حل الوحدة العاشرة Energy and its conservation منهج انسباير

Module 10 Energy and Its Conservation

Lesson 1 Work and Energy

Practice Problems

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1. Refer to Example Problem 1 to solve the following problem.

a. If the hockey player exerted twice as much force (9.00 N) on the puck over the same distance, how would the amount of work the stick did on the puck be affected?

Because $W = Fd$, doubling the force would double the work to 1.35 J.

b. If the player exerted a 9.00-N force, but the stick was in contact with the puck for only half the distance (0.075 m), how much work does the stick do on the puck?

Because $W = Fd$, halving the distance would cut the work in half to 0.68 J.

2. Together, two students exert a force of 825 N in pushing a car a distance of 35 m.

a. How much work do the students do on the car?

$$\begin{aligned} W &= Fd = (825\ \text{N})(35\ \text{m}) \\ &= 2.9\times10^{4}\ \text{J} \end{aligned}$$

b. If their force is doubled, how much work must they do on the car to push it the same distance?

$$\begin{aligned} W &= Fd \\ &= (2)(825\ \text{N})(35\ \text{m}) \\ &= 5.8\times10^{4}\ \text{J}, \end{aligned}$$

which is twice as much work

3. A rock climber wears a 7.5-kg backpack while scaling a cliff. After 30.0 min, the climber is 8.2 m above the starting point.

a. How much work does the climber do on the backpack?

$$\begin{aligned} W &= Fd = mgd \\ &= (7.5\ \text{kg})(9.8\ \text{N/kg})(8.2\ \text{m}) \\ &= 6.0\times10^{2}\ \text{J} \end{aligned}$$

b. If the climber weighs 645 N, how much work does she do lifting herself and the backpack?

$$\begin{aligned} W &= F_g d + 6.0\times10^{2}\ \text{J} \\ &= (645\ \text{N})(8.2\ \text{m}) + 6.0\times10^{2}\ \text{J} \\ &= 5.9\times10^{3}\ \text{J} \end{aligned}$$

4. CHALLENGE Marisol pushes a 3.0-kg box 7.0 m across the floor with a force of 12 N. She then lifts the box to a shelf 1 m above the ground. How much work does Marisol do on the box?

work to push the box:

$$\begin{aligned} W &= Fd = (12\ \text{N})(7.0\ \text{m}) \\ &= 84\ \text{J} \end{aligned}$$

work to lift the box:

$$\begin{aligned} W &= Fd = mgd \\ &= (3.0\ \text{kg})(9.8\ \text{N/kg})(1.0\ \text{m}) \\ &= 29.4\ \text{J} \end{aligned}$$

total work:

$84\ \text{J} + 29.4\ \text{J} = 1.1\times10^{2}\ \text{J}$

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5. If the sailor in Example Problem 2 pulls with the same force through the same displacement but at an angle of 50.0°, how much work is done on the boat by the rope?

$$\begin{aligned} \boldsymbol{W} &= \boldsymbol{Fd}\,\mathbf{cos}\,\theta \\ &= (\mathbf{255\ N})(\mathbf{30.0\ m})(\mathbf{cos\,50.0°}) \\ &= \mathbf{4.92\times10^{3}\ J} \end{aligned}$$

6. Two people lift a heavy box a distance of 15 m. They use ropes, each of which makes an angle of 15° with the vertical. Each person exerts a force of 225 N. Calculate the work done by the ropes?

$$\begin{aligned} \boldsymbol{W} &= \boldsymbol{Fd}\,\mathbf{cos}\,\theta \\ &= (\mathbf{2})(\mathbf{255\ N})(\mathbf{15\ m})(\mathbf{cos\,15°}) \\ &= \mathbf{6.5\times10^{3}\ J} \end{aligned}$$

7. An airplane passenger carries a 215-N suitcase up the stairs, a displacement of 4.20 m vertically and 4.60 m horizontally.

a. How much work does the passenger do on the suitcase?

Since gravity acts vertically, only the vertical displacement needs to be considered.

$\boldsymbol{W} = \boldsymbol{Fd} = \mathbf{(215\ N)(4.20\ m) = 903\ J}$

b. The same passenger carries the same suitcase back down the same set of stairs. How much work does the passenger do on the suitcase to carry it down the stairs?

Force is upward, but vertical displacement is downward, so

$$\begin{aligned} \boldsymbol{W} &= \boldsymbol{Fd}\,\mathbf{cos}\,\theta \\ &= (\mathbf{215\ N})(\mathbf{4.20\ m})(\mathbf{cos\,180.0°}) \\ &= \mathbf{-903\ J} \end{aligned}$$

8. A rope is used to pull a metal box a distance of 15.0 m across the floor. The rope is held at an angle of 46.0° with the floor, and a force of 628 N is applied to the rope. How much work does the rope do on the box?

$$\begin{aligned} \boldsymbol{W} &= \boldsymbol{Fd}\,\mathbf{cos}\,\theta \\ &= (\mathbf{628\ N})(\mathbf{15.0\ m})(\mathbf{cos\,46.0°}) \\ &= \mathbf{6.54\times10^{3}\ J} \end{aligned}$$

9. **CHALLENGE** A bicycle rider pushes a 13-kg bicycle up a steep hill. The incline is 25° and the hill is 275 m long, as shown in **Figure 5.** The rider pushes the bike parallel to the road with a force of 25 N.

a. How much work does the rider do on the bike?

Force and displacement are in the same direction.

$$\begin{aligned} \boldsymbol{W} &= \boldsymbol{Fd} \\ &= \mathbf{(25\ N)(275\ m) = 6.9\times10^{3}\ J} \end{aligned}$$

b. How much work is done by the force of gravity on the bike?

The force is downward (–90°), and the displacement is 25° above the horizontal or 115° from the force.

$$\begin{aligned} \boldsymbol{W} &= \boldsymbol{Fd}\,\mathbf{cos}\,\theta = \boldsymbol{mgd}\,\mathbf{cos}\,\theta \\ &= (\mathbf{13\ kg})(\mathbf{9.8\ N/kg})(\mathbf{275\ m})(\mathbf{cos\,115°}) \\ &= \mathbf{-1.5\times10^{4}\ J} \end{aligned}$$

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10. A catamaran with a mass of 5.44×103 kg is moving at 12 knots. How much work is required to increase the speed to 16 knots? (One knot = 0.51 m/s.)

12 knots × (0.51 m/s)/knot = 6.12 m/s
16 knots × (0.51 m/s)/knot = 8.16 m/s

$$\begin{aligned} \boldsymbol{W} &= \Delta \boldsymbol{E} = \boldsymbol{E}_{\mathrm{f}} - \boldsymbol{E}_{\mathrm{i}} \\ &= \tfrac{1}{2}\boldsymbol{m}\boldsymbol{v}_{\mathrm{f}}^{2} - \tfrac{1}{2}\boldsymbol{m}\boldsymbol{v}\mathbf{i}^{2} = \tfrac{1}{2}\boldsymbol{m}(\boldsymbol{v}_{\mathrm{f}}^{2} - \boldsymbol{v}_{\mathrm{i}}^{2}) \\ &= \tfrac{1}{2}\,(\mathbf{5.44\times10^{3}\ kg}) \\ &\qquad \times ((\mathbf{8.16\ m/s})^{2} - (\mathbf{6.12\ m/s})^{2}) \\ &= \mathbf{8.07\times10^{4}\ J} \end{aligned}$$

11. A 52.0-kg skater moves at 2.5 m/s and stops over a distance of 24.0 m. Find the skater's initial kinetic energy. How much of her kinetic energy is transformed into other forms of energy by friction as she stops? How much work must she do to speed up to 2.5 m/s again?

While stopping:

$$\begin{aligned} \boldsymbol{E}_{\text{transformed}} &= \boldsymbol{E}_{\text{i}} - \boldsymbol{E}_{\text{f}} = \boldsymbol{KE}_{\text{i}} - \mathbf{0} \\ &= \frac{1}{2}\boldsymbol{m}\boldsymbol{v}_{\text{i}}^{2} \\ &= \frac{1}{2}(\mathbf{52.0\ kg})(\mathbf{2.5\ m/s})^{2} \\ &= \mathbf{160\ J} \end{aligned}$$

All of her kinetic energy is transformed to other forms of energy when she stops.

To Speed up again:

$$\begin{aligned} \boldsymbol{W} &= \Delta \boldsymbol{E} = \boldsymbol{KE}_{\text{f}} - \boldsymbol{KE}_{\text{i}} \\ &= \frac{1}{2}\boldsymbol{m}\boldsymbol{v}_{\text{f}}^{2} - \frac{1}{2}\boldsymbol{m}\boldsymbol{v}_{\text{i}}^{2} \\ &= \frac{1}{2}(\mathbf{52.0\ kg})(\mathbf{2.5\ m/s})^{2} - \\ &\qquad \frac{1}{2}(\mathbf{52.0\ kg})(\mathbf{0.00\ m/s})^{2} \\ &= +\mathbf{160\ J} \end{aligned}$$

12. An 875.0-kg car speeds up from 22.0 m/s to 44.0 m/s. What are the initial and final kinetic energies of the car? How much work is done on the car to increase its speed?

The initial kinetic energy of the car is

$$\boldsymbol{KE}_{\text{i}} = \frac{1}{2}\boldsymbol{m}\boldsymbol{v}^{2} = \frac{1}{2}(\mathbf{875.0\ kg})(\mathbf{22.0\ m/s})^{2}$$

$$= \mathbf{2.12{\times}10^{5}\ J}$$

The final kinetic energy is

$$\boldsymbol{KE}_{\text{f}} = \frac{1}{2}\boldsymbol{m}\boldsymbol{v}^{2} = \frac{1}{2}(\mathbf{875.0\ kg})(\mathbf{44.0\ m/s})^{2}$$

$$= \mathbf{8.47{\times}10^{5}\ J}$$

The work done is

$$\begin{aligned} \boldsymbol{KE}_{\text{f}} - \boldsymbol{KE}_{\text{i}} &= \mathbf{8.47{\times}10^{5}\ J - 2.12 \times 10^{5}\ J} \\ &= \mathbf{6.35{\times}10^{5}\ J} \end{aligned}$$

13. **CHALLENGE** A comet with a mass of $7.85{\times}10^{11}$ kg strikes Earth at a speed of 25.0 km/s. Find the kinetic energy of the comet in joules, and compare the work that is done by Earth in stopping the comet to the $4.2{\times}10^{15}$ J of energy that was released by the largest nuclear weapon ever exploded.

$$\begin{aligned} \boldsymbol{KE} &= \frac{1}{2}\boldsymbol{m}\boldsymbol{v}^{2} \\ &= \frac{1}{2}(\mathbf{7.85 \times 10^{11}\ kg})(\mathbf{2.50 \times 10^{4}\ m/s})^{2} \\ &= \mathbf{2.45 \times 10^{20}\ J} \end{aligned}$$

$$\textbf{So } \frac{\boldsymbol{KE}_{\text{comet}}}{\boldsymbol{KE}_{\text{bomb}}} = \frac{\mathbf{2.45 \times 10^{20}\ J}}{\mathbf{4.2 \times 10^{15}\ J}} = \mathbf{5.8 \times 10^{4}}$$

$5.8{\times}10^{4}$ bombs would be required to produce the same amount of energy used by Earth in stopping the comet.

Practice Problems

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14. A cable attached to a motor lifts a 575-N box up a distance of 20.0 m. The box moves with a constant velocity and the job is done in 10.0 s. What power is developed by the motor in W and kW?

$$\begin{aligned} \boldsymbol{P} &= \frac{\boldsymbol{W}}{\boldsymbol{t}} = \frac{\boldsymbol{Fd}}{\boldsymbol{t}} = \frac{(\mathbf{575\ N})(\mathbf{20.0\ m})}{\mathbf{10.0\ s}} \\ &= \mathbf{1.15 \times 10^{3}\ W = 1.15\ kW} \end{aligned}$$

15. You push a wheelbarrow a distance of 60.0 m at a constant speed for 25.0 s by exerting a 145-N force horizontally.

a. What power do you develop?

$$\begin{aligned} \boldsymbol{P} &= \frac{\boldsymbol{W}}{\boldsymbol{t}} = \frac{\boldsymbol{Fd}}{\boldsymbol{t}} \\ &= \frac{(\mathbf{145\ N})(\mathbf{60.0\ m})}{\mathbf{25.0\ s}} = \mathbf{348\ W} \end{aligned}$$

b. If you move the wheelbarrow twice as fast, how much power is developed?

***t* is halved, so *P* is doubled to 696 W.**

16. What power does a pump develop to lift 35 L of water per minute from a depth of 110 m? (One liter of water has a mass of 1.00 kg.)

$$P = \frac{W}{t} = \frac{mgd}{t} = \left(\frac{m}{t}\right)gd$$

Where $\frac{m}{t} = \mathbf{(35\ L/min)(1.00\ kg/L)}$

Thus,

$$P = \left(\frac{m}{t}\right)gd$$

$$= (\mathbf{35\ L/min})(\mathbf{1.00\ kg/L})\left(\frac{\mathbf{1\ min}}{\mathbf{60\ s}}\right)(\mathbf{9.8\ N/kg})(\mathbf{110\ m})$$

$$= \mathbf{0.63\ kW}$$

17. An electric motor develops 65 kW of power as it lifts a loaded elevator 17.5 m in 35 s. How much force does the motor exert?

$$P = \frac{W}{t} = \frac{Fd}{t}$$

$$F = \frac{Pt}{d} = \frac{(\mathbf{65\times10^3\ W})(\mathbf{35\ s})}{\mathbf{17.5\ m}}$$

$$= \mathbf{1.3\times10^5\ N}$$

18. **Challenge** A winch designed to be mounted on a truck, as shown in **Figure 10,** is advertised as being able to exert a 6.8×10^3-N force and to develop a power of 0.30 kW. How long would it take the truck and the winch to pull an object 15 m?

$$P = \frac{W}{t} = \frac{Fd}{t}$$

$$t = \frac{Fd}{P}$$

$$= \frac{(\mathbf{6.8\times10^3\ N})(\mathbf{15\ m})}{(\mathbf{0.30\times10^3\ W})}$$

$$= \mathbf{340\ s = 5.7\ min}$$

Lesson 1 Check Your Progress

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19. **Work-Energy Theorem** How can you apply the work-energy theorem to lifting a bowling ball from a storage rack to your shoulder?

The bowling ball has zero kinetic energy when it is resting on the rack or when it is held near your shoulder. Therefore, the total work done on the ball by you and by gravity must equal zero.

20. **Work and Energy** If the work done on an object doubles its kinetic energy, does it double its speed? If not, by what ratio does it change the speed?

Kinetic energy is proportional to the square of the velocity, so doubling the energy doubles the square of the velocity. The velocity increases by a factor of the square root of 2, or 1.4.

21. **Work** Murimi pushes a 20-kg mass 10 m across a floor with a horizontal force of 80 N. Calculate the amount of work done by Murimi on the mass.

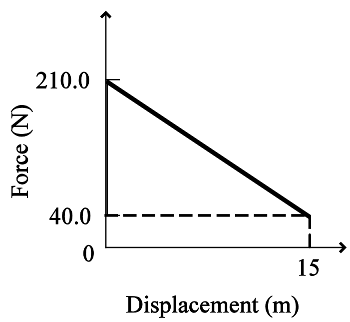
$W = Fd = \mathbf{(80\ N)(10\ m) = 8\times10^2\ J}$

The mass is not important to this problem.

22. **Work** Suppose you are pushing a stalled car. As the car gets going, you need less and less force to keep it going. For the first 15 m, your force decreases at a constant rate from 210.0 N to 40.0 N. How much work did you do on the car? Draw a force-displacement graph to represent the work done during this period.

The work done is the area of the trapezoid under the solid line:

$$\begin{aligned} W &= \frac{1}{2}d(F_1 + F_2) \\ &= \frac{1}{2}(15\ \text{m})(210.0\ \text{N} + 40.0\ \text{N}) \\ &= 1.9\times 10^3\ \text{J} \end{aligned}$$



23. **Work** A mover loads a 185-kg refrigerator into a moving van by pushing it at a constant speed up a 10.0-m, friction-free ramp at an angle of inclination of 11°. How much work is done by the mover on the refrigerator?

$$\begin{aligned} y &= (10.0\ \text{m})(\sin\ 11.0°) \\ &= 1.91\ \text{m} \end{aligned}$$

$$\begin{aligned} W &= Fd\sin\theta \\ &= mgd\sin\theta \\ &= (185\ \text{kg})(9.8\ \text{N/kg}) \\ &\quad\ (10.0\ \text{m})(\sin\ 11.0°) \\ &= 3.46\times 10^3\ \text{J} \end{aligned}$$

24. **Work** A 0.180-kg ball falls 2.5 m. How much work does the force of gravity do on the ball?

$$\begin{aligned} W &= F_g d = mgd \\ &= (0.180\ \text{kg})(9.8\ \text{N/kg})(2.5\ \text{m}) \\ &= 4.4\ \text{J} \end{aligned}$$

25. **Work and Power** Does the work required to lift a book to a shelf depend on how fast you raise it? Does the power required to lift it depend on how fast you raise it? Explain.

No, work is not a function of time. However, power is a function of time, so the power required to lift the book does depend on how fast you raise it.

26. **Power** An elevator lifts a total mass of 1.1×10^3 kg a distance of 40.0 m in 12.5 s. How much power does the elevator deliver?

$$\begin{aligned} P &= \frac{W}{t} = \frac{Fd}{t} = \frac{mgd}{t} \\ &= \frac{(1.1\times 10^3\ \text{kg})(9.8\ \text{N/kg})(40.0\ \text{m})}{12.5\ \text{s}} \\ &= 3.4\times 10^4\ \text{W} \end{aligned}$$

27. **Mass** A forklift raises a box 1.2 m and does 7.0 kJ of work on it. What is the mass of the box?

$$W = Fd = mgd$$

$$\begin{aligned} \text{so } m &= \frac{W}{gd} = \frac{7.0\times 10^3\ \text{J}}{(9.8\ \text{N/kg})(1.2\ \text{m})} \\ &= 6.0\times 10^2\ \text{kg} \end{aligned}$$

28. **Work** You and a friend carry identical boxes from the first floor of a building to a room on the second floor, farther down the hall. You carry the box first up the stairs, and then down the hall to the room. Your friend carries it down the hall on the first floor, then up a different stairwell to the second floor. How do the amounts of work done by the two of you on your boxes compare?

Both do the same amount of work. Only the height lifted and the vertical force exerted count.

29. **Critical Thinking** Explain how to find the change in energy of a system if three agents exert forces on the system at once.

Since work is the change in kinetic energy, calculate the work done by each force. The work can be positive, negative, or zero, depending on the relative angles of the force and displacement of the object. The sum of the three works is the change in energy of the system.

Lesson 2 The Many Forms of Energy

Practice Problems

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30. In Example Problem 4, what is the potential energy of the ball-Earth system when the bowling ball is on the floor? Use the rack as your reference level.

$$\begin{aligned} \boldsymbol{GPE} &= \boldsymbol{mgh} \\ &= \mathbf{(7.30\ kg)(9.8\ N/kg)(-0.610\ m)} \\ &= \mathbf{-44\ J} \end{aligned}$$

31. If you slowly lower a 20.0-kg bag of sand 1.20 m from the trunk of a car to the driveway, how much work do you do?

$$\begin{aligned} \boldsymbol{W} &= \boldsymbol{Fd} \\ &= \boldsymbol{mg(h_f - h_i)} \\ &= \mathbf{(20.0\ kg)(9.8\ N/kg)(0.00\ m - 1.20\ m)} \\ &= \mathbf{-2.4\times10^2\ J} \end{aligned}$$

32. A boy lifts a 2.2-kg book from his desk, which is 0.80 m high, to a bookshelf that is 2.10 m high. What is the potential energy of the book-Earth system relative to the desk when the book is on the shelf?

$$\begin{aligned} \boldsymbol{GPE} &= \boldsymbol{mg(h_f - h_i)} \\ &= \mathbf{(2.2\ kg)(9.8\ N/kg)(2.10\ m - 0.80\ m)} \\ &= \mathbf{28\ J} \end{aligned}$$

33. You are walking around an old building and notice that it is falling apart. If a 1.8-kg brick falls to the ground from the building's chimney, which is 6.7 m high, what is the change in the potential energy of the brick-Earth system?

Choose the ground as the reference level.

$$\begin{aligned} \boldsymbol{\Delta GPE} &= \boldsymbol{mg(h_f - h_i)} \\ &= \mathbf{(1.8\ kg)(9.8\ N/kg)} \\ &\qquad \mathbf{(0.0\ m - 6.7\ m)} \\ &= \mathbf{-1.2\times10^2\ J} \end{aligned}$$

34. **CHALLENGE** A worker picks up a 10.1-kg box from the floor and sets it on a table that is 1.1 m high. He slides the box 5.0 m along the table and then lowers it back to the floor. What were the changes in the box-Earth system's energy, and how did the system's total energy change? (Ignore friction.)

To lift the box to the table:

$$\begin{aligned} \boldsymbol{W} = \boldsymbol{Fd} &= \boldsymbol{mg(h_f - h_i)} \\ &= \boldsymbol{\Delta GPE} \\ &= \mathbf{(10.1\ kg)(9.8\ N/kg)(1.1\ m - 0.0\ m)} \\ &= \mathbf{1.1\times10^2\ J} \end{aligned}$$

To slide the box across the table, $\boldsymbol{W}$ = 0.0 because the height did not change, the kinetic energy did not change, and we ignored friction.

To lower the box to the floor:

$$\begin{aligned} \boldsymbol{W} &= \boldsymbol{Fd} \\ &= \boldsymbol{mg(h_f - h_i)} \\ &= \boldsymbol{\Delta GPE} \\ &= \mathbf{(10.1\ kg)(9.8\ N/kg)(0.0\ m - 1.1\ m)} \\ &= \mathbf{-1.1\times10^2\ J} \end{aligned}$$

The sum of the three energy changes is

$$\mathbf{1.1\times10^2\ J + 0.0\ J + (-1.1\times10^2\ J) = 0.0\ J}$$

Lesson 2 Check Your Progress

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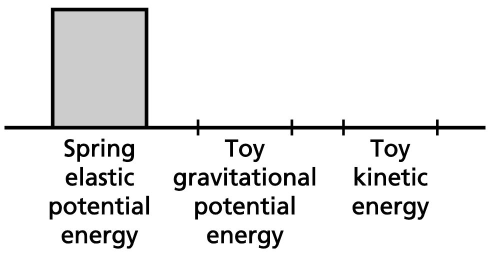
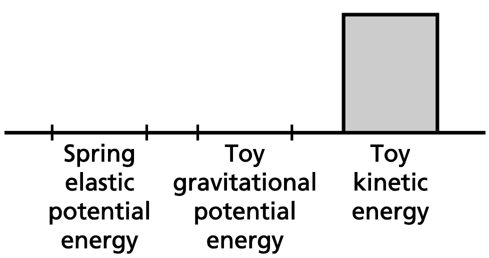
35. **Elastic Potential Energy** You compress the spring in a jumping toy, then release it. The toy then flies straight up. Draw bar graphs that show the forms of energy present in the following instances. Assume the system includes the spring toy and Earth.

a. The toy is pushed down thereby compressing the spring.



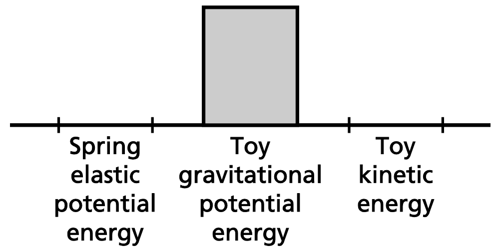
There should be three bars: one for the spring's potential energy, one for gravitational potential energy, and one for kinetic energy. The spring's potential energy is at the maximum level, and the other two are zero.

b. The spring expands and the toy jumps.



The kinetic energy is at the maximum level, and the other two are zero.

c. The toy reaches the top of its flight.



The gravitational potential energy is at the maximum level, and the other two are zero.

d. Describe how energy manifests itself in different ways in this system.

In this system, the spring has elastic potential energy. When the spring is pushed down, the elastic potential energy transforms to kinetic energy. When the spring is released, the kinetic energy transforms back to elastic potential energy. There will also be a small amount of sound energy and thermal energy, although may not be immediately detectable.

36. **Potential Energy** A 25.0-kg shell is shot from a cannon at Earth's surface. The reference level is Earth's surface.

a. What is the shell-Earth system's gravitational potential energy when the shell's height is 425 m?

$$GPE = mgh$$
$$= (25.0\ \text{kg})(9.8\ \text{N/kg})(425\ \text{m})$$
$$= 1.0\times10^{5}\ \text{J}$$

b. What is the change in the system's potential energy when the shell falls to a height of 225 m?

$$GPE_f = mgh_f$$
$$= (25.0\ \text{kg})(9.8\ \text{N/kg})(225\ \text{m})$$
$$= 5.5\times10^{4}\ \text{J}$$

The change in energy is

$$\Delta E = (5.51\times10^{4}\ \text{J}) - (1.0\times10^{5}\ \text{J})$$
$$= -4.9\times10^{4}\ \text{J}$$

c. What motions and interactions does this system depend on?

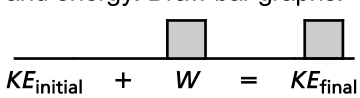
The system depends on the motions and interactions of the composition of the shell and the reaction with gravity and with being shot from a cannon.

37. Rotational Kinetic Energy On a playground, some children push a merry-go-round so that it turns twice as fast as it did before they pushed it. What are the relative changes in angular momentum and rotational kinetic energy of the merry-go-round?

The angular momentum is doubled because it is proportional to the angular velocity. The rotational kinetic energy is quadrupled because it is proportional to the square of the angular velocity. The children did work in rotating the merry-go-round.

38. Critical Thinking In the school lab, Karl uses an air hose to exert a constant horizontal force to move a puck a fixed distance on a frictionless air table.

a. Explain what happens in terms of work and energy. Draw bar graphs.



Karl exerted a constant force *F* over a distance *d* and did an amount of work $W = Fd$ on the puck. This work changed the kinetic energy of the puck.

$$\begin{aligned} W &= (KE_f - KE_i) \\ &= \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 \\ &= \frac{1}{2}mv_f^2 \end{aligned}$$

b. Karl uses a different puck with half the first one's mass. All other conditions remain the same. How do the kinetic energy and work done differ from the kinetic energy and work done in part a?

If the puck has half the mass, it still receives the same amount of work and has the same change in kinetic energy. However, the smaller mass will move faster by a factor of 1.414.

c. Describe what happened in parts a and b in terms of impulse and momentum.

The two pucks do not have the same final momentum.

Momentum of the first puck:

$$p_1 = m_1v_1$$

Momentum of the second puck:

$$\begin{aligned} p_2 &= m_2v_2 \\ &= \left(\frac{1}{2}m_1\right)(1.414v_1) \\ &= 0.707\,p_1 \end{aligned}$$

Thus, the second puck has less momentum than the first puck does. Because the change in momentum is equal to the impulse provided by the air hose, the second puck receives a smaller impulse.

Lesson 3 Conservation of Energy

Practice Problems

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39. A bike rider approaches a hill at a speed of 8.5 m/s. The combined mass of the bike and the rider is 85.0 kg. Choose a suitable system. Find the initial kinetic energy of the system. The rider coasts up the hill. Assuming friction is negligible, at what height will the bike come to rest?

The system is the bike + rider + Earth.

Initial kinetic energy:

$$\begin{aligned} KE_{\text{i}} &= \frac{1}{2}mv^2 \\ &= \frac{1}{2}(85.0\text{ kg})(8.5\text{ m/s})^2 \\ &= 3.1\times10^3\text{ J} \end{aligned}$$

There are no external forces, so total energy is conserved.

$$KE_{\text{i}} + PE_{\text{i}} = KE_{\text{f}} + PE_{\text{f}}$$

$$\frac{1}{2}mv^2 + 0 = 0 + mgh$$

Therefore,

$$\begin{aligned} h &= \frac{v^2}{2g} = \frac{(8.5\text{ m/s})^2}{(2)(9.8\text{ N/kg})} \\ &= 3.7\text{ m} \end{aligned}$$

40. Suppose that the bike rider in the previous problem pedaled up the hill and never came to a stop. In what system is energy conserved? From what form of energy did the bike gain mechanical energy?

The system of Earth, bike, and rider remains the same, but now the energy involved is not mechanical energy alone. The rider must be considered as having chemical potential energy, some of which is converted to mechanical energy.

41. A skier starts from rest at the top of a hill that is 45.0 m high, skis down a 30° incline into a valley, and continues up a hill that is 40.0 m high. The heights of both hills are measured from the valley floor. Assume that friction is negligible and ignore the effect of the ski poles.

a. How fast is the skier moving at the bottom of the valley?

Mechanical energy is conserved,

so $KE_{\text{i}} + PE_{\text{i}} + KE_{\text{f}} + PE_{\text{f}}$

$$0 + mgh = \frac{1}{2}mv^2 + 0$$

$$\begin{aligned} v^2 &= 2gh \\ v &= \sqrt{2gh} \\ &= \sqrt{(2)(9.8\text{ N/kg})(45.0\text{ m})} \\ &= 3.0\times10^1\text{ m/s} \end{aligned}$$

b. What is the skier's speed at the top of the second hill?

$$KE_{\text{i}} + PE_{\text{i}} = KE_{\text{f}} + PE_{\text{f}}$$

$$0 + mgh_{\text{i}} = \frac{1}{2}mv^2 + mgh_{\text{f}}$$

$$\begin{aligned} v^2 &= 2g(h_{\text{i}} - h_{\text{f}}) \\ &= \sqrt{2g(h_{\text{i}} - h_{\text{f}})} \\ &= \sqrt{(2)(9.8\text{ N/kg})(45.0\text{ m} - 40.0\text{ m})} \\ &= 9.9\text{ m/s} \end{aligned}$$

c. Do the angles of the hills affect your answers?

No, the angles do not have any impact.

42. In a belly-flop diving contest, the winner is the diver who makes the biggest splash upon hitting the water. The size of the splash depends not only on the diver's style, but also on the amount of kinetic energy the diver has. Consider a contest in which each diver jumps from a 3.00-m platform. One diver has a mass of 136 kg and simply steps off the platform. Another diver has a mass of 100 kg and leaps upward from the platform. How high would the second diver have to leap to make a competitive splash?

Using the water as a reference level, the kinetic energy on entry is equal to the potential energy of the diver at the top of his flight. The large diver has

$$GPE = mgh = (136\text{ kg})(9.8\text{ N/kg})(3.00\text{ m}) = 4.00\times10^3\text{ J}$$

To equal this, the smaller diver would have to jump to

$$h = \frac{GPE}{mg} = \frac{4.00\times10^3\text{ J}}{(102\text{ kg})(9.8\text{ N/kg})} = 4.0\text{ m}$$

Thus, the smaller diver would have to leap 1.0 m above the platform.

43. **CHALLENGE** The spring in a pinball machine exerts an average force of 2 N on a 0.08-kg pinball over 5 cm. As a result, the ball has both translational and rotational kinetic energy. If the ball is a uniform sphere ($I = 5/2\ mr^2$), what is its linear speed after leaving the spring? (Ignore the table's tilt.)

Using the work-energy theorem:

$$W = \Delta E = E_f - E_i$$

$$W = Fd\cos\theta$$

$$\text{But } \theta = 0°, \text{so } W = Fd$$

$$E_i = 0 \text{ and } E_f = KE_{\text{trans,f}} + KE_{\text{rot,f}}$$

$$KE_{\text{trans,f}} + KE_{\text{rot,f}} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 = \frac{1}{2}mv^2 + \frac{1}{2}\left(\frac{5}{2}mr^2\right)\left(\frac{v}{r}\right)^2 = \frac{7}{4}mv^2$$

$$Fd = \frac{7}{4}mv^2$$

$$v = \sqrt{\frac{4Fd}{7m}} = \sqrt{\frac{4(2\text{ N})(0.05\text{ m})}{7(0.08\text{ kg})}} = 0.8\text{ m/s}$$

Practice Problems

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44. An 8.00-g bullet is fired horizontally into a 9.00-kg block of wood on an air table and is embedded in it. After the collision, the block and bullet slide along the frictionless surface together with a speed of 10.0 cm/s. Find the initial speed of the bullet.

Conservation of momentum:

$$mv = (m+M)V, \text{ so}$$

$$v = \frac{(m+M)V}{m}$$

$$= \frac{(0.00800\text{ kg} + 9.00\text{ kg})(0.100\text{ m/s})}{0.00800\text{ kg}}$$

$$= 1.13\times10^2\text{ m/s}$$

45. A 91.0-kg hockey player is skating on ice at 5.50 m/s. Another hockey player of equal mass, moving at 8.1 m/s in the same direction, hits him from behind. They slide off together.

a. What are the total mechanical energy and momentum of the system before the collision?

$$\begin{aligned} KE_i &= \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 \\ &= \frac{1}{2}(91.0\ \text{kg})(5.50\ \text{m/s})^2 + \frac{1}{2}(91.0\ \text{kg})(8.1\ \text{m/s})^2 \\ &= 4.4\times10^3\ \text{J} \end{aligned}$$

$$\begin{aligned} p_i &= m_1v_1 + m_2v_2 \\ &= (91.0\ \text{kg})(5.5\ \text{m/s}) + (91.0\ \text{kg})(8.1\ \text{m/s}) \\ &= 1.2\times10^3\ \text{kg·m/s} \end{aligned}$$

b. What is the velocity of the two hockey players after the collision?

After the collision:

$$p_i = p_f$$

$$m_1v_1 + m_2v_2 = (m_1 + m_2)v_f$$

Therefore,

$$\begin{aligned} v_f &= \frac{m_1v_1 + m_2v_2}{(m_1 + m_2)} \\ &= \frac{(91.0\ \text{kg})(5.50\ \text{m/s}) + (91.0\ \text{kg})(8.1\ \text{m/s})}{(91.0\ \text{kg} + 91.0\ \text{kg})} \\ &= 6.8\ \text{m/s} \end{aligned}$$

c. How much was the system's kinetic energy decreased in the collision?

The final kinetic energy is

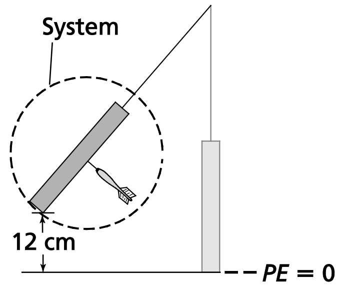
$$\begin{aligned} KE_f &= \frac{1}{2}(m_i + m_f)v_f^2 \\ &= \frac{1}{2}(91.0\ \text{kg} + 91.0\ \text{kg})(6.8\ \text{m/s})^2 \\ &= 4.2\times10^3\ \text{J} \end{aligned}$$

Thus, the decrease in kinetic energy during the collision is

$$\begin{aligned} KE_f - KE_i &= 4.2\times10^3\ \text{J} - 4.4\times10^3\ \text{J} \\ &= -200\ \text{J} \end{aligned}$$

46. **CHALLENGE** A 0.73-kg magnetic target is suspended on a string. A 0.025-kg magnetic dart, shot horizontally, strikes the target head-on. The dart and the target together act like a pendulum and swing 12.0 cm above the initial level before instantaneously coming to rest.

a. Sketch the situation and choose a system.



The system includes the suspended target and the dart.

b. Decide what is conserved in each step of the process and explain why.

Only momentum is conserved in the inelastic dart-target collision, so $mv_i + MV_i = (m + M)V_f$ where $V_i = 0$ since the target is initially at rest and V_f is the common velocity just after impact. As the dart-target combination swings upward, energy is conserved, so $\Delta GPE = \Delta KE$ or, at the top of the swing,

$$(m+M)gh_f = \frac{1}{2}(m+M)(V_f)^2$$

c. What was the initial velocity of the dart?

Solve for V_f.

$$V_f = \sqrt{2gh_f}$$

Substitute v_f into the momentum equation and solve for v_i.

$$v_i = \left(\frac{m+M}{m}\right)\sqrt{2gh_f}$$
$$= \left(\frac{(0.025\text{ kg} + 0.73\text{ kg})}{0.025\text{ kg}}\right)\left(\sqrt{(2)(9.8\text{ N/kg})(0.120\text{ m})}\right) = 46\text{ m/s}$$

Physics Challenge

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A bullet of mass *m,* moving at speed v_1, goes through a motionless wooden block and exits with speed v_2. After the collision, the block, which has mass m_B, is moving.

1. What is the final speed, v_B, of the block?

Conservation of momentum:

$mv_1 = mv_2 + m_Bv_B$, so $m_Bv_B = m(v_1 - v_2)$

$$v_B = \frac{m(v_1 - v_2)}{m_B}$$

Module 10 continued

2. What was the change in the bullet's mechanical energy?

For the bullet alone:

$$KE_1 = \frac{1}{2}mv_1^2$$

$$KE_2 = \frac{1}{2}mv_2^2$$

$$\Delta KE = \frac{1}{2}m\left(v_1^2 - v_2^2\right)$$

3. How much energy was lost to friction inside the block?

Energy lost to friction $= KE_1 - KE_2 - KE_{block}$

$$E_{lost} = \frac{1}{2}mv_1^2 - \frac{1}{2}mv_2^2 - \frac{1}{2}m_Bv_B^2$$

Lesson 2 Check Your Progress

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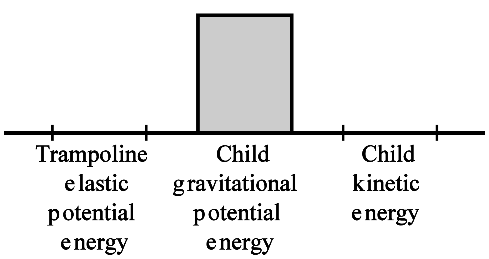
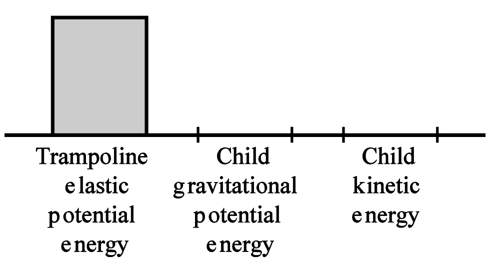
47. Energy Diagrams A child jumps on a trampoline. Draw energy bar diagrams to show the forms of energy present in the following situations.

a. The child is at the highest point.



b. The child is at the lowest point.



48. Energy Explain why energy is considered a single quantity.

Energy is considered a single quantity because, even though energy transformations take place all the time, the transformations just involve different manifestations of the same energy.

49. Kinetic Energy Suppose a glob of chewing gum and a small, rubber ball collide head-on in midair and then rebound apart. Would you expect kinetic energy to be conserved? If not, what happens to the energy?

Even though the rubber ball rebounds with little waste of energy, kinetic energy would not be conserved in this case because the glob of chewing gum probably was deformed in the collision.

50. Potential Energy A rubber ball drops from a height of 8.0 m onto a concrete floor and bounces repeatedly. Each time it hits the floor, the ball-Earth system loses 1/5 of its *ME*. How many times will the ball bounce before it bounces back up to a height of only 4 m?

$E_{total} = mgh$

Since the rebound height is proportional to energy, each bounce will rebound to $\frac{4}{5}$ the height of the previous bounce.

After one bounce:

$$h = \left(\frac{4}{5}\right)(8\text{ m}) = 6.4\text{ m}$$

After two bounces:

$$h = \left(\frac{4}{5}\right)(6.4\text{ m}) = 5.1\text{ m}$$

After three bounces:

$$h = \left(\frac{4}{5}\right)(5.1\text{ m}) = 4.1\text{ m}$$

Module 10 continued

51. Energy In **Figure 27,** a child slides down a playground slide. At the bottom, she is moving at 3.0 m/s. How much energy was transformed by friction as she slid down the slide?

$$\boldsymbol{E_i = mgh}$$
$$\mathbf{= (36.0\ kg)(9.8\ N/kg)(2.5\ m)}$$
$$\mathbf{= 880\ J}$$
$$\boldsymbol{E_f = \frac{1}{2}mv^2}$$
$$\mathbf{= \frac{1}{2}(36.0\ kg)(3.0\ m/s)^2}$$
$$\mathbf{= 160\ J}$$
$$\boldsymbol{W = \Delta KE} \mathbf{= 880\ J - 160\ J}$$
$$\mathbf{= 720\ J}$$

52. Conservation of Energy Your friend wants to solve the world's energy problems by inventing a device that will deliver ten times more energy than put into the device. Can this device work? Explain.

The availability of energy limits what can occur in a system, so if my friend's device only receives a certain amount of energy, then it cannot deliver/transfer/transform more than it receives

53. Critical Thinking A ball drops 20 m. When it has fallen 10 m, half of the energy is potential energy and half is kinetic energy. When the ball has fallen for half the amount of time it takes to fall, will more, less, or exactly half of the energy be potential energy?

The ball falls more slowly during the beginning part of its drop. Therefore, in the first half of the time that it falls, it will not have traveled half of the distance that it will fall. Therefore, the ball will have more potential energy than kinetic energy.

Lesson 4 Machines

Physics Challenge

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In many rural areas, residents do not get their water supply from a central water tower or other common source. Many residents need to use an electric pump to get their water from a well. A certain electric pump pulls water at a rate of 0.25 m^3/s from a well that is 25 m deep. The water leaves the pump at a speed of 8.5 m/s.

1. What power is needed to lift the water to the surface?

The work done in lifting is $\boldsymbol{F_g d = mgd}$. Therefore, the power is

$$\boldsymbol{P_{lift} = \frac{W}{t} = \frac{F_g d}{t} = \frac{mgd}{t}}$$
$$\mathbf{= \frac{(0.25\ m^3)(1.00\times10^3\ kg/m^3)(9.8\ N/kg)(25\ m)}{1.0\ s}}$$
$$\mathbf{= 6.1\times10^4\ W}$$
$$\mathbf{= 61\ kW}$$

2. What power is needed to increase the water's kinetic energy?

The work done in increasing the water's kinetic energy is $\frac{1}{2}mv^2$.

Therefore,

$$P=\frac{W}{t}=\frac{\Delta KE}{t}=\frac{\frac{1}{2}mv^2}{t}=\frac{mv^2}{2t}$$
$$=\frac{(0.25\text{ m}^3)(1.00\times10^3\text{ kg/m}^3)(8.5\text{ m/s})^2}{(2)(1.0\text{ s})}$$
$$=9.0\times10^3\text{ W}=9.0\text{ kW}$$

3. If the pump's efficiency is 80 percent, how much power must be delivered to the pump?

$$e=\frac{W_\text{o}}{W_\text{i}}\times100=\frac{\frac{W_\text{o}}{t}}{\frac{W_\text{i}}{t}}\times100=\frac{P_\text{o}}{P_\text{i}}\times100$$

$$\text{So, } P_\text{i}=\frac{P_\text{o}}{e}\times100$$
$$=\frac{(9.0\text{ kW}+61\text{ kW})}{80}\times100$$
$$=88\text{ kW}$$

Practice Problems

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54. If the gear radius of the bicycle in Example Problem 7 is doubled while the force exerted on the chain and the distance the wheel rim moves remain the same, what quantities change, and by how much?

$$IMA=\frac{r_\text{e}}{r_\text{r}}=\frac{8.00\text{ cm}}{35.6\text{ cm}}=0.225\text{ (doubled)}$$

$$MA=\left(\frac{e}{100}\right)IMA=\frac{95.0}{100}(0.225)$$
$$=0.214\text{ (doubled)}$$

$$MA=\frac{F_\text{r}}{F_\text{e}}\text{ so }F_\text{r}=(MA)(F_\text{e})$$
$$=(0.214)(155\text{ N})$$
$$=33.2\text{ N}$$

$$IMA=\frac{d_\text{e}}{d_\text{r}}$$

$$\text{So, }d_\text{e}=(IMA)(d_\text{r})$$
$$=(0.225)(14.0\text{ cm})$$
$$=3.15\text{ cm}$$

55. A sledgehammer is used to drive a wedge into a log to split it. When the wedge is driven 0.20 m into the log, the log is separated a distance of 5.0 cm. A force of 1.7×10^4 N is needed to split the log, and the sledgehammer exerts a force of 1.1×10^4 N.

a. What is the *IMA* of the wedge?

$$\boldsymbol{IMA = \frac{d_e}{d_r} = \frac{(0.20\ \text{m})}{(0.050\ \text{m})} = 4.0}$$

b. What is the *MA* of the wedge?

$$\boldsymbol{MA = \frac{F_r}{F_e} = \frac{(1.7\times10^4\ \text{N})}{(1.1\times10^4\ \text{N})} = 1.5}$$

c. Calculate the efficiency of the wedge as a machine.

$$\boldsymbol{e = \frac{MA}{IMA}\times100 = \frac{1.5}{4.0}\times100 = 38\%}$$

56. A worker uses a pulley to raise a 24.0-kg carton 16.5 m, as shown in **Figure 33.** A force of 129 N is exerted, and the rope is pulled 33.0 m.

a. What is the *MA* of the pulley?

$$\boldsymbol{MA = \frac{F_r}{F_e} = \frac{mg}{F_e} = \frac{(24.0\ \text{kg})(9.8\ \text{N/kg})}{129\ \text{N}} = 1.82}$$

b. What is the efficiency of the pulley?

$$\boldsymbol{\text{efficiency} = \left(\frac{MA}{IMA}\right)\times100 = \frac{(MA)(100)}{\frac{d_e}{d_r}} = \frac{(MA)(d_r)(100)}{d_e} = \frac{(1.82)(16.5\ \text{m})(100)}{33.0\ \text{m}} = 91.0\%}$$

57. A winch has a crank with a 45-cm radius. A rope is wrapped around a drum with a 7.5-cm radius. One revolution of the crank turns the drum one revolution.

a. What is the ideal mechanical advantage of this machine?

Compare effort and resistance distances for 1 rev:

$$\boldsymbol{IMA = \frac{d_e}{d_r} = \frac{2\pi(45\ \text{cm})}{2\pi(7.5\ \text{cm})} = 6.0}$$

b. If, due to friction, the machine is only 75 percent efficient, how much force would have to be exerted on the handle of the crank to exert 750 N of force on the rope?

$$\boldsymbol{\text{efficiency} = \left(\frac{MA}{IMA}\right)\times100 = \frac{F_r}{(F_e)(IMA)}\times100}$$

$$\boldsymbol{\text{So, } F_e = \frac{(F_r)(100)}{(\text{efficiency})(IMA)} = \frac{(750\ \text{N})(100)}{(75)(6.0)} = 1.7\times10^2\ \text{N}}$$

58. **CHALLENGE** You exert a force of 225 N on a lever to raise a 1.25×10^3-N rock a distance of 13 cm. If the efficiency of the lever is 88.7 percent, how far did you move your end of the lever?

$$\boldsymbol{\text{efficiency} = \frac{W_o}{W_i}\times100 = \frac{F_r d_r}{F_e d_e}\times100}$$

So,

$$\boldsymbol{d_e = \frac{F_r d_r(100)}{F_e(\text{efficiency})} = \frac{(1.25\times10^3\ \text{N})(0.13\ \text{m})(100)}{(225\ \text{N})(88.7)} = 0.81\ \text{m}}$$

Lesson 4 Check Your Progress

p. 274

59. **Machines** Classify each tool below as a lever, a wheel and axle, an inclined plane, or a wedge. Describe how it changes the force to make the task easier.

a. screwdriver

wheel and axle; increases the size of the force

b. pliers

lever; increases the size of the force and changes the direction of the force

c. chisel

wedge; increases the size of the force and changes the direction of the force

d. nail puller

lever; increases the size of the force and changes the direction of the force

60. ***IMA*** A worker is testing a multiple pulley system to estimate the heaviest object that he could lift. The largest downward force he can exert is equal to his weight, 875 N. When the worker moves the rope 1.5 m, the object moves 0.25 m. What is the heaviest object that he could lift?

$$MA = \frac{F_r}{F_e}$$

so $F_r = (MA)(F_e)$

Assuming the efficiency is 100%,

$$\begin{aligned} MA = IMA &= \left(\frac{d_e}{d_r}\right)(F_e) \\ &= \frac{(1.5\text{ m})}{(0.25\text{ m})}(875\text{ N}) \\ &= 5.2\times10^3\text{ N} \end{aligned}$$

61. **Compound Machines** A winch has a crank on a 45-cm arm that turns a drum with a 7.5-cm radius through a set of gears. It takes three revolutions of the crank to rotate the drum through one revolution. What is the *IMA* of this compound machine?

The *IMA* of the system is the product of the *IMA* of each machine. For the crank and drum, the ratio of distances is

$$\frac{2\pi(45\text{ cm})}{2\pi(7.5\text{ cm})} = 6.0.$$

$$\begin{aligned} IMA_{\text{system}} &= (3)\frac{d_e}{d_r} \\ &= \frac{(3)(2\pi)(45\text{ cm})}{(2\pi)(7.5\text{ cm})} \\ &= 18 \end{aligned}$$

62. **Efficiency** Suppose you increase the efficiency of a simple machine. Do the *MA* and *IMA* increase, decrease, or remain the same?

Either *MA* increases while *IMA* remains the same, or *IMA* decreases while *MA* remains the same, or *MA* increases while *IMA* decreases.

63. **Critical Thinking** The mechanical advantage of a multi-gear bicycle is changed by moving the chain to a suitable rear gear.

a. To start out, you must accelerate the bicycle, so you want to have the bicycle exert the greatest possible force. Should you choose a small or large gear?

large, to increase $IMA = \frac{r_{\text{gear}}}{r_{\text{wheel}}}$

b. As you reach your traveling speed, you want to rotate the pedals as few times as possible. Should you choose a small or large gear?

Small, because less chain travel, hence few pedal revolutions, will be required per wheel revolution.

c. Many bicycles also let you choose the size of the front gear. If you want even more force to accelerate while climbing a hill, would you move to a larger or smaller front gear? Explain.

smaller, to increase pedal-front gear *IMA* because

$$\boldsymbol{IMA = \frac{r_{\text{pedal}}}{r_{\text{front gear}}}}$$

Go Further

Data Analysis Lab

p. 277

How much kinetic energy does a falling object have?

Five clay pots are dropped from the same rooftop. The results are summarized in the table.

Clay Pot	Mass (kg)	Initial Velocity (m/s)
A	1,0	0
B	1.0	2.0; downward
C	1.0	2.0; upward
D	1.0	2.0; horizontally
E	2.0	0

Analyze and Interpret Data

1. **Claim** Rank the clay pots according to speed when they strike the ground, from least to greatest. Specifically indicate any ties.

   $\boldsymbol{v_A = v_E < v_B = v_C = v_D}$

2. **Evidence and Reasoning** Explain how you determined your ranking.

   Students should use their sketches and calculations to explain their reasoning and justify their claims. Energy is conserved, so

$$\boldsymbol{E_f = E_i}$$

$$\boldsymbol{KE_f + PE_f = KE_i + KE_f}$$

$$\boldsymbol{\frac{1}{2}mv_f^2 + 0 = \frac{1}{2}mv_i^2 + mgh}$$

$$\boldsymbol{\text{So, } v_f = \sqrt{v_i^2 + 2gh}}$$

   2*gh* is the same for each scenario, so the final speed depends on the initial speed.