction and air resistance?

52. (II) An outboard motor for a boat is rated at 35 hp. If it can move a particular boat at a steady speed of 35 km/h, what is the total force resisting the motion of the boat?

53. (II) A shot-putter accelerates a 7.3-kg shot from rest to 14 m/s in 1.5 s. What average power was developed?

54. (II) A driver notices that her 1080-kg car, when in neutral, slows down from 95 km/h to 65 km/h in about 7.0 s on a flat horizontal road. Approximately what power (watts and hp) is needed to keep the car traveling at a constant 80 km/h?

55. (II) How much work can a 2.0-hp motor do in 1.0 h?

56. (II) A 975-kg sports car accelerates from rest to 95 km/h in 6.4 s. What is the average power delivered by the engine?

57. (II) During a workout, football players ran up the stadium stairs in 75 s. The distance along the stairs is 83 m and they are inclined at a 33° angle. If a player has a mass of 82 kg, estimate his average power output on the way up. Ignore friction and air resistance.

58. (II) A pump lifts 27.0 kg of water per minute through a height of 3.50 m. What minimum output rating (watts) must the pump motor have?

59. (II) A ski area claims that its lifts can move 47,000 people per hour. If the average lift carries people about 200 m (vertically) higher, estimate the maximum total power needed.

60. (II) What minimum horsepower must a motor have to be able to drag a 370-kg box along a level floor at a speed of 1.20 m/s if the coefficient of friction is 0.45?

61. (III) A bicyclist coasts down a 6.0° hill at a steady speed of 4.0 m/s. Assuming a total mass of 75 kg (bicycle plus rider), what must be the cyclist's power output to climb the same hill at the same speed?

General Problems

62. Spiderman uses his spider webs to save a runaway train moving about 60 km/h, Fig. 6–44. His web stretches a few city blocks (500 m) before the 10^4-kg train comes to a stop. Assuming the web acts like a spring, estimate the effective spring constant.

FIGURE 6–44 Problem 62.

63. A 36.0-kg crate, starting from rest, is pulled across a floor with a constant horizontal force of 225 N. For the first 11.0 m the floor is frictionless, and for the next 10.0 m the coefficient of friction is 0.20. What is the final speed of the crate after being pulled these 21.0 m?

64. How high will a 1.85-kg rock go from the point of release if thrown straight up by someone who does 80.0 J of work on it? Neglect air resistance.

65. A mass m is attached to a spring which is held stretched a distance x by a force F, Fig. 6–45, and then released. The spring pulls the mass to the left, towards its natural equilibrium length. Assuming there is no friction, determine the speed of the mass m when the spring returns: (*a*) to its normal length $(x = 0)$; (*b*) to half its original extension $(x/2)$.

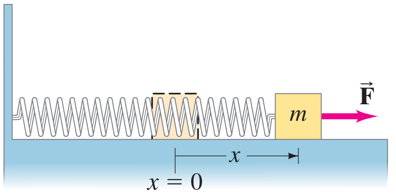


FIGURE 6–45 Problem 65.

66. An elevator cable breaks when a 925-kg elevator is 28.5 m above the top of a huge spring $(k = 8.00 \times 10^4\ \mathrm{N/m})$ at the bottom of the shaft. Calculate (*a*) the work done by gravity on the elevator before it hits the spring; (*b*) the speed of the elevator just before striking the spring; (*c*) the amount the spring compresses (note that here work is done by both the spring and gravity).

67. (*a*) A 3.0-g locust reaches a speed of 3.0 m/s during its jump. What is its kinetic energy at this speed? (*b*) If the locust transforms energy with 35% efficiency, how much energy is required for the jump?

68. In a common test for cardiac function (the "stress test"), the patient walks on an inclined treadmill (Fig. 6–46). Estimate the power required from a 75-kg patient when the treadmill is sloping at an angle of 12° and the velocity is 3.1 km/h. (How does this power compare to the power rating of a lightbulb?)

FIGURE 6–46 Problem 68.

69. An airplane pilot fell 370 m after jumping from an aircraft without his parachute opening. He landed in a snowbank, creating a crater 1.1 m deep, but survived with only minor injuries. Assuming the pilot's mass was 88 kg and his speed at impact was 45 m/s, estimate: (*a*) the work done by the snow in bringing him to rest; (*b*) the average force exerted on him by the snow to stop him; and (*c*) the work done on him by air resistance as he fell. Model him as a particle.

70. Many cars have "5 mi/h (8 km/h) bumpers" that are designed to compress and rebound elastically without any physical damage at speeds below 8 km/h. If the material of the bumpers permanently deforms after a compression of 1.5 cm, but remains like an elastic spring up to that point, what must be the effective spring constant of the bumper material, assuming the car has a mass of 1050 kg and is tested by ramming into a solid wall?

71. In climbing up a rope, a 62-kg athlete climbs a vertical distance of 5.0 m in 9.0 s. What minimum power output was used to accomplish this feat?

72. If a 1300-kg car can accelerate from 35 km/h to 65 km/h in 3.8 s, how long will it take to accelerate from 55 km/h to 95 km/h? Assume the power stays the same, and neglect frictional losses.

73. A cyclist starts from rest and coasts down a 4.0° hill. The mass of the cyclist plus bicycle is 85 kg. After the cyclist has traveled 180 m, (*a*) what was the net work done by gravity on the cyclist? (*b*) How fast is the cyclist going? Ignore air resistance and friction.

74. A film of Jesse Owens's famous long jump (Fig. 6–47) in the 1936 Olympics shows that his center of mass rose 1.1 m from launch point to the top of the arc. What minimum speed did he need at launch if he was traveling at 6.5 m/s at the top of the arc?

FIGURE 6–47 Problem 74.

75. Water flows over a dam at the rate of 680 kg/s and falls vertically 88 m before striking the turbine blades. Calculate (*a*) the speed of the water just before striking the turbine blades (neglect air resistance), and (*b*) the rate at which mechanical energy is transferred to the turbine blades, assuming 55% efficiency.

76. Electric energy units are often expressed in "kilowatt-hours." (*a*) Show that one kilowatt-hour (kWh) is equal to 3.6×10^6 J. (*b*) If a typical family of four uses electric energy at an average rate of 580 W, how many kWh would their electric bill show for one month, and (*c*) how many joules would this be? (*d*) At a cost of \$0.12 per kWh, what would their monthly bill be in dollars? Does the monthly bill depend on the *rate* at which they use the electric energy?

77. A 65-kg hiker climbs to the top of a mountain 4200 m high. The climb is made in 4.6 h starting at an elevation of 2800 m. Calculate (*a*) the work done by the hiker against gravity, (*b*) the average power output in watts and in horsepower, and (*c*) assuming the body is 15% efficient, what rate of energy input was required.

78. A ball is attached to a horizontal cord of length ℓ whose other end is fixed, Fig. 6–48. (*a*) If the ball is released, what will be its speed at the lowest point of its path? (*b*) A peg is located a distance h directly below the point of attachment of the cord. If $h = 0.80\ell$, what will be the speed of the ball when it reaches the top of its circular path about the peg?

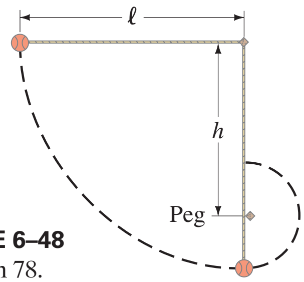


FIGURE 6–48 Problem 78.

79. An 18-kg sled starts up a 28° incline with a speed of 2.3 m/s. The coefficient of kinetic friction is $\mu_k = 0.25$. (*a*) How far up the incline does the sled travel? (*b*) What condition must you put on the coefficient of static friction if the sled is not to get stuck at the point determined in part (*a*)? (*c*) If the sled slides back down, what is its speed when it returns to its starting point?

80. Some electric power companies use water to store energy. Water is pumped from a low reservoir to a high reservoir. To store the energy produced in 1.0 hour by a 180-MW electric power plant, how many cubic meters of water will have to be pumped from the lower to the upper reservoir? Assume the upper reservoir is an average of 380 m above the lower one. Water has a mass of 1.00×10^3 kg for every $1.0\ \text{m}^3$.

81. A softball having a mass of 0.25 kg is pitched horizontally at 120 km/h. By the time it reaches the plate, it may have slowed by 10%. Neglecting gravity, estimate the average force of air resistance during a pitch. The distance between the plate and the pitcher is about 15 m.

Search and Learn

1. We studied forces earlier and used them to solve Problems. Now we are using energy to solve Problems, even some that could be solved with forces. (*a*) Give at least three advantages of using energy to solve a Problem. (*b*) When must you use energy to solve a Problem? (*c*) When must you use forces to solve a Problem? (*d*) What information is not available when solving Problems with energy? Look at the Examples in Chapters 6 and 4.

2. (*a*) Only two conservative forces are discussed in this Chapter. What are they, and how are they accounted for when you are dealing with conservation of energy? (*b*) Not mentioned is the force of water on a swimmer. Is it conservative or nonconservative?

3. Give at least two examples of friction doing positive work. Reread parts of Chapters 4 and 6.

4. The brakes on a truck can overheat and catch on fire if the truck goes down a long steep hill without shifting into a lower gear. (*a*) Explain why this happens in terms of energy and power. (*b*) Would it matter if the same elevation change was made going down a steep hill or a gradual hill? Explain your reasoning. [*Hint:* Read Sections 6–4, 6–9, and 6–10 carefully.] (*c*) Why does shifting into a lower gear help? [*Hint:* Use your own experience, downshifting in a car.] (*d*) Calculate the thermal energy dissipated from the brakes in an 8000-kg truck that descends a 12° hill. The truck begins braking when its speed is 95 km/h and slows to a speed of 35 km/h in a distance of 0.36 km measured along the road.

ANSWERS TO EXERCISES

A: (*c*).

B: (*a*) Less, because $(20)^2 = 400 < (30)^2 - (20)^2 = 500$; (*b*) 2.0×10^5 J.

C: No, because the speed v would be the square root of a negative number, which is not real.

D: (*a*) $\sqrt{2}$; (*b*) 4.

E: Yes. It is nonconservative, because for a conservative force $W = 0$ in a round trip.

F: (*e*), (*e*); (*e*), (*c*).