Chapter 11: Energy

Practice Problems

page 221

1. a. Using the data in Table 11–1, calculate the kinetic energy of a compact car moving at 50 km/h.

   50 km/h is 14 m/s, so

   $KE = \frac{1}{2}mv^2 = \frac{1}{2}(750 \text{ kg})(14 \text{ m/s})^2$

   $= 7.4 \times 10^4$ J

   b. How much work must be done on the car to slow it from 100 km/h to 50 km/h?

   $W = \Delta KE = KE_f - KE_i$
   $= 0.74 \times 10^5 \text{ J} - 2.94 \times 10^5 \text{ J}$
   $= -2.20 \times 10^5$ J

   c. How much work must be done on the car to bring it to rest?

   $W = \Delta KE = 0 - 7.4 \times 10^4$ J
   $= -7.4 \times 10^4$ J

   d. The force that does the work slowing the car is constant. Find the ratio of the distance needed to slow the car from 100 km/h to 50 km/h to the distance needed to slow it from 50 km/h to rest. State your conclusion in a sentence.

   $W = Fd$, so distance is proportional to work. The ratio is
   $(-2.2 \times 10^5 \text{ J})/(-7.4 \times 10^4 \text{ J}) = 3$.
   It takes three times the distance to slow the car to half its speed than it does to slow it to a complete stop.

page 222

2. A rifle can shoot a 4.20–g bullet at a speed of 965 m/s.

   a. Find the kinetic energy of the bullet.

   $KE = \frac{1}{2}mv^2 = \frac{1}{2}(0.00420 \text{ kg})(965 \text{ m/s})^2$

   $= 1.96 \times 10^3$ J

Practice Problems

   b. What work is done on the bullet if it starts from rest?

   $W = \Delta KE = 1.96 \times 10^3$ J

   c. If the work is done over a distance of 0.75 m, what is the average force on the bullet?

   $W = Fd$, so

   $F = \frac{W}{d} = (1.96 \times 10^3 \text{ J})/(0.75 \text{ m})$

   $= 2.6 \times 10^3$ N

   d. If the bullet comes to rest by pushing 1.5 cm into metal, what is the average force it exerts?

   $F = \frac{W}{d} = \frac{KE}{d} = (1.96 \times 10^3 \text{ J})/(0.015 \text{ m})$

   $= 1.3 \times 10^5$ N

3. A comet with mass 7.85×10^{11} kg strikes Earth at a speed, relative to Earth, of 25 km/s.

   a. Find the kinetic energy of the comet in joules.

   $KE = \frac{1}{2} mv^2$

   $= \frac{1}{2}(7.85 \times 10^{11} \text{ kg})(2.5 \times 10^4 \text{ m/s})^2$

   $= 2.5 \times 10^{20}$ J

   b. Compare the work done on Earth with the energy released in exploding the largest nuclear weapon ever built, equivalent to 100 million tons of TNT, or 4.2×10^{15} J of energy. Such a comet collision has been suggested as having caused the extinction of the dinosaurs.

   The work is that of 60,000 100–megaton bombs.

Practice Problems

4. Table 11–1 shows that 2.2×10^6 J of work are needed to accelerate a 5700–kg trailer truck to 100 km/h.

a. How fast would it go if just 1/2 as much work were done on it?

Since $W = \Delta KE = \frac{1}{2}mv^2$, then $v = \sqrt{2W/m}$.

If $W' = \frac{1}{2}W$,

$$v' = \sqrt{2W'/m}$$
$$= \sqrt{2\left[\frac{1}{2}W\right]/m} = \sqrt{\frac{1}{2}}v$$
$$= (0.707)(100 \text{ km/h}) = 71 \text{ km/h}$$

b. What if twice as much work was done?

If $W' = 2W$,

$$v' = \sqrt{2}(100 \text{ km/h})$$
$$= 140 \text{ km/h}$$

5. A 90–kg rock climber first climbs 45 m upward to the top edge of a quarry, then, from the top, descends 85 m to the bottom. Find the potential energy of the climber at the edge and at the bottom, using the initial height as reference level.

$PE = mgh$. At the edge,

$$PE = (90 \text{ kg})(9.8 \text{ m/s}^2)(+45 \text{ m})$$
$$= +4.0 \times 10^4 \text{ J}.$$

At the bottom,

$$PE = (90 \text{ kg})(9.8 \text{ m/s}^2)(+45 \text{ m} - 85 \text{ m})$$
$$= -3.5 \times 10^4 \text{ J}$$

6. A 50.0–kg shell is shot from a cannon at Earth's surface to a height of 4.00×10^2 m.

a. What is the gravitational potential energy with respect to Earth's surface of the Earth–shell system when the shell is at this height?

$$PE = mgh = (50.0 \text{ kg})(9.80 \text{ m/s}^2)(400 \text{ m})$$
$$= 1.96 \times 10^5 \text{ J}.$$

b. What is the change in potential energy of the system when the shell falls to a height of 2.00×10^2 m?

$$\Delta PE = mgh_f - mgh_i = mg(h_f - h_i)$$
$$= (50.0 \text{ kg})(9.80 \text{ m/s}^2)(200 \text{ m} - 400 \text{ m})$$
$$= -9.80 \times 10^4 \text{ J}.$$

Practice Problems

page 224

7. A person weighing 630 N climbs up a ladder to a height of 5.0 m.

a. What work does the person do?

$$W = Fd = Fh = (630 \text{ N})(5.0 \text{ m}) = 3200 \text{ J}$$

b. What is the increase in the gravitational potential energy of the person from the ground to this height?

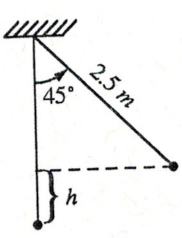
$\Delta PE = (mg)h = (630 \text{ N})(5.0 \text{ m}) = 3200$ J. The increase in gravitational potential energy is equal to the work done.

c. Where does the energy come from to cause this increase in the gravitational potential energy?

Directly from the work done by the person. Indirectly from the chemical energy stored in the person's body.

8. A pendulum is constructed from a 7.26–kg bowling ball hanging on a 2.5–m long rope. The ball is pulled back until the rope makes a 45° angle with the vertical.

a. What is the potential energy of the ball?



$$h = (2.5 \text{ m})(1 - \cos\theta) = 0.73 \text{ m},$$
$$PE = mgh = (7.26 \text{ kg})(9.80 \text{ m/s}^2)(0.73 \text{ m})$$
$$= 52 \text{ J}$$

b. What reference level did you use in your calculation?

the height of the ball when the rope was vertical

Practice Problems

page 230

9. A bike rider approaches a hill with a speed of 8.5 m/s. The total mass of the bike and rider is 85 kg.

   a. Find the kinetic energy of the bike and rider.

   $$KE = \frac{1}{2}mv^2$$

   $$= \frac{1}{2}(85 \text{ kg})(8.5 \text{ m/s})^2 = 3.1 \times 10^3 \text{ J}$$

   b. The rider coasts up the hill. Assuming there is no friction, at what height will the bike come to a stop?

   $$KE_i + PE_i = KE_f + PE_f$$

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

   $$h = \frac{v^2}{2g} = \frac{(8.5 \text{ m/s})^2}{(2)(9.8 \text{ m/s}^2)} = 3.7 \text{ m}$$

   c. Does your answer depend on the mass of the bike and rider? Explain.

   No. It cancels because both *KE* and *PE* are proportional to *m*.

10. Tarzan, mass 85 kg, swings down from a tree limb on the end of a 20-m vine. His feet touch the ground 4.0 m below the limb.

   a. How fast is Tarzan moving when he reaches the ground?

   $$KE_i + PE_i = KE_f + PE_f$$

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

   $$v^2 = 2gh = 2(9.8 \text{ m/s}^2)(4.0 \text{ m}) = 78.4 \text{ m}^2/\text{s}^2,$$
   $$v = 8.9 \text{ m/s}$$

   b. Does your answer depend on Tarzan's mass?

   No

   c. Does your answer depend on the length of the vine?

   No

Practice Problems

11. A skier starts from rest at the top of a 45-m hill, skis down a 30° incline into a valley, and continues up a 40-m hill. Both hill heights are measured from the valley floor. Assume you can neglect friction and the effect of ski poles.

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

   $$KE_i + PE_i = KE_f + PE_f,$$

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

   $$v^2 = 2gh = 2(9.8 \text{ m/s}^2)(45 \text{ m}) = 880 \text{ m}^2/\text{s}^2,$$
   $$v = 30 \text{ m/s}$$

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

   $$KE_i + PE_i = KE_f + PE_f,$$

   $$0 + mgh_i = \frac{1}{2}mv^2 + mgh_f,$$

   $$v^2 = 2g(h_i - h_f)$$
   $$= 2(9.8 \text{ m/s}^2)(45 \text{ m} - 40 \text{ m}) = 98 \text{ m}^2/\text{s}^2,$$
   $$v = 10 \text{ m/s}.$$

12. Suppose, in the case of Practice Problem 9, the bike rider pedaled up the hill and never came to a stop.

   a. How could you define a system in which energy is conserved?

   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 stored energy, some of which is converted to mechanical energy.

   b. From what form of energy did the bike gain kinetic energy?

   Energy came from the chemical potential energy stored in the rider's body.

Practice Problems

page 234

13. A 2.00-g bullet, moving at 538 m/s, strikes a 0.250-kg piece of wood at rest on a frictionless table. The bullet sticks in the wood, and the combined mass moves slowly down the table.

a. Find the speed of the combination after the collision.

From the conservation of momentum,

$mv = (m + M)V$, so

$V = mv/(m + M)$

$= \frac{(0.002 \text{ kg})(538 \text{ m/s})}{0.002 \text{ kg} + 0.250 \text{ kg}} = 4.27 \text{ m/s}$

b. Find the kinetic energy of the bullet before the collision.

$KE_i = \frac{1}{2}mv^2 = \frac{1}{2}(0.002 \text{ kg})(538 \text{ m/s})^2$

$= 289 \text{ J}$

c. Find the kinetic energy of the combination after the collision.

$KE_f = \frac{1}{2}(m + M)V^2$

$= \frac{1}{2}(0.002 \text{ kg} + 0.250 \text{ kg})(4.27 \text{ m/s})^2$

$= 2.30 \text{ J}$

d. How much kinetic energy did the bullet lose?

$\Delta KE = KE_i - KE_f = 289 \text{ J} - 2 \text{ J} = 287 \text{ J}$

e. What per cent of the bullet's original kinetic energy is lost?

$\% \ KE \text{ lost} = (\Delta KE/KE_i) \times 100$

$= (287 \text{ J}/298 \text{ J}) \times 100$

$= 99.3\%$

page 235

14. 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 the bullet slide along a frictionless surface together with a speed of 10 cm/s. What was the initial speed of the bullet?

Conservation of momentum $mv = (m + M)V$, or

$v = (m + M)V/m$

$= \frac{(0.008 \text{ kg} + 9.00 \text{ kg})(0.10 \text{ m/s})}{(0.008 \text{ kg})}$

$= 1.1 \times 10^2 \text{ m/s}$

Practice Problems

15. As everyone knows, bullets bounce from Superman's chest. Suppose Superman, mass 104 kg, while not moving, is struck by a 4.2-g bullet moving with a speed of 835 m/s. If the collision is elastic, find the speed that Superman has after the collision.

We have conservation of momentum $mv + MV = mv' + MV'$ and conservation of energy $\frac{1}{2}mv^2 + \frac{1}{2}MV^2 = \frac{1}{2}mv'^2 + \frac{1}{2}MV'^2$ where m, v, v' refer to the bullet, M, V, V' to Superman, and $V = 0$. v' may be eliminated from these equations by solving the momentum equation for $v' = (mv - MV')/m$ and substituting this into the energy equation $mv^2 = mv'^2 + MV'^2$. This gives a quadratic equation for V' which, in factored form, is $MV'[(M + m)V' - 2mv] = 0$. We are not interested in the solution $V' = 0$ which corresponds to the case where the bullet does not hit Superman. We want the other,

$V' = 2mv/(M + m) = \frac{2(0.0042 \text{ kg})(835 \text{ m/s})}{(104 \text{ kg} + 0.0042 \text{ kg})}$

$= 6.7 \times 10^{-2} \text{ m/s}$.

16. A 0.73-kg magnetic target is suspended on a long string. A 0.025-kg magnetic dart, shot horizontally, strikes it head on. The dart and the target together swing up 12 cm above the initial level. What was the initial velocity of the dart? (**HINT:** Since your equation will have two unknowns, you will need an additional equation to solve for v_i. Consider the fact that the target had zero potential energy before the collision, but the dart and target no longer had zero potential energy after the collision.

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 $\Delta PE = \Delta KE$ or, at the top of the swing,

$(m + M)gh = \frac{1}{2}(m + M)V_f^2$. Solving this for V_f and inserting into the momentum equation gives

$v_i = (m + M)\sqrt{gh}/m$

$= \frac{(0.025 \text{ kg} + 0.73 \text{ kg})\sqrt{2(9.8 \text{ m/s}^2)(0.12 \text{ m})}}{(0.025 \text{ kg})}$

$= 46 \text{ m/s}$.

11

Chapter Review Problems

page 237–239

1. A 1660–kg car travels at a speed of 12.5 m/s. What is its kinetic energy?

$$KE = \frac{1}{2}mv^2 = \left[\frac{1}{2}\right](1600 \text{ kg})(12.5 \text{ m/s})^2$$

$$= 1.25 \times 10^5 \text{ J}$$

2. A racing car has a mass of 1500 kg. What is the kinetic energy if it has a speed of 108 km/h?

$$v = \frac{(108 \text{ km/h})(1000 \text{ m/km})}{(3600 \text{ s/h})} = 30.0 \text{ m/s}$$

$$KE = \frac{1}{2}mv^2 = \left[\frac{1}{2}\right](1500 \text{ kg})(30.0 \text{ m/s})$$

$$= 6.75 \times 10^5 \text{ J}$$

3. Sally has a mass of 45 kg and is moving with a speed of 10.0 m/s.

a. Find Sally's kinetic energy.

$$KE = \frac{1}{2}mv^2 = \left[\frac{1}{2}\right](45 \text{ kg})(10.0 \text{ m/s})^2$$

$$= 2.3 \times 10^3 \text{ J}$$

b. Sally's speed changes to 5.0 m/s. Now what is her kinetic energy?

$$KE = \frac{1}{2}mv^2 = \left[\frac{1}{2}\right](45 \text{ kg})(5.0 \text{ m/s})^2$$

$$= 5.6 \times 10^2 \text{ J}$$

c. What is the ratio of the kinetic energies in a. and b.? Explain the ratio.

$$\frac{1/2(mv_1^2)}{1/2(mv_2^2)} = \frac{v_1^2}{v_2^2} = \frac{(10.0)^2}{(5.0)^2} = \frac{4}{1}$$

Twice the velocity gives four times the kinetic energy.

4. Shawn and his bike have a total mass of 45.0 kg. Shawn rides his bike 1.80 km in 10.0 min at a constant velocity. What is Shawn's kinetic energy?

$$v = \frac{d}{t} = \frac{(1.80 \text{ km})(1000 \text{ m/km})}{(10.0 \text{ min})(60 \text{ s/min})} = 3.00 \text{ m/s}$$

$$KE = \frac{1}{2}mv^2 = \left[\frac{1}{2}\right](45.0 \text{ kg})(3.00 \text{ m/s})^2$$

$$= 203 \text{ J}$$

5. It is not uncommon during the service of a professional tennis player for the racquet to exert an average force of 150.0 N on the ball. If the ball has a mass of 0.060 kg and is in contact with the strings of the racquet for 0.030 s, what is the kinetic energy of the ball as it leaves the racquet? Assume the ball starts from rest.

$Ft = m\Delta v = mv_f - mv_i$, and $v_i = 0$, so

$$v_f = \frac{Ft}{m} = \frac{(150.0 \text{ N})(3.0 \times 10^2 \text{ s})}{(6.0 \times 10^{-2} \text{ kg})}$$

$$= 75 \text{ m/s}$$

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(6.0 \times 10^{-2} \text{ kg})(75 \text{ m/s})^2$$

$$= 1.7 \times 10^2 \text{ J}$$

6. Pam has a mass of 40.0 kg and is at rest on smooth, level, frictionless ice. Pam straps on a rocket pack. The rocket supplies a constant force for 22.0 m and Pam acquired a speed of 62.0 m/s.

a. What is the magnitude of the force?

$F = ma$ and $v_f^2 = v_i^2 + 2ad$, so

$$a = \frac{v_f^2 - v_i^2}{2d} \text{ but } v_i = 0, \text{ so } a = \frac{v_f^2}{2d}$$

$$= \frac{(62.0 \text{ m/s})^2}{2(22.0)} = 87.4 \text{ m/s}^2. \text{ Therefore,}$$

$$F = ma = (40.0 \text{ kg})(87.4 \text{ m/s}^2)$$
$$= 3.50 \times 10^3 \text{ N.}$$

b. What is Pam's final kinetic energy?

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(40.0 \text{ kg})(62.0 \text{ m/s})^2$$

$$= 7.69 \times 10^4 \text{ J}$$

Chapter Review Problems

7. Sally and Lisa have a mass of 45 kg and they are moving together with a speed of 10.0 m/s.

a. What is their combined kinetic energy?

$$KE_c = \frac{1}{2}mv^2 = \frac{1}{2}(m_s + m_l)(v^2)$$

$$= \frac{1}{2}(45 \text{ kg} + 45 \text{ kg})(10.0 \text{ m/s})^2$$

$$= 4.5 \times 10^3 \text{ J}$$

b. What is the ratio of their combined mass to Sally's mass?

$$\frac{m_s + m_l}{m_s} = \frac{45 \text{ kg} + 45 \text{ kg}}{45 \text{ kg}} = \frac{90 \text{ kg}}{45 \text{ kg}} = \frac{2}{1}$$

c. What is the ratio of their combined kinetic energy to Sally's kinetic energy? Explain.

$$KE_s = \frac{1}{2}m_s v^2 = \frac{1}{2}(45 \text{ kg})(10.0 \text{ m/s})^2$$

$$= 2.25 \times 10^3 \text{ J}$$

$$\frac{KE_c}{KE_m} = \frac{4.5 \times 10^3 \text{ J}}{2.35 \times 10^3 \text{ J}} = \frac{2}{1}$$

The ratio of the kinetic energies is the same as the ratio of their masses

8. In the 1950s an experimental train that had a mass of 2.50×10^4 kg was powered across a level track by a jet engine that produced a thrust of 5.00×10^5 N for a distance of 500 m.

a. Find the work done on the train.

$$w = F \cdot d = (5.00 \times 10^5 \text{ N})(500 \text{ m})$$
$$= 2.50 \times 10^8 \text{ J}$$

b. Find the change in kinetic energy.

$$\Delta KE = w = 2.50 \times 10^8 \text{ J}$$

c. Find the final kinetic energy of the train if it started from rest.

$$\Delta KE = KE_f - KE_i, \text{ so } KE_f = \Delta KE + KE_i$$
$$= 2.50 \times 10^8 \text{ J} - 0$$
$$= 2.50 \times 10^8 \text{ J}$$

d. Find the final speed of the train if there was no friction.

$$KE_f = \frac{1}{2}mv^2, \text{ so}$$

$$v^2 = \frac{KE_f}{1/2\, m}$$

$$= \frac{2.50 \times 10^8 \text{ J}}{1/2(2.50 \times 10^4 \text{ kg})} \quad \text{so}$$

$$v = \sqrt{2.00 \times 10^4 \, m^2/s^2} = 141 \text{ m/s}$$

9. A 14 700–N car is traveling at 25 m/s. The brakes are suddenly applied and the car slides to a stop. The average braking force between the tires and the road is 7100 N. How far will the car slide once the brakes are applied?

$$W = F \cdot d = \frac{1}{2}mv^2$$

$$\text{Now } m = \frac{w}{g} = \frac{14{,}700 \text{ N}}{9.80 \text{ m/s}^2} = 1500 \text{ kg.}$$

$$\text{So } d = \frac{\frac{1}{2}mv^2}{F} = \frac{\frac{1}{2}(1500 \text{ kg})(25 \text{ m/s}^2)}{7100 \text{ N}} = 66 \text{ m.}$$

10. A 15.0–kg cart is moving with a velocity of 7.50 m/s down a level hallway. A constant force of −10.0 N acts on the cart and its velocity becomes 3.20 m/s.

a. What is the change in kinetic energy of the cart?

$$\Delta KE = KE_f - KE_i = \frac{1}{2}m(v_f^2 - v_i^2)$$

$$= \frac{1}{2}(15.0 \text{ kg})[(3.20 \text{ m/s})^2 - (7.50 \text{ m/s})^2]$$

$$= -345 \text{ J}$$

b. How much work was done on the cart?

$$W = \Delta KE = -345 \text{ J}$$

c. How far did the cart move while the force acted?

$$W = Fd, \text{ so } d = \frac{W}{F} = \frac{-345 \text{ J}}{-10.0 \text{ N}} = 34.5 \text{ m}$$

11. A 2.00×10^3–kg car has a speed of 12.0 m/s. The car then hits a tree. The tree doesn't move and the car comes to rest.

a. Find the change in kinetic energy of the car.

$$\Delta KE = KE_f - KE_i = \frac{1}{2}m(v_f^2 - v_i^2)$$

$$= \frac{1}{2}(2.00 \times 10^3 \text{ kg})(0^2 - (12.0 \text{ m/s})^2)$$

$$= -1.44 \times 10^5 \text{ J}$$

b. Find the amount of work done in pushing in the front of the car.

$$W = \Delta KE = -1.44 \times 10^5 \text{ J}$$

c. Find the size of the force that pushed the front of the car in 50.0 cm.

$W = F \cdot d$, so

$$F = \frac{W}{d} = \frac{-1.44 \times 10^5 \text{ J}}{0.500 \text{ m}}$$

$$= -2.88 \times 10^5 \text{ N.}$$

The negative sign implies a retarding force.

12. How much potential energy does Tim, mass of 60.0 kg, gain when he climbs a gymnasium rope a distance of 3.5 m?

$$PE = mgh = (60.0 \text{ kg})(9.80 \text{ m/s}^2)(3.5 \text{ m}) = 2.1 \times 10^3 \text{ J}$$

13. A 6.4–kg bowling ball is lifted 2.1 m into a storage rack. Calculate the increase in the ball's potential energy.

$$PE = mgh = (6.4 \text{ kg})(9.80 \text{ m/s}^2)(2.1 \text{ m}) = 1.3 \times 10^2 \text{ J}$$

14. Mary weighs 500 N. She walks down a flight of stairs to a level 5.50 m below her starting point. What is the change in Mary's potential energy?

$$\Delta PE = mg\Delta h = W\Delta h = (500 \text{ N})(-5.50 \text{ m}) = -2.75 \times 10^3 \text{ J}$$

Chapter Review Problems

15. A weightlifter raises a 180–kg barbell to a height of 1.95 m. What is the increase in the barbell's potential energy?

$$PE = mgh = (180 \text{ kg})(9.80 \text{ m/s}^2)(1.95 \text{ m}) = 3.44 \times 10^3 \text{ J}$$

16. A 10.0–kg test rocket is fired vertically from Cape Canaveral. Its fuel gives it a kinetic energy of 1960 J by the time the rocket motor burns all of the fuel. What additional height will the rocket rise?

$$PE = mgh = KE$$

$$h = \frac{KE}{mg} = \frac{1960 \text{ J}}{(10.0 \text{ kg})(9.80 \text{ m/s}^2)} = 20.0 \text{ m}$$

17. Ace raised a 12.0–N Physics book from a table, 75 cm above the floor, to a shelf, 2.15 m above the floor. What was the change in potential energy?

$$PE = mg\Delta h = W\Delta h = W(h_f - h_i) = (12.0 \text{ N})(2.15 \text{ m} - 0.75 \text{ m}) = 16.8 \text{ J}$$

18. A hallway display of energy is constructed. People are told that to do 1.00 J of work, they should pull on a rope that lifts a block 1.00 m. What should be the mass of the block?

$W = \Delta PE = mgh$, so

$$m = \frac{W}{gh} = \frac{(1.00 \text{ J})}{(9.80 \text{ m/s}^2)(1.00 \text{ m})} = 0.102 \text{ kg}$$

19. A constant net force of 410 N, up, is applied to a stone that weighs 32 N. The upward force is applied through a distance of 2.0 m, and the stone is then released. To what height, from the point of release, will the stone rise?

$W = Fd = (410 \text{ N})(2.0 \text{ m}) = 8.20 \times 10^2$ J.
But $W = \Delta PE = mg\Delta h$, so

$$\Delta h = \frac{W}{mg} = \frac{8.20 \times 10^2 \text{ J}}{32 \text{ N}} = 26 \text{ m}$$

20. A 98–N sack of grain is hoisted to a storage room 50 m above the ground floor of a grain elevator.

a. How much work was required?

$$W = Fd = (98 \text{ N})(50 \text{ m}) = 4.9 \times 10^3 \text{ J}$$

Chapter Review Problems

b. What is the potential energy of the sack of grain at this height?

$\Delta PE = W = 4.9 \times 10^3$ J

c. The rope being used to lift the sack of grain breaks just as the sack reaches the storage room. What kinetic energy does the sack have just before it strikes the ground floor?

$KE = \Delta PE = 4.9 \times 10^3$ J

21. A 20-kg rock is on the edge of a 100 m cliff.

a. What potential energy does the rock possess relative to the base of the cliff?

$$PE = mgh = (20 \text{ kg})(9.80 \text{ m/s}^2)(100 \text{ m}) = 2.0 \times 10^4 \text{ J}$$

b. The rock falls from the cliff. What is its kinetic energy just before it strikes the ground?

$KE = \Delta PE = 2.0 \times 10^4$ J

c. What speed does the rock have as it strikes the ground?

$$KE = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(2.0 \times 10^4 \text{ J})}{(20 \text{ kg})}}$$

$$= 45 \text{ m/s}$$

22. An archer puts a 0.30-kg arrow to the bowstring. An average force of 201 N is exerted to draw the string back 1.3 m.

a. Assuming no frictional loss, with what speed does the arrow leave the bow?

$$W = KE$$

$$Fd = \frac{1}{2}mv^2$$

$$v^2 = \frac{2Fd}{m}$$

$$v = \sqrt{\frac{2Fd}{m}} = \sqrt{\frac{(2)(201 \text{ N})(1.3 \text{ m})}{(0.30 \text{ kg})}}$$

$$= 42 \text{ m/s}$$

b. If the arrow is shot straight up, how high does it rise?

$$PE = \Delta KE$$

$$mgd = \frac{1}{2}mv^2$$

$$d = \frac{v^2}{2g} = \frac{(42 \text{ m/s})^2}{(2)(9.8 \text{ m/s}^2)} = 90 \text{ m}$$

23. A 2.0-kg rock initially at rest loses 400 J of potential energy while falling to the ground.

a. Calculate the kinetic energy that the rock gains while falling.

$$PE_i + KE_i = PE_f + KE_f$$
$$KE_f = PE_i = 400 \text{ J}$$

b. What is the rock's speed just before it strikes the ground?

$$KE = \frac{1}{2}mv^2, \text{ so } v^2 = (2)\frac{KE}{m} = \frac{(2)(400 \text{ J})}{(2.0 \text{ kg})}$$

$$= 400 \text{ m}^2/\text{s}^2, \text{ so } v = 20 \text{ m/s}.$$

24. Betty weighs 420 N and is sitting on a playground swing seat that hangs 0.40 m above the ground. Tom pulls the swing back and releases it when the seat is 1.00 m above the ground.

a. How fast is Betty moving when the swing passes through its lowest position?

$$\Delta PE = Fd = (420 \text{ N})(0.40 \text{ m} - 1.00 \text{ m}) = -250 \text{ J}$$

$$KE = -\Delta PE = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(250 \text{ J})}{(420 \text{ N}/9.8 \text{ m/s}^2)}}$$

$$= 3.4 \text{ m/s}$$

b. If Betty moves through the lowest point at 2.0 m/s, how much work was done on the swing by friction?

$$W = PE - KE = 250 \text{ J} - \frac{1}{2}mv^2$$

$$= 250 \text{ J} - \left(\frac{1}{2}\right)\left(\frac{420 \text{ N}}{9.80 \text{ m/s}^2}\right)(2.0 \text{ m/s})^2$$

$$= 250 \text{ J} - 86 \text{ J} = 164 \text{ J} = 1.6 \times 10^2 \text{ J}$$

11

25. Bill throws a 10.0–g ball straight down from a height of 2.0 m. The ball strikes the floor at a speed of 7.5 m/s. What was the initial speed of the ball?

$KE_f = KE_i + PE_i$

$\frac{1}{2}mv_2^2 = \frac{1}{2}mv_1^2 + mgh$, the mass of the ball

dividing out, so $v_1^2 = v_2^2 - 2gh$,

$v_1 = \sqrt{v_2^2 - 2gh}$

$= \sqrt{(7.5\text{ m/s})^2 - (2)(9.80\text{ m/s}^2)(2.0\text{ m})}$

$= 4.1\text{ m/s}$

26. Magen's mass is 28 kg. She climbs the 4.8–m ladder of a slide, then reaches a velocity of 3.2 m/s at the bottom of the slide. How much work was done by friction on Magen.

At the top,

$PE = mgh = (28\text{ kg})(9.80\text{ m/s}^2)(4.8\text{ m})$

$= 1.3 \times 10^3\text{ J}.$

At the bottom,

$KE = \frac{1}{2}mv^2 = \left[\frac{1}{2}\right](28\text{ kg})(3.2\text{ m/s})^2$

$= 1.4 \times 10^2\text{ J}$

$W_i = PE - KE = 1.2 \times 10^3\text{ J}$

27. A physics book, mass unknown, is dropped 4.50 m. What speed does the book have just before it hits the ground?

$KE = PE$

$\frac{1}{2}mv^2 = mgh$; the mass of the book divides out,

so $\frac{1}{2}v^2 = gh$, or

$\sqrt{2gh} = \sqrt{2(9.80\text{ m/s}^2)(4.50\text{ m})}$

$= 9.39\text{ m/s}.$

Chapter Review Problems

28. A 30.0–kg gun is standing on a frictionless surface. The gun fires a 50.0–g bullet with a muzzle velocity of 310 m/s.

a. Calculate the momenta of the bullet and the gun after the gun was fired.

$P_g = -P_h$ and $P_b = m_b v_b$

$= (0.0500\text{ kg})(310\text{ m/s})$

$= 15.5\ \frac{\text{kg}\cdot\text{m}}{\text{s}}$

$P_g = -P_b = -15.5\ \frac{\text{kg m}}{\text{s}}$

b. Calculate the kinetic energy of both the bullet and the gun just after firing.

$KE_b = \frac{1}{2}mv^2 = \frac{1}{2}(0.0500\text{ kg})(310\text{ m/s})^2$

$= 2.40 \times 10^3\text{ J}$

$P_g = mv$, so

$v = \frac{P_g}{\text{m}} = \frac{-15.5\ \frac{\text{kg}\cdot\text{m}}{\text{s}}}{30.0\text{ kg}}$

$= 0.517\text{ m/s}$

$KE_g = \frac{1}{2}mv^2 = \frac{1}{2}(30.0\text{ kg})(0.517\text{ m/s})^2$

$= 4.00\text{ J}$

29. A railroad car with a mass of 5.0×10^5 kg collides with a stationary railroad car of equal mass. After the collision, the two cars lock together and move off at 4.0 m/s.

a. Before the collision, the first railroad car was moving at 8.0 m/s. What was its momentum?

$mv = (5.0 \times 10^5\text{ kg})(8.0\text{ m/s})$

$= 4.0 \times 10^6\ \frac{\text{kg}\cdot\text{m}}{\text{s}}$

b. What is the total momentum of the two cars after the collision?

Since momentum is conserved, it must be

$4.0 \times 10^6\ \frac{\text{kg}\cdot\text{m}}{\text{s}}$

c. Find the kinetic energies of the two cars before and after the collision.

Before the collision:

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

$$= \left[\frac{1}{2}\right](5.0 \times 10^5 \text{ kg})(8.0 \text{ m/s})^2$$

$$= 1.6 \times 10^7 \text{ J}$$

$KE_2 = 0$ since it is at rest.

After the collision:

$$KE = \frac{1}{2}mv^2$$

$$= \left[\frac{1}{2}\right](5.0 \times 10^5 \text{ kg} + 5.0 \times 10^5 \text{ kg})(4.0 \text{ m/s})^2$$

$$= 8.0 \times 10^6 \text{ J}$$

d. Account for the loss of kinetic energy.

While momentum was conserved during the collision, kinetic energy was not. The amount not conserved was turned into heat and sound.

30. From what height would a compact car have to be dropped to have the same kinetic energy that it has when being driven at 100 km/h?

$$V = \left[100 \frac{\text{km}}{\text{h}}\right]\left[\frac{1000 \text{ m}}{1 \text{ km}}\right]\left[\frac{1 \text{ h}}{3600 \text{ s}}\right]$$

$$= 27.8 \text{ m/s}$$

$KE = PE$

$\frac{1}{2}mv^2 = mgh$; the mass of the car divides out,

so

$$\frac{1}{2}v^2 = gh, \text{ so } h = \frac{v^2}{2g} = \frac{(27.8 \text{ m/s})^2}{2(9.80 \text{ m/s}^2)} = 39.4 \text{ m}$$

Chapter Review Problems

31. A golf ball, mass 0.046 kg, rests on a tee. It is struck by a golf club with an effective mass of 0.220 kg and a speed of 44 m/s. Assuming the collision is elastic, find the speed of the ball when it leaves the tee.

From conservation of momentum, $m_cv_c = m_cv_c' + m_bv_b'$. Solve for v_c',

$$v_c' = v_c - \frac{m_b v_b'}{m_c}.$$

From conservation of energy,

$\frac{1}{2}m_cv_c = \frac{1}{2}m_c(v_c')^2 + \frac{1}{2}m_b(v_b')^2$. Multiply by two and substitution gives

$m_cv_c^2 = m_c[v_c - \frac{m_bv_b'}{m_c}] + m_b(v_b')^2$, or $m_cv_c^2$

$$= m_cv_c^2 - 2m_bv_b'v_c + \frac{m_b(v_b')^2}{m_c} + m_b(v_b')^2.$$

Simplify and factor:

$0 = (m_bv_b')[-2v_c + \frac{m_b(v_b')}{m_c} + v_b']$. Either

$m_bv_b' = 0$ or $-2v_c + \left[\frac{m_b}{m_c} + 1\right]v_b' = 0$ so

$$v_b' = \frac{2v_c}{\left[\frac{m_b}{m_c} + 1\right]} = \frac{2(44 \text{ m/s})}{\left[\frac{0.046 \text{ kg}}{0.220 \text{ kg}} + 1\right]} = 73 \text{ m/s}$$

11

32. A steel ball has a mass of 4.0 kg and rolls along a smooth, level surface at 62 m/s.

a. Find its kinetic energy.

$$KE = \frac{1}{2}mv^2 = \left[\frac{1}{2}\right](4.0\ \text{kg})(62\ \text{m/s})^2$$
$$= 7.7 \times 10^3\ \text{J}$$

b. At first, the ball was at rest on the surface. A constant force acted on it through a distance of 22 m to give it the speed of 62 m/s. What was the magnitude of the force?

a. $W = Fd$

b. $F = \frac{W}{d} = \frac{7.7 \times 10^3\ \text{J}}{22\ \text{m}} = 3.5 \times 10^2\ \text{N}$

33. Show that $W = KE_f - KE_i$ if an object is not originally at rest. Use the equation relating initial and final velocity with constant acceleration and distance.

$v_f^2 = v_i^2 + 2ad$, or $d = \frac{v_f^2 - v_i^2}{2a}$. But

$$W = mad = ma\left[\frac{v_f^2 - v_i^2}{2a}\right] = \frac{1}{2}m(v_f^2 - v_i^2)$$
$$= \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2.$$ Therefore,

$W = KE_f - KE_i$.

Supplemental Problems (Appendix B)

1. Calculate the kinetic energy of a proton, mass of 1.67×10^{-27} kg, traveling at 5.20×10^7 m/s.

$$KE = \frac{1}{2}mv^2$$
$$= \frac{1}{2}(1.67 \times 10^{-27}\ \text{kg})(5.20 \times 10^7\ \text{m/s})^2$$
$$= 2.26 \times 10^{-12}\ \text{J}$$

2. What is the kinetic energy of a 3.2-kg pike swimming at 2.7 km/hr?

$$2.7\ \text{km/hr} \cdot \frac{1000\ \text{m}}{\text{km}} \cdot \frac{\text{hr}}{3600\ \text{s}} = 0.75\ \text{m/s}$$

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(3.2\ \text{kg})(0.75\ \text{m/s})^2 = 0.90\ \text{J}$$

3. A force of 30.0 N pushes a 1.5-kg cart, initially at rest, a distance of 2.8 m along a frictionless surface.

a. Find the work done on the cart.

$$W = Fd = (30.0\ \text{N})(2.8\ \text{m}) = 84\ \text{J}$$

b. What is its change in kinetic energy?

$$W = \Delta KE = 84\ \text{J}$$

c. What is the cart's final velocity?

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2(84\ \text{J})}{1.5\ \text{kg}}} = 11\ \text{m/s}$$

4. A bike and rider of 82.0-kg combined mass are traveling at 4.2 m/s. A constant force of −140 N is applied by the brakes in stopping the bike. What braking distance is needed?

$$KE = \frac{1}{2}mv^2$$
$$= \frac{1}{2}(82.0\ \text{kg})(4.2\ \text{m/s})^2$$
$$= 723\ \text{J of } KE \text{ is lost}$$

$(-140\ \text{N})d = -723\ \text{J}$
$d = 5.2\ \text{m}$

5. A 712-kg car is traveling at 5.6 m/s when a force acts on it for 8.4 s, changing its velocity to 10.2 m/s.

a. What is the change in kinetic energy of the car?

$$KE_{\text{final}} = \frac{1}{2}mv_f^2 = \frac{1}{2}(712\ \text{kg})(10.2\ \text{m/s})^2$$
$$= 3.7 \times 10^4\ \text{J}$$

$$KE_{\text{initial}} = \frac{1}{2}mv_i^2 = \frac{1}{2}(712\ \text{kg})(5.6\ \text{m/s})^2$$
$$= 1.1 \times 10^4\ \text{J}$$

$$\Delta KE = KE_{\text{final}} - KE_{\text{initial}} = 2.6 \times 10^4\ \text{J}$$

b. How far did the car move while the force acted?

$$d = \left[\frac{v_f + v_i}{2}\right]t = \left[\frac{10.2 \text{ m/s} + 5.6 \text{ m/s}}{2}\right](8.4 \text{ s})$$

$= 66$ m

c. How large is the force?

$Fd = \Delta KE$

$F(66.4 \text{ m}) = 2.6 \times 10^4 \text{ J}$

$F = 3.9 \times 10^2 \text{ N}$

6. Five identical 0.85–kg books of 2.50–cm thickness are each lying flat on a table. Calculate the gain in potential energy of the system if they are stacked one on top of the other.

Height raised:

book 1	none
book 2	2.5 cm
book 3	5.0 cm
book 4	7.5 cm
book 5	10.0 cm
	25 cm total

$\Delta PE = mg\Delta h = (0.85 \text{ kg})(9.80 \text{ m/s}^2)(0.25 \text{ m})$

$= 2.1 \text{ J}$

7. Each step of a ladder increases one's vertical height 40 cm. If a 90.0–kg painter climbs 8 steps of the ladder, what is the increase in potential energy?

$(40 \text{ cm})(8) = 320 \text{ cm}$

$\Delta PE = mg\Delta h = (90.0 \text{ kg})(9.80 \text{ m/s}^2)(3.2 \text{ m})$

$= 2.8 \times 10^3 \text{ J}$

8. A 0.25–kg ball is dropped from a height of 3.2 m and bounces to a height of 2.4 m. What is its loss in potential energy?

$\Delta h = 2.4 \text{ m} - 3.2 \text{ m} = -0.80 \text{ m}$

$\Delta PE = mg\Delta h = (0.25 \text{ kg})(9.80 \text{ m/s}^2)(-0.80 \text{ m})$

$= -2.0 \text{ J}$

9. A 0.18–kg ball is placed on a compressed spring on the floor. The spring exerts an average force of 2.8 N through a distance of 15 cm as it shoots the ball upward. How high will the ball travel above the release spring?

$W = Fd$

$= (2.8 \text{ N})(0.15 \text{ m}) = 0.42 \text{ J}$

$W = \Delta PE = mg\Delta h$

$0.42 \text{ J} = (0.18 \text{ kg})(9.80 \text{ m/s}^2)(\Delta h)$

$\Delta h = 0.24 \text{ m}$

10. A force of 14.0 N is applied to a 1.5–kg cart as it travels 2.6 m along an inclined plane. What is the angle of inclination of the plane.

$W = Fd = (14.0 \text{ N})(2.6 \text{ m}) = 36.4 \text{ J}$

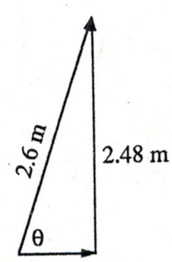
$W = \Delta PE = mg\Delta h$

$36.4k \text{ J} = (1.5 \text{ kg})(9.80 \text{ m/s}^2)(|h)$

$\Delta h = 2.48 \text{ m}$

$$\sin \theta = \frac{2.48}{2.6}$$

$\theta = 72°$



11. A 15.0–kg model plane flies horizontally at a constant speed of 12.5 m/s.

a. Calculate its kinetic energy.

$$KE = \frac{1}{2}mv^2 = \left[\frac{1}{2}\right](15.0 \text{ kg})(12.5 \text{ m/s})^2$$

$= 1.17 \times 10^3 \text{ J}$

b. The plane goes into a dive and levels off 20.4 m closer to Earth. How much potential energy does it lose during the dive? Assume no additional drag.

$\Delta PE = mgh = (15.0 \text{ kg})(9.80 \text{ m/s}^2)(20.4 \text{ m})$

$= 3.00 \times 10^3 \text{ J}$

c. How much kinetic energy does the plane gain during the dive?

$\Delta KE = \Delta PE = 3.00 \times 10^3$ J

d. What is its new kinetic energy?

$KE = 1.17 \times 10^3 \text{ J} + 3.00 \times 10^3 \text{ J}$
$= 4.17 \times 10^3 \text{ J}$

e. What is its new horizontal velocity?

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(4170 \text{ J})}{15.0 \text{ kg}}} = 23.6 \text{ m/s}$$

12. A 1200–kg car starts from rest and accelerates to 72 km/h in 20.0 s. Friction exerts an average force of 450 N on the car during this time.

a. What is the net work done on the car?

$$W = \Delta KE = \frac{1}{2}mv^2$$
$$= \left(\frac{1}{2}\right)(1200 \text{ kg})(20 \text{ m/s})^2$$
$$= 2.4 \times 10^5 \text{ J}$$

b. How far does the car move during its acceleration?

$$d = \frac{(v_f + v_i)t}{2} = \frac{(20 \text{ m/s} + 0)(20.0 \text{ s})}{2}$$
$$= 2.0 \times 10^2 \text{ m}$$

c. What is the net force exerted on the car during this time?

$W = Fd$

$$F = \frac{W}{d} = \frac{(2.4 \times 10^5 \text{ J})}{(2.0 \times 10^2 \text{ m})}$$
$$= 1.2 \times 10^3 \text{ N}$$

d. What is the forward force exerted on the car as a result of the engine, power train, and wheels pushing backward on the road?

$$F_{net} = F_{forward} - F_{friction}$$
$$F_{forward} = F_{net} + F_{friction}$$
$$= (1.2 \times 10^3 \text{ N}) + (450 \text{ N})$$
$$= 1.7 \times 10^3 \text{ N}$$

Supplemental Problems

13. In an electronics factory, small cabinets slide down a 30.0° incline a distance of 16.0 m to reach the next assembly stage. The cabinets have a mass of 10.0 kg each.

a. Calculate the speed each cabinet would acquire if the incline were frictionless.

$$d_v = d \sin \theta = (16.0 \text{ m})(\sin 30.0)$$
$$= 8.00 \text{ m}$$

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

$$v = \sqrt{2gh} = \sqrt{(2)(9.80 \text{ m/s}^2)(8.00 \text{ m})}$$
$$= 12.5 \text{ m/s}$$

b. What kinetic energy would a cabinet have under such circumstances?

$$KE = \frac{1}{2}mv^2 = \left(\frac{1}{2}\right)(10.0 \text{ kg})(12.5 \text{ m/s})^2$$
$$= 781 \text{ J}$$

14. An average force of 8.2 N is used to pull a 0.40–kg rock, stretching a sling shot 43 cm. The rock is shot downward from a bridge 18 m above a stream. What will be the velocity of the rock just before it enters the water?

Initial energy: $W + PE$
$= (8.2 \text{ N})(0.43 \text{ m}) + (0.40 \text{ kg})(9.80 \text{ m/s}^2)(18 \text{ m})$
$= 3.5 \text{ J} + 70.6 \text{ J}$
$= 74.1 \text{ J}$

Energy at water is kinetic energy:

$$KE = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2(74.1 \text{ J})}{0.40 \text{ kg}}} = 19 \text{ m/s}$$

15. A 15–g bullet is fired horizontally into a 3.000–kg block of wood suspended by a long cord. The bullet sticks in the block. Compute the velocity of the bullet if the impact causes the block to swing 10 cm above its initial level.

Consider first the collision of block and bullet. During the collision, momentum is conserved, so momentum just before = momentum just after

$$(0.015 \text{ kg})v_i + 0 = (3.015 \text{ kg})v_f$$

where v_i is the initial speed of the bullet and v_f is the speed of block and bullet after collision.

We have two unknowns in this equation. To find another equation, we can use the fact that the block swings 10 cm high. Therefore, choosing gravitational potential energy = 0 at the initial level of the block,

KE just after collision = final *GPE*

$$\frac{1}{2}(3.015\text{kg})v_f^2 = (3.015\text{ kg})(9.80\text{ m/s}^2)(0.10\text{ m})$$

$$v_f = 1.40\text{ m/s}$$

$$v_i = \frac{(3.015\text{ kg})(1.40\text{ m/s})}{(0.015\text{ kg})}$$

$$= 2.8 \times 10^2\text{ m/s}$$