Chapter 10: Work, Energy and Simple Machines

Practice Problems

1. A force of 825 N is needed to push a car across a lot. Two students push the car 35 m.

   a. How much work is done?

   $W = Fd = (825 \text{ N})(35 \text{ m}) = 2.9 \times 10^4 \text{ J}$.

   b. After a rainstorm, the force needed to push the car doubled because the ground became soft. By what amount does the work done by the student change?

   The work doubles; when displacement remains the same, work is directly proportional to force.

2. A delivery clerk carries a 34–N package from the ground to the fifth floor of an office building, a total height of 15 m. How much work is done by the clerk?

   $W = Fd = (34 \text{ N})(15 \text{ m}) = 510 \text{ J}$

3. What work is done by a forklift raising a 583–kg box a distance of 1.2 m?

   $W = Fd = mgd = (583 \text{ kg})(9.80 \text{ m/s}^2)(1.2 \text{ m})$
   $= 6.9 \times 10^3 \text{ J}$

4. You and a friend each carry identical boxes to a room one floor above you and down the hall. You choose to carry it first up the stairs, then down the hall. Your friend carries it down the hall, then up another stairwell. Who does more work?

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

5. How much work does the force of gravity do when a 25–N object falls a distance of 3.5 m?

   Both the force and displacement are in the same direction, so
   $W = Fd = (25 \text{ N})(3.5 \text{ m}) = 88 \text{ J}$

Practice Problems

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

   a. How much work does the passenger do?

   Since gravity acts vertically, only the vertical displacement needs to be considered.
   $W = Fd = (215 \text{ N})(4.20 \text{ m}) = 903 \text{ J}$

   b. The same passenger carries the same suitcase back down the same stairs. How much work does the passenger do now?

   Force is upward, but vertical displacement is downward, so
   $W = Fd \cos \theta = Fd \cos 180°$
   $= (215 \text{ N})(4.20 \text{ m})(-1) = -903 \text{ J}$.

7. A rope is used to pull a metal box 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 used. How much work does the force on the rope do?

   $W = Fd \cos \theta = (628 \text{ N})(15.0 \text{ m})(\cos 46.0°)$
   $= 6.54 \times 10^3 \text{ J}$

8. A worker pushes a crate weighing 93 N up an inclined plane, pushing horizontally, parallel to the ground (Figure 10–6).

   a. The worker exerts a force of 85 N. How much work does he do?

   Displacement in direction of force is 4.0 m, so $W = (85 \text{ N})(4.0 \text{ m}) = 340 \text{ J}$

   b. How much work is done by gravity? (Be careful of signs.)

   Displacement in direction of force is −3.0 m, so $W = (93 \text{ N})(-3.0 \text{ m}) = -279 \text{ J}$ (work done against gravity).

Practice Problems

c. The coefficient of friction is $\mu = 0.20$. How much work is done by friction? (Be careful of signs.)

$$W = \mu F_N d$$
$$= 0.20 \left[85 \text{ N} \cdot \frac{3}{5} + 93 \text{ N} \cdot \frac{4}{5} \right] 5.0 \text{ m}$$
$$= 1.3 \times 10^2 \text{ J}$$

page 203

9. A box that weighs 575 N is lifted a distance of 20.0 m straight up by a rope. The job is done in 10.0 s. What power is developed in watts and kilowatts?

$$P = \frac{W}{t} = \frac{Fd}{t} = \frac{(575 \text{ N})(20.0 \text{ m})}{10.0 \text{ m}}$$
$$= 1.15 \times 10^3 \text{ W} = 1.15 \text{ kW}$$

10. A rock climber wears a 7.50–kg knapsack while scaling a cliff. After 30.0 minutes, the climber is 8.2 m above the starting point.

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

$$W = mgd = (750 \text{ kg})(9.80 \text{ m/s}^2)(8.2 \text{ m})$$
$$= 6.0 \times 10^2 \text{ J}$$

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

$$W = Fd + 6.0 \times 10^2 \text{ J}$$
$$= (645 \text{ N})(8.2 \text{ m}) + 6.0 \times 10^2 \text{ J}$$
$$= 5.9 \times 10^3 \text{ J}$$

c. What is the average power developed by the climber?

$$P = \frac{W}{t} = \frac{5.9 \times 10^3 \text{ J}}{(30 \text{ min})(60 \text{ s/min})}$$
$$= 3.3 \text{ W}$$

Practice Problems

11. An electric motor develops 65 kW of power as it lifts a loaded elevator 17.5 m in 35.0 s. How much force does the motor exert?

$$P = \frac{W}{t}, \text{ and } W = Fd$$

$$\text{so } F = \frac{Pt}{d} = \frac{(65 \times 10^3 \text{ W})(35.0 \text{ s})}{17.5 \text{ m}}$$
$$= 1.3 \times 10^3 \text{ N}.$$

12. Two cars travel the same speed, so that they move 105 km in one hour. One car, a sleek sports car, has a motor that delivers only 35 kW of power at this speed. The other car needs its motor to produce 65 kW to move the car this fast. Forces exerted by friction from the air resistance cause the difference.

a. For each car, list the external horizontal forces exerted on it, and give the cause of each force. Compare their magnitudes.

Forward: force of road on cart
Rearward; force of air on car;
These forces are equal in magnitude when the car moves with constant speed.

b. By Newton's third law, the car exerts forces. What are their directions?

Car exerts a rearward force on road and a forward force on air.

c. Calculate the magnitude of the forward frictional force exerted by each car.

$$P = \frac{W}{t} \text{ and } W = Fd, \text{ so } P = \frac{Fd}{t},$$

$$\text{so } F = \frac{Pt}{d} = \frac{P}{v}. \text{ For sports car,}$$

$$F = \frac{35 \times 10^3 \text{ W}}{29.2 \text{ m/s}} = 1.2 \times 10^3 \text{ N};$$

for other,

$$F = \frac{65 \times 10^3 \text{ W}}{29.2 \text{ m/s}} = 2.2 \times 10^3 \text{ N}.$$

d. The car engines did work. Where did the energy they transferred come from?

From the chemical energy in the gasoline.

Practice Problems

13. A sledge hammer is used to drive a wedge into a log to split it. When the wedge is driven 20 cm into the log, the log is separated a distance of 5.0 cm. A force of 1.9 x 10⁴ N is needed to split the log, and the sledge exerts a force of 9.8 × 10³ N.

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

   $$IMA = \frac{d_e}{d_f} = \frac{20 \text{ cm}}{5.0 \text{ cm}} = 4.0$$

   b. Find the *MA* of the wedge.

   $$MA = \frac{F_r}{F_e} = \frac{1.9 \times 10^4 \text{ N}}{9.8 \times 10^3 \text{ N}} = 1.9$$

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

   $$Efficiency = \left[\frac{MA}{IMA}\right] \times 100\%$$
   $$= \left[\frac{1.9}{4.0}\right] \times 100\% = 48\%$$

14. A worker uses a pulley system to raise a 225–N carton 16.5 m. A force of 129 N is exerted and the rope is pulled 33.0 m.

   a. What is the mechanical advantage of the pulley system?

   $$MA = \frac{F_r}{F_e} = \frac{225 \text{ N}}{129 \text{ N}} = 1.74$$

   b. What is the efficiency of the system?

   $$Efficiency = \left[\frac{MA}{IMA}\right] \times 100\%, \text{ where}$$
   $$IMA = \frac{d_e}{d_r} = \frac{33.0 \text{ m}}{16.5 \text{ m}} = 2.00, \text{ so}$$
   $$efficiency = \frac{1.74}{2.00} \times 100\% = 87\%$$

Practice Problems

15. A boy exerts a force of 225 N on a lever to raise a 1.25×10^3–N rock a distance of 0.13 m. If the efficiency of the lever is 88.7%, how far did the boy move his end of the lever?

   $$eff = \frac{W_o}{W_i} \times 100\% = \frac{F_r d_r}{F_e d_e} \times 100\%, \text{ so}$$
   $$d = \frac{F_r d_r (100\%)}{F_e (eff)}$$
   $$= \frac{(125 \times 10^3 \text{ N})(0.13 \text{ m})(100\%)}{(225 \text{ N})(88.7\%)}$$
   $$= 0.81 \text{ m}$$

16. If the gear radius is doubled in the example above, while the force exerted on the chain and the distance the wheel rim moves remain the same, what quantities change, and by how much?

   $$IMA = \frac{8.00 \text{ cm}}{35.6 \text{ cm}} = 0.224$$
   $$MA = (95\%)\frac{0.224}{100\%} = 0.214 \text{ (both doubled)}$$

   The force exerted by the distance the chain moved, d_e, would also be doubled to 3.14 cm.

Chapter Review Problems

1. Lee pushes horizontally with an 80–N force on a 20–kg mass 10 m across the floor. Calculate the amount of work Lee did.

   $W = Fd = (80 \text{ N})(10 \text{ m}) = 800 \text{ J}.$
   The mass is not important to this problem.

2. The third floor of a house is 8.0 m above street level. How much work is needed to move a 150–kg refrigerator to the third floor?

   $F = mg$, so
   $W = Fd = mgd = (150 \text{ kg})(9.8 \text{ m/s}^2)(8.0 \text{ m})$

3. Stan does 176 J of work lifting himself 0.300 m. What is Stan's mass?

$F = mg$, so $W = Fd = mgd$; therefore,

$$m = \frac{W}{gd} = \frac{176 \text{ J}}{(9.80 \text{ m/s}^2)(0.300 \text{ m})} = 59.9 \text{ kg}$$

4. A crane lifts a 2.25×10^3-N bucket containing 1.15 m³ of soil (density = 2.00×10^3 kg/m³) to a height of 7.50 m. Calculate the work the crane performs.

$W = Fd$, where F is the weight of bucket plus soil. The soil mass is
$(1.15 \text{m}^3)(2.00 \times 10^3 \text{ kg/m}^3) = 2.30 \times 10^3$ kg. The bucket's weight is 2.25×10^4 N, so the total weight is 2.48×10^4 N. Thus,
$W = Fd = (2.48 \times 10^4 \text{ N})(7.50 \text{ m})$
     $= 1.86 \times 10^5$ J.

5. The graph in Figure 10-16 shows the force needed to stretch a spring. Find the work needed to stretch it from 0.12 m to 0.28 m.

Add the areas of the triangle and rectangle. The area of the triangle is
(base)(height)/2 = (0.16 m)(4.0 N)/2 = 0.32 J.
The area of the rectangle is
(base)(height) = (0.16 m)(3.0 N) = 0.48 J.
Total work is 0.32 J + 0.48 J = 0.80 J.

6. In Figure 10-10 the magnitude of the force necessary to stretch a spring is plotted against the distance the spring is stretched.

Force (N) vs Elongation (m)
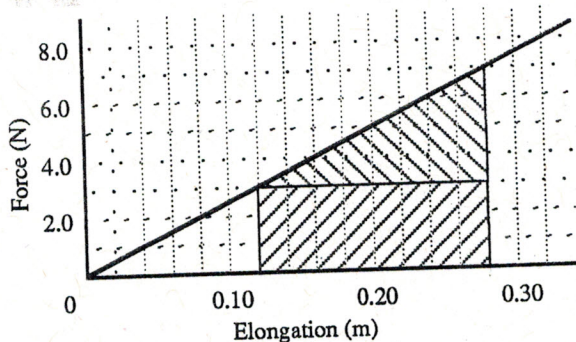
a. Calculate the slope of the graph and show that
$$F = kd$$
where $k = 25$ N/m.

$$m = \frac{\Delta_y}{\Delta_x} = \frac{(5.0 \text{ N} - 0.0 \text{ N})}{(0.20 \text{ m} - 0.00 \text{ m})}$$

$$= \frac{5.0 \text{ N}}{0.20 \text{ m}} = 25 \text{ N/m}$$

$F = kd = (25 \text{ N/m})(0.20 \text{ m}) = 5.0$ N

b. Find the amount of work done in stretching the spring from 0.00 m to 0.20 m by calculating the area under the curve from 0.00 m to 0.20 m in Figure 10-10.

$$A = \frac{1}{2}(\text{base})(\text{height}) = \left[\frac{1}{2}\right](5.0 \text{ N})(0.20 \text{ m})$$

$$= 0.50 \text{ J}$$

c. Show that the answer to part b can be calculated using the formula

$$W = \frac{1}{2}kd^2$$

where W is the work, $k = 25$ N/m (the slope of the graph), and d is the distance the spring is stretched (0.20 m).

$$W = \frac{1}{2}kd^2 = \left[\frac{1}{2}\right](25 \text{ N/m})(0.20 \text{ m})^2 = 0.50 \text{ J}$$

7. John pushes a crate across the floor of a factory with a horizontal force. The roughness of the floor changes, and John must exert a force of 20 N for 5 meters, then 35 N for 12 m, then 10 N for 8 m.

a. Draw a graph of force as a function of distance.

Force (N) vs Distance (m)
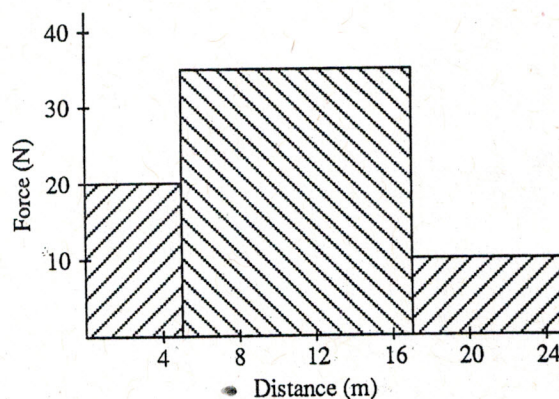
b. Find the work John does pushing the crate.

Add the areas under the rectangles
(5 m)(20N) + (12 m)(35 N) + (8 m)(10 N)
= 100 J + 420 J + 80 J = 600 J.

8. Sally applies a horizontal force of 462 N with a rope to drag a wooden crate across a floor with a constant speed. The rope tied to the crate is pulled at an angle of 56.0°.

a. How much force is exerted by the rope on the crate?

462 N is the horizontal component, so the force is $\dfrac{462 \text{ N}}{\cos 56.0°} = 826$ N.

b. What work is done by Sally if the crate is moved 24.5 m?

$W = Fd = (462 \text{ N})(24.5 \text{ m}) = 1.13 \times 10^4$ J

c. What work is done by the floor through force of friction between the floor and the crate?

Force and displacement are in opposite directions, so
$W = -(462 \text{ N})(24.5 \text{ m}) = -1.13 \times 10^4$ J.

9. Mike pulls a sled across level snow with a force of 225 N along a rope that is 35.0° above the horizontal. If the sled moved a distance of 65.3 m, how much work did Mike do?

$W = Fd \cos \theta = (225 \text{ N})(65.3 \text{ m})\cos 35.0°$
$= 1.20 \times 10^4$ J.

10. An 845–N sled is pulled a distance of 185 m. The task requires 1.20×10^4 J of work and is done by pulling on a rope with a force of 125 N. At what angle is the rope held?

$W = Fd \cos \theta$, so

$\cos \theta = \dfrac{W}{Fd} = \dfrac{(1.20 \times 10^4 \text{ J})}{(125 \text{ N})(185 \text{ m})} = 0.519;$

therefore, $\theta = 58.7°$.

11. Karen has a mass of 57.0 kg and rides the up escalator at Woodley Park Station of the Washington D.C. Metro. Karen rode a distance of 65 m, the longest escalator in the free world. How much work did the escalator do on Karen if it has an inclination of 30°?

$W = Fd$ but $F = mg$, so
$W = mgd$
$= (57.0 \text{ kg})(9.80 \text{ m/s}^2)(65 \text{ m})\sin 30°$
$= 1.8 \times 10^4$ J.

12. Chris carried a carton of milk, weight 10.0 N, along a level hall to the kitchen, a distance of 3.50 m. How much work did Chris do?

No work because the force and the displacement are perpendicular.

13. A student librarian picks up a 22–N book from the floor to a height of 1.25 m. He carries the book 8.0 m to the stacks and places the book on a shelf that is 0.35 m high. How much work does he do on the book?

Only the net vertical displacement counts.
$W = Fd = (22 \text{ N})(0.35 \text{ m}) = 7.7$ J.

14. Pete slides a crate up a ramp at an angle of 30.0° by exerting a 225–N force parallel to the ramp. The crate moves at a constant speed. The coefficient of friction is 0.28. How much work has been done when the crate is raised a vertical distance of 1.15 m?

To find the distance, d, along the plane from h, the vertical distance

$d = \dfrac{h}{\sin 30.0°} = \dfrac{(1.15 \text{ m})}{0.500} = 2.30$ m.

F and d are parallel so
$W = Fd = (225 \text{ N})(2.30 \text{ m}) = 518$ J.

15. A 4200–N piano is to be slid up a 3.5–m frictionless plank that makes an angle of 30.0° with the horizontal. Calculate the work done in sliding the piano up the plank.

The force parallel to the plane is given by
$F_{11} = F \sin \theta$, so $W = F_{11}d = Fd \sin \theta$
$W = (4200 \text{ N})(3.5 \text{ m})(\sin 30.0°) = 7.4 \times 10^3$ J

16. A 60–kg crate is slid up an inclined ramp 2.0 m long onto a platform 1.0 m above floor level. A 400–N force, parallel to the ramp, is needed to slide the crate up the ramp at a constant speed.

    a. How much work is done in sliding the crate up the ramp?

    $W = Fd = (400 \text{ N})(2.0 \text{ m}) = 800 \text{ J}$

    b. How much work would be done if the crate were simply lifted straight up from the floor to the platform?

    $W = Fd = mgd = (60 \text{ kg})(9.80 \text{ m/s}^2)(1.0 \text{ m})$
    $= 600 \text{ J}.$

17. Brutus, a champion weightlifter, raises 240 kg a distance of 2.35 m.

    a. How much work is done by Brutus lifting the weights?

    $W = Fd = mgd$
    $= (240 \text{ kg})(9.80 \text{ m/s}^2)(2.35 \text{ m})$
    $= 5.53 \times 10^3 \text{ J}$

    b. How much work is done holding the weights above his head?

    $d = 0$ so no work.

    c. How much work is done lowering them back to the ground?

    d is opposite of motion in part a, so W is also the opposite, $-5.53 \times 10^3 \text{ J}$.

    d. Does Brutus do work if the weights are let go and fall back to the ground?

    No. He exerts no force, so he does no work, positive or negative.

    e. If Brutus completes the lift in 2.5 seconds, how much power is developed?

    $P = \dfrac{W}{t} = (5.53 \times 10^3 \text{ J})/(2.5 \text{ s}) = 2.2 \text{ kW}.$

18. A force of 300 N is used to push a 145–kg mass 30.0 m horizontally in 3.00 s.

    a. Calculate the work done on the mass.

    $W = Fd = (300 \text{ N})(30.0 \text{ m}) = 9.00 \times 10^3 \text{ J}$

    b. Calculate the power.

    $P = \dfrac{W}{t} = \dfrac{9.00 \times 10^3 \text{ J}}{3.00 \text{ s}} = 3.00 \times 10^3 \text{ W}$
    $= 3.00 \text{ kW}$

19. Robin pushes a wheelbarrow by exerting a 145–N force horizontally. Robin moves it 60.0 m at a constant speed for 25.0 s.
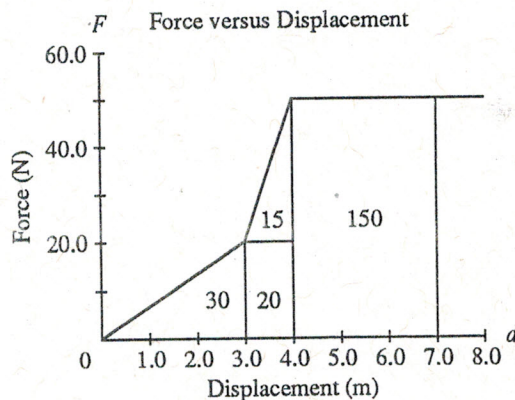
    a. What power does Robin develop?

    $P = \dfrac{W}{t} = \dfrac{F \cdot d}{t} = \dfrac{(145 \text{ N})(60.0 \text{ m})}{25.0 \text{ s}} = 348 \text{ W}$

    b. If Robin moves the wheelbarrow twice as fast, how much power is developed?

    Either d is doubled or t is halved, so P is doubled to 696 W.

20. a. Use the graph to calculate the work done to pull the object 7.0 m.

Force versus Displacement

Chapter Review Problems

Find the area under the curve (see graph):
0 to 3 m;

$$\frac{1}{2}(20.0 \text{ N})(3.0 \text{ m}) = 30 \text{ J}$$

3 m to 4 m;

$$\frac{1}{2}(30.0 \text{ N})(1.0 \text{ m}) + (20 \text{ N})(1.0 \text{ m}) = 15 \text{ J} + 20 \text{ J} = 35 \text{ J}$$

4 m to 7 m;
$$(50.0 \text{ N})(3.0 \text{ m}) = 1.5 \times 10^2 \text{ J}$$

Total work;
$$30 \text{ J} + 35\text{J} + 1.5 \times 10^2 \text{ J} = 2.2 \times 10^2 \text{ J}$$

b. Calculate the power if the work were done in 2.0 seconds.

$$P = \frac{W}{t} = \frac{2.2 \times 10^2 \text{ J}}{2.0 \text{ s}} = 1.1 \times 10^2 \text{ W}$$

21. In 35.0 s, a pump delivers 550 dm³ of oil into barrels on a platform 25.0 m above the pump intake pipe. The density of the oil is 0.820 g/cm³.

a. Calculate the work done by the pump.

Mass lifted = $(550 \text{ dm}^3)(1000 \text{ cm}^3/\text{dm}^3)(0.820 \text{ g/cm}^3) = 4.51 \times 10^5 \text{ g} = 451 \text{ kg}$

The work done is
$W = F_w d = mg(h) = (451 \text{ kg})(9.80 \text{ m/s}^2)(25.0 \text{ m}) = 1.10 \times 10^5 \text{ J} = 110 \text{ kJ}$

b. Calculate the power produced by the pump.

$$P = \frac{W}{t} = \frac{(110 \text{ kJ})}{(35.0 \text{ s})} = 3.14 \text{ kW}$$

22. A horizontal force of 805 N is needed to drag a crate across a horizontal floor with a constant speed. Pete drags the crate using a rope held at an angle of 32°.

a. What force does Pete exert on the rope?

$F_x = F \cos \theta$, so

$$F = \frac{F_x}{\cos \theta} = \frac{(805 \text{ N})}{\cos 32°} = 949 \text{ N}$$

b. How much work does Pete do on the crate when moving it 22 m?

$$W = F_x d = (805 \text{ N})(22 \text{ m}) = 1.8 \times 10^4 \text{ J}$$

c. If Pete completes the job in 8.0 s, what power is developed?

$$P = \frac{W}{t} = \frac{1.8 \times 10^4 \text{ J}}{8.0 \text{ s}} = 2.3 \text{ kW}$$

Chapter Review Problems

23. Wayne pulls a 305–N sled along a snowy path using a rope that makes a 45.0° angle with the ground. Wayne pulls with a force of 42.3 N. The sled moves 16 m in 3.0 s. What is Wayne's power?

$$P = \frac{W}{t} = \frac{F_{\parallel}d}{t} = \frac{Fd_{\parallel}}{t} \cos\theta = (42.3\ N)(16\ m)(\cos 45.0°)/(3.0\ s) = 1.6 \times 10^2\ W$$

24. A lawn roller is rolled across a lawn by a force of 115 N along the direction of the handle, which is 22.5° above the horizontal. If George develops 64.6 W of power for 90.0 seconds, what distance is the roller pushed?

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

$$d = \frac{Pt}{F \cos\theta} = \frac{(64.6\ W)(90.0\ s)}{(115\ N)\ (\cos 22.5°)} = 54.7\ m$$

25. A 12.0–m long conveyor belt, inclined at 30.0°, is used to transport bundles of newspapers from the mail room up to the cargo bay to be loaded on delivery trucks. Each newspaper has a mass of 1.00 kg and there are 25 newspapers per bundle. Determine the useful power of the conveyor if it delivers 15 bundles per minute.

$$P = \frac{W}{t} = \frac{Fd}{t} = \frac{mgd}{t} = \frac{(25)(15)(1.00\ kg)(9.80\ m/s^2)(\sin 30.0°)(12.0\ m)}{60.0\ s} = 3.68 \times 10^2\ W$$

26. An engine moves a boat through the water at a constant speed of 15 m/s. The engine must exert a force of 6.0×10^3 N to balance the force that water exerts against the hull. What power does the engine develop?

$$P = \frac{W}{t} = \frac{Fd}{t} = Fv = (6.0 \times 10^3\ N)(15\ m/s) = 90\ kW$$

27. A 188–W motor will lift a load at the rate (speed) of 6.50 cm/s. How great a load can the motor lift at this speed?

$$v = 6.50\ cm/s = 0.0650\ m/s$$

$$P = \frac{W}{t} = \frac{Fd}{t} = F\left[\frac{d}{t}\right] = Fv$$

$$P = F_w v$$

$$F_w = \frac{P}{v} = \frac{(188\ W)}{(0.0650\ m/s)} = 2.89 \times 10^3\ N$$

28. A car is driven at a constant speed of 21 m/s (76/km/h) down a road. The car's engine delivers 48 kW of power. Calculate the average force of friction that is resisting the motion of the car.

$$P = \frac{W}{t} = \frac{Fd}{t} = Fv,\ so\ F = \frac{P}{v} = \frac{(48,000\ W)}{(21\ m/s)} = 2.3 \times 10^3\ N$$

29. Stan raises a 1000–N piano a distance of 5.00 m using a set of pulleys. Stan pulls in 20.0 m of rope.

   a. How much effort did Stan apply if this was an ideal machine?

   $F_e d_e = F_r d_r$, so

   $$F_e = \frac{F_r d_r}{d_e} = \frac{(1000 \text{ N})(5.00 \text{ m})}{(20.0 \text{ m})} = 250 \text{ N}$$

   b. What force is used to overcome friction if the actual effort is 300 N?

   $F = F_f + F_e$,
   $F_f = F - F_e = 300\text{N} - 250 \text{ N} = 50 \text{ N}$

   c. What is the work output?

   $W_o = F_r d_r = (1000 \text{ N})(5.00 \text{ m})$
   $= 5.00 \times 10^3 \text{ J}$

   d. What is the work input?

   300 N

   e. What is the mechanical advantage?

   $$MA = \frac{d_e}{d_r} = \frac{20.0 \text{ m}}{5.00 \text{ m}} = 4.00$$

30. A mover's dolly is used to deliver a refrigerator up a ramp into a house. The refrigerator has a mass of 115 kg. The ramp is 2.10 m long and rises 0.850 m. The mover pulls the dolly with a force of 496 N up the ramp. The dolly and ramp constitute a machine.

   a. What work does the mover do?

   $W_i = Fd = (496 \text{ N})(2.10 \text{ m})$
   $= 1.04 \times 10^3 \text{ J}$

   b. What is the work done on the refrigerator by the machine?

   d = height raised = 0.850 m
   $W_o = mgd = (115 \text{ kg})(9.80 \text{ m/s}^2)(0.850 \text{ m})$
   $= 958 \text{ J}$

   c. What is the efficiency of the machine?

   $$Efficiency = \frac{W_o}{W_i} \times 100\%$$

   $$= \frac{(958 \text{ J})}{(1.04 \times 10^3 \text{ J})} \times 100\%$$

   $$= 92.1\%$$

31. A pulley system lifts a 1345–N weight a distance of 0.975 m. Paul pulls the rope a distance of 3.90 m, exerting a force of 375 N.

   a. What is the ideal mechanical advantage of the system?

   $$IMA = \frac{d_e}{d_r} = \frac{(3.90 \text{ m})}{(0.975 \text{ m})} = 4.00$$

   b. What is the mechanical advantage?

   $$MA = \frac{F_r}{F_e} = \frac{(1345 \text{ N})}{(375 \text{ N})} = 3.59$$

   c. How efficient is the system?

   $$Efficiency = \frac{MA}{IMA} \times 100\%$$

   $$= \frac{3.59}{4.00} \times 100\%$$

   $$= 89.8\%$$

32. The ramp in Figure 10–18 is 18 m long and 4.5 m high.

   a. What force parallel to the ramp $(F_{||})$ is required to slide a 25 kg box to the top of the ramp if friction is neglected?

   $W = F_w h = (25 \text{ kg})(9.8 \text{ m/s}^2)(4.5 \text{ m})$
   $= 1.1 \times 10^3 \text{ J}$
   $W = F_{||} d$

   $$F_{||} = \frac{W}{d} = \frac{(1.1 \times 10^3 \text{ J})}{18 \text{ m}} = 61 \text{ N}$$

   b. What is the IMA of the ramp?

   $$IMA = \frac{d_e}{d_r} = \frac{(18 \text{ m})}{(4.5 \text{ m})} = 4.0$$

c. What are the real MA and the efficiency of the ramp if a parallel force of 75 N is actually required?

$$MA = \frac{F_r}{F_e} = \frac{(25 \text{ kg})(9.8 \text{ m/s}^2)}{75 \text{ N}} = 3.3$$

$$eff = \frac{MA}{IMA} \times 100\% = \frac{(3.3)}{(4.0)} \times 100\%$$

$$= 83\%$$

33. Because there is very little friction, the lever is an extremely efficient simple machine. Using a 90.0% efficient lever, what input work is required to lift an 18.0-kg mass through a distance of 0.50 m?

$$efficient = \frac{W_d}{W_i} \times 100\%$$

$$W_i = \frac{(W_d)(100\%)}{efficient} = \frac{(mgd)(100\%)}{(90.0\%)}$$

$$= \frac{(18.0\text{kg})(9.80 \text{ m/s}^2)(0.50\text{m})(100\%)}{90.0\%}$$

$$= 98 \text{ J}$$

34. What work is required to lift a 215-kg mass a distance of 5.65 m using a machine that is 72.5% efficient?

$$W_o = F_r d_r = (215 \text{ kg})(9.80 \text{ m/s}^2)(5.65 \text{ m})$$
$$= 1.19 \times 10^4 \text{ J}$$

$$\frac{W_o}{W_i} \times 100\% = 72.5\% = 0.725$$

$$W_i = \frac{W_o}{0.725} = \frac{(1.19 \times 10^4 \text{ J})}{(0.725)} = 1.64 \times 10^4 \text{ J}$$

35. A motor having an efficiency of 88% operates a crane having an efficiency of 42%. With what constant speed does the crane lift a 410-kg crate of machine parts if the power supplied to the motor is 5.5 kW?

Total efficiency = 88% × 42% = 37%
Useful power = 5.5 kW × 37% = 2.0 kW
$$= 2.0 \times 10^3 \text{ W}$$

$$P = \frac{W}{t} = \frac{Fd}{t} = F\left[\frac{d}{t}\right] = Fv$$

$$v = \frac{P}{F_w} = \frac{(2.0 \times 10^3 \text{ W})}{(410 \text{ kg})(9.8 \text{ m/s}^2)} = 0.50 \text{ m/s}$$

36. A complex machine is constructed by attaching the lever to the pulley system. Consider an ideal complex machine consisting of a lever with an IMA of 3.0 and a pulley system with an IMA of 2.0.

a. Show that the IMA of this complex machine is 6.0.

$$W_{ir} = W_o = W_{ir}' = W_o'$$
$$W_i = W_o$$
$$F_e d_e = F_r' d_r'$$
For the complex machine

$$IMA_c = \frac{d_e}{d_r'}$$

$$\frac{d_e}{d_r} = IMA; \quad \frac{d_e'}{d_r'} = IMA'$$

$$d_r = d_e'$$

$$\frac{d_e}{IMA} = d_r = d_e' = (IMA')(d_r')$$

$$d_e = (IMA)(IMA')(d_r')$$

$$\frac{d_e}{d_r'} = IMA_c = (IMA)(IMA')$$

$$= (3.0)(2.0) = 6.0$$

b. If the complex machine is 60.0% efficient, how much effort must be applied to the lever to lift a 540-N box?

$$\frac{F_r'}{F_e} = MA_c = \frac{(IMA) \times (eff)}{100\%}$$

$$\frac{F_r'}{F_e} = \frac{(6.0)(60.0\%)}{(100\%)} = 3.6$$

$$F_e = \frac{F_r'}{3.6} = \frac{540 \text{ N}}{3.6} = 150 \text{ N}$$

c. If you move the effort side of the lever 12.0 cm, how far is the box lifted?

$$\frac{d_e}{d_r'} = IMA_c$$

$$d_r' = \frac{d_e}{IMA} = \frac{12.0 \text{ cm}}{6.0} = 2.0 \text{ cm}$$

Chapter Review Problems

Supplemental Problems (Appendix B)

37. A powerful rifle is one that propels a bullet with a high muzzle velocity. Does this use of the word 'powerful' agree with the Physics definition of power?

Yes. The higher the muzzle velocity, the larger the kinetic energy and the greater the power for a given time interval. In this case the time interval is really smaller, because of the higher velocity of the bullet and the smaller time interval requires more power.

Supplemental Problems (Appendix B)

1. After scoring a touchdown, an 84.0–kg wide receiver celebrates by leaping 120 cm off the ground. How much work was done in the celebration?

$W = Fd = mgd$
$= (84.0 \text{ kg})(9.80 \text{ m/s}^2)(1.20 \text{ m})$
$= 988 \text{ J}$

2. During a tug–of–war, Team A does 2.20×10^5 J of work in pulling Team B 8.00 m. What force was Team A exerting?

$F = \dfrac{W}{d} = \dfrac{2.2 \times 10^5 \text{ J}}{8.00 \text{ m}} = 2.75 \times 10^4 \text{ N}$

3. To keep a car traveling at a constant velocity, 551 N of force is needed to overcome frictional forces. How much work is done against friction by the car in traveling from Columbus to Cincinnati, a distance of 161 km?
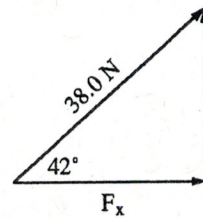
$W = Fd = (551 \text{ N})(1.61 \times 10^5 \text{ m})$
$= 8.87 \times 10^7 \text{ J}$

4. A weightlifter raises a 180–kg barbell to a height of 1.95 m. How much work was done by the weightlifter in lifting the barbell?

$PE = mgh = (180 \text{ kg})(9.80 \text{ m/s}^2)(1.95 \text{ m})$
$= 3.44 \times 10^3 \text{ J}$
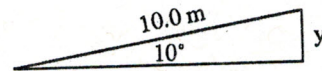
5. A wagon is pulled by a force of 38.0 N on the handle at an angle of 42° with the horizontal. If the wagon is pulled in a circle of radius 25.0 m, how much work is done?
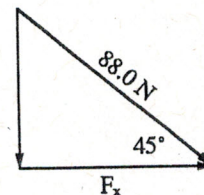
$F_x = (\cos 42°)(38.0 \text{ N})$
$F_x = 28 \text{ N}$
$C = 2\pi r = 2\pi(25.0 \text{ m}) = 157 \text{ m}$
$W = F_x d = (28 \text{ N})(157 \text{ m}) = 4.4 \times 10^3 \text{ J}$

6. A 185–kg refrigerator is loaded into a moving van by pushing it up a 10.0–m ramp at an angle of inclination of 11°. How much work is done?

$y = (10.0 \text{ m})(\sin 11°)$
$y = 1.9 \text{ m}$
$W = Fd = (185 \text{ kg})(9.8 \text{ m/s}^2)(1.9 \text{ m})$
$= 3.4 \times 10^3 \text{ J}$

7. A lawn mower is pushed with a force of 88.0 N along a handle that makes an angle of 41° with the horizontal. How much work is done in pushing the mower 1.2 km in mowing the yard?

$F_x = (\cos 41°)(88.0 \text{ N}) = 66.4 \text{ N}$
$W = F_x d = (66.4 \text{ N})(122 \text{ m}) = 8.0 \times 10^4 \text{ J}$

8. A 17.0–kg crate is to be pulled a distance of 20.0 m requiring 1210 J of work being done. If the job is done by attaching a rope and pulling with a force of 75.0 N, at what angle is the rope held?
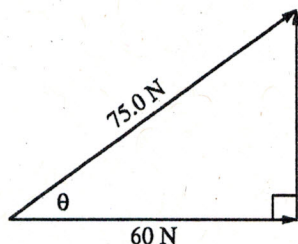
$$F_x = \frac{W}{d} = \frac{1210 \text{ J}}{20.0 \text{ m}} = 60.5 \text{ N}$$

$$\cos \theta = \frac{60.5}{75.0} = 0.807$$

$$\theta = 36.2°$$

9. 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 demonstrate?

$$P = \frac{W}{t} = \frac{(1.1 \times 10^3 \text{ kg})(9.8 \text{ m/s}^2)(40.0 \text{ m})}{12.5 \text{ s}}$$

$$= 3.4 \times 10^4 \text{ W}$$

10. A cyclist exerts a force of 15.0 N in riding a bike 251 m in 30.0 s. What is the cyclist's power?

$$P = \frac{W}{t} = \frac{(15.0 \text{ N})(251 \text{ m})}{30.0 \text{ s}} = 126 \text{ W}$$

11. A 120–kg lawn tractor goes up a 21° incline of 12.0 m in 2.5 s. What power is shown by the tractor?
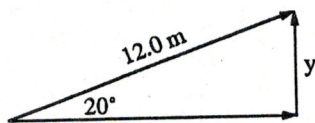
$y = (12.0 \text{ m})(\sin 21°) = 4.3 \text{ m}$

$W = Fd = (120 \text{ kg})(9.8 \text{ m/s}^2)(4.3 \text{ m})$

$\quad = 5.1 \times 10^3 \text{ J}$

$P = \frac{W}{t} = \frac{5.1 \times 10^3 \text{ J}}{2.5 \text{ s}} = 2.04 \times 10^3 \text{ W}$

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

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

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

Thus,

$P = (35 \text{ kg/min})(1 \text{ min/60 s})(9.80 \text{ m/s}^2)(110 \text{ m})$

$\quad = 0.63 \text{ kW}$

13. A force of 1.4 N is exerted through a distance of 40.0 cm on a rope in a pulley system to lift a 0.50–kg mass 10.0 cm.

a. Calculate the MA.

$$MA = \frac{F_r}{F_e} = \frac{(0.50 \text{ kg})(9.8 \text{ m/s}^2)}{1.4 \text{ N}} = \frac{4.9 \text{ N}}{1.4 \text{ N}}$$

$$= 3.5$$

b. Calculate the IMA.

$$IMA = \frac{d_e}{d_r} = \frac{40.0 \text{ cm}}{10.0 \text{ cm}} = 4.00$$

c. What is the efficiency of the pulley system?

$$EFF = \frac{MA}{IMA} \times 100\% = \frac{3.5}{4.00} \times 100\% = 88\%$$

14. A student exerts a force of 250 N through a distance of 1.6 m on a lever in lifting a 150–kg crate. If the efficiency of the lever is 90%, how far is the crate lifted?

$F_r = (150 \text{ kg})(9.8 \text{ m/s}^2) = 1470 \text{ N}$

$MA = \frac{F_r}{F_e} = \frac{1470 \text{ N}}{250 \text{ N}} = 5.9$

$IMA = \frac{(MA)(100\%)}{EFF} = \frac{(5.9)(100\%)}{90\%} = 6.6$

$d_r = \frac{d_e}{IMA} = \frac{1.6 \text{ m}}{6.6} = 0.24 \text{ m}$

15. Karen pedals a bicycle with a gear radius of 5.00 cm and a wheel radius of 38.6 cm. What length of chain must be pulled through to make the wheel revolve once?

$IMA = \frac{GR}{WR} = \frac{5.00 \text{ cm}}{38.6 \text{ cm}} = 0.130$

$d_r = 2\pi r = 2\pi(38.6 \text{ cm}) = 242.5 \text{ cm}$

$d_e = IMA(d_r) = (0.130)(242.5 \text{ cm}) = 31.5 \text{ cm}$