# Supplemental Problems

## ANSWER KEY

# Chapter 1

1. Express the following quantities in scientific notation.
   - **a.** 4501 m

     **$4.501 \times 10^3$ m**
   - **b.** 75,000 km

     **$7.5 \times 10^4$ km**
   - **c.** 6438 g

     **$6.438 \times 10^3$ g**
   - **d.** 0.6438 g

     **$6.438 \times 10^{-1}$ g**
   - **e.** 0.00048 s

     **$4.8 \times 10^{-4}$ s**
   - **f.** 24 h

     **$2.4 \times 10^1$ h**

2. Convert each of the following quantities as indicated.
   - **a.** 3600 cm to meters

     $= (3600 \text{ cm}) \times \left(\frac{1 \text{ m}}{100 \text{ cm}}\right)$

     $= 36$ m
   - **b.** 5000 m to kilometers

     $= (5000 \text{ m}) \times \left(\frac{1 \text{ km}}{1000 \text{ m}}\right)$

     $= 5$ km
   - **c.** 5000 km to meters

     $= (5000 \text{ km}) \times \left(\frac{1000 \text{ m}}{1 \text{ km}}\right)$

     $= 5{,}000{,}000$ m
   - **d.** 15 kg to grams

     $= (15 \text{ kg}) \times \left(\frac{1000 \text{ g}}{1 \text{ kg}}\right)$

     $= 15{,}000$ g
   - **e.** 1.5 mg to grams

     $= (1.5 \text{ mg}) \times \left(\frac{1 \text{ g}}{1000 \text{ mg}}\right)$

     $= 0.0015$ g

     $= 1.5 \times 10^{-3}$ g

3. Write the conversion factor for each of the following conversions.
   - **a.** mL to liters

     $\frac{1 \text{ L}}{1000 \text{ mL}}$
   - **b.** kg to grams

     $\frac{1000 \text{ g}}{1 \text{ kg}}$
   - **c.** nm to meters

     $\frac{1 \text{ m}}{1{,}000{,}000{,}000 \text{ nm}}$
   - **d.** $\mu$g to grams

     $\frac{1 \text{ g}}{1{,}000{,}000\ \mu\text{g}}$
   - **e.** km/$s^2$ to m/$s^2$

     $\frac{1000 \text{ m}}{1 \text{ km}}$

4. Calculate each of the following and express the results in scientific notation with the correct number of significant digits and correct units.
   - **a.** 4.098 m + 56.03 m + 10.2 m

     **4.098 m + 56.03 m + 10.2 m**

     **$= 7.03 \times 10^1$ m or 70.3 m**
   - **b.** $\frac{603 \text{ km}}{1000 \text{ s}}$

     $\frac{603 \text{ km}}{1000 \text{ s}}$

     **$= 6.0 \times 10^{-1}$ km/s or 0.6 km/s**
   - **c.** 4.000 m $\times$ 20.3 m

     **$= 8.120 \times 10^2$ m$^2$ or 81.20 m$^2$**
   - **d.** $5.5 \times 10^{-1}$ mm + $2.0 \times 10^{-3}$ mm

     **$5.5 \times 10^{-1}$ mm + $2.0 \times 10^{-3}$ mm**

     **= 0.55 mm + 0.0020 mm**

     **= 0.55 mm or $5.5 \times 10^{-1}$ mm**

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**Chapter 1 continued**

5. On Earth, the force of gravity on an object is expressed as $F = m \times g$, where $F$ is the force applied on the object, $m$ is the mass of the object, and $g$ is the gravitational constant, which is 9.80 m/s$^2$.

   **a.** What are the units of the force of gravity if the mass is expressed in kilograms?

   $\boldsymbol{F = m \times g}$

   $\boldsymbol{F = \text{kg} \times 9.80\ \text{m/s}^2}$

   **Therefore, the units are kg·m/s$^2$**

   **b.** Calculate the gravitational force on an object with a mass of 10.32 kg.

   $\boldsymbol{F = m \times g}$

   $\boldsymbol{= 10.32\ \text{kg} \times 9.80\ \text{m/s}^2}$

   $\boldsymbol{= 101\ \text{kg·m/s}^2}$

6. State the number of significant digits in each of the following measurements and express the value in scientific notation.

   **a.** 903 kg

   **3; $9.03\times10^2$ kg**

   **b.** 600.00 m

   **5; $6.0000\times10^2$ m**

   **c.** 0.0030 mm

   **2; $3.0\times10^{-3}$ mm**

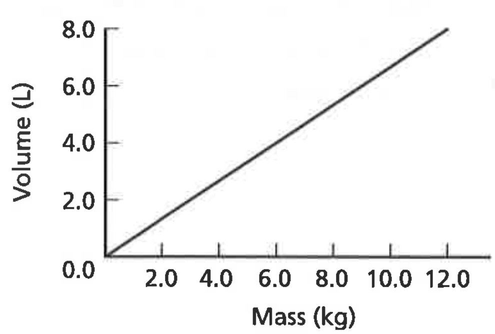
   **d.** $8.030\times10^{-4}$ J

   **4; $8.030\times10^{-4}$ J**

   **e.** $38.60\times10^{-3}$ m/s

   **4; $3.860\times10^{-2}$ m/s**

7. The figure below shows a graph of the mass of a substance compared to its volume.




   **a.** What type of relationship is mass versus volume?

   **linear**

   **b.** What is the volume of 6.0 kg of the substance?

   **4.0 L**

   **c.** What is the mass of each liter of the substance?

   **1.0 kg**

8. The surface of a rectangular table is measured as 2.24 m long and 1.103 m wide.

   **a.** Calculate the perimeter of the tabletop.

   **Perimeter = 2.24 m + 2.24 m + 1.103 m + 1.103 m**

   **= 6.686 m**

   **= 6.69 m**

   **b.** Calculate the area of the tabletop.

   **Area = 2.24 m × 1.103 m**

   **= 2.47 m$^2$**

   **c.** What is the area of the tabletop, expressed in square centimeters?

   $$2.47\ \text{m}^2 \times \left(\frac{100\ \text{cm}}{1\ \text{m}}\right) \times \left(\frac{100\ \text{cm}}{1\ \text{m}}\right) =$$

   **$2.47\times10^4$ cm$^2$**

9. As a pump transfers water into a cylindrical tank, the mass of water in the tank is measured on a balance. **Table 1-1** shows the mass of water in the tank and its depth.

**Table 1-1**

| Depth of Water (cm) | Mass of Water (kg) |
|---|---|
| 10 | 75 |
| 20 | 149 |
| 30 | 225 |
| 40 | 302 |
| 50 | 376 |
| 60 | 453 |

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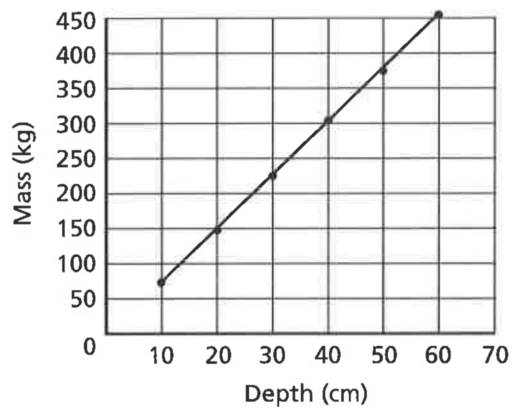
**a.** Plot the values given in the table and draw a graph that best fits all the points.




**b.** Describe the resulting graph.

**It represents a linear relationship.**

**c.** Write an equation relating the depth of water in the tank to the mass of water.

**mass = depth $\times$ 7.5 kg/cm**

**d.** What is the slope of the line in your graph?

**7.5 kg/cm**

**e.** Why is the value for the mass of water measured at 40 cm not exactly twice the value measured at 20 cm?

**There is a slight variation in the data.**

**10.** A student measures the mass of a standard set of calibration weights on a triple-beam balance and an electronic balance, obtaining the data in **Table 1-2.**

**Table 1-2**

| Standard Value | Triple-Beam Balance | Electronic Balance |
|---|---|---|
| 1.000 g | 1.001 g | 1.1033 g |
| 2.000 g | 2.002 g | 2.1033 g |
| 3.000 g | 3.001 g | 3.1034 g |
| 5.000 g | 5.000 g | 5.1033 g |

**a.** Which set of results is more precise? Explain your answer.

**The results on the electronic balance are more precise because they measure the values to more significant digits.**

**b.** Which set of results is more accurate? Explain your answer.

**The results on the triple-beam balance are more accurate because they are closer to the known values of the calibration weights.**

**11.** Add or subtract as indicated. Make sure that your answers contain the correct number of significant digits.

**a.** 0.00039 mm + 0.0025 mm

**0.0029 mm**

**b.** 2103 s − 2.4 s

**2101 s**

**c.** $2.3\times10^{-4}$ kg + $6.7\times10^{-3}$ kg

**$6.9\times10^{-3}$ kg**

**d.** $5.85\times10^{3}$ m − $5.2\times10^{2}$ m

**5330 m**

**12.** Multiply or divide as indicated. Make sure your answers contain the correct number of significant digits.

**a.** (2.21 kg)(100.0 m/s$^2$)

**221 kg·m/s$^2$**

**b.** $\frac{3.3\times10^{-5}\text{ m}}{6.55\times10^{-6}\text{ s}}$

**5.0 m/s**

**c.** $\frac{200.0\text{ cm}^2}{1.23\text{ cm}}$

**163 cm**

**d.** $(7.89\times10^{4}\text{ km})(3\times10^{2}\text{ km})$

**$2\times10^{7}$ km$^2$**

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# Chapter 2

1. An airplane travels at a constant speed, relative to the ground, of 900.0 km/h.

   a. How far has the airplane traveled after 2.0 h in the air?

   $d = vt$

   $= (900.0\ \text{km/h})(2.0\ \text{h})$

   $= 1800\ \text{km}$

   b. How long does it take for the airplane to travel between City A and City B if the cities are 3240 km apart?

   $t = \frac{d}{v}$

   $= \frac{3240\ \text{km}}{900.0\ \text{km/h}}$

   $= 3.600\ \text{h}$

   c. If a second plane leaves 1 h after the first, and travels at 1200 km/h, which flight will arrive at City B first?

   $t = \frac{d}{v}$

   $= \frac{3240\ \text{km}}{1200\ \text{km/h}}$

   $= 2.7\ \text{h}$

   **The second plane arrives 3.7 h after the first plane departs, so the first plane arrives before the second.**

2. You and your friend start jogging around a $2.00\times10^3$-m running track at the same time. Your average running speed is 3.15 m/s, while your friend runs at 3.36 m/s. How long does your friend wait for you at the finish line?

   $t = \frac{d}{v}$

   $t_1 = \frac{2.00\times10^3\ \text{m}}{3.15\ \text{m/s}} = 635\ \text{s (your time)}$

   $t_2 = \frac{2.00\times10^3\ \text{m}}{3.36\ \text{m/s}} = 595\ \text{s (friend's time)}$

   **Your friend's wait time is:**
   **$635\ \text{s} - 595\ \text{s} = 4.0\times10^1\ \text{s}$**

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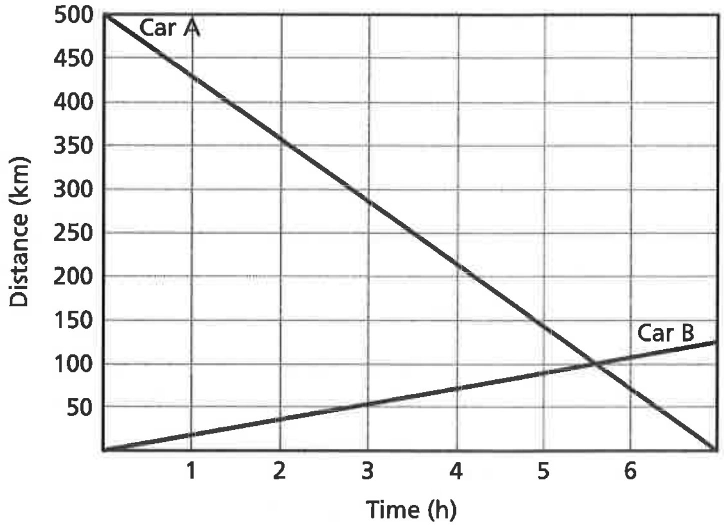
**Chapter 2 continued**

3. The graph to the right shows the distance versus time for two cars traveling on a straight highway.




   a. What can you determine about the relative direction of travel of the cars?

   **The cars are traveling in opposite directions.**

   b. At what time do they pass one another?

   **They pass 5 h after starting.**

   c. Which car is traveling faster? Explain.

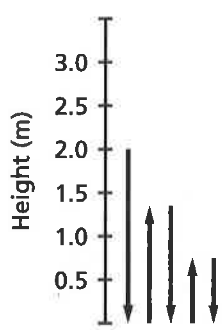
   **Car A is traveling faster because the slope of its line has a larger magnitude. The slope represents $\frac{\Delta d}{\Delta t}$, or speed.**

   d. What is the speed of the slower car?

   **The speed is equal to the slope of the line $\frac{\Delta d}{\Delta t}$, which is calculated from two points on the graph as 20 km/h.**

4. You drop a ball from a height of 2.0 m. It falls to the floor, bounces straight upward 1.3 m, falls to the floor again, and bounces 0.7 m.

   a. Use vector arrows to show the motion of the ball.




   b. At the top of the second bounce, what is the total distance that the ball has traveled?

   $$\begin{aligned} d &= d_1 + d_2 + d_3 + d_4 \\ &= 2.0\text{ m} + 1.3\text{ m} + 1.3\text{ m} + 0.7\text{ m} \\ &= 5.3\text{ m} \end{aligned}$$

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**c.** At the top of the second bounce, what is the ball's displacement from its starting point?

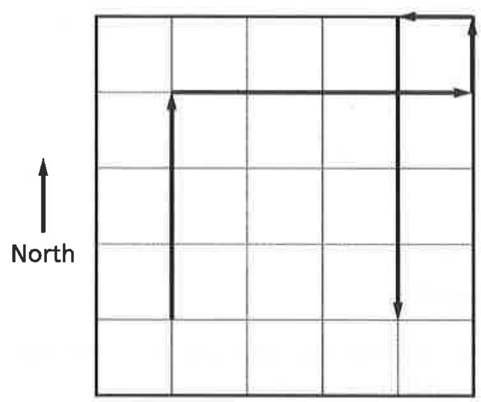
$$\Delta d = d_1 + (-d_2) + d_4 + (-d_4)$$
$$= 2.0\text{ m} - 1.3\text{ m} + 1.3\text{ m} - 0.7\text{ m}$$
$$= 1.3\text{ m downward}$$

**d.** At the top of the second bounce, what is the ball's displacement from the floor?

**0.7 m upward**

**5.** You are making a map of some of your favorite locations in town. The streets run north–south and east–west and the blocks are exactly 200 m long. As you map the locations, you walk three blocks north, four blocks east, one block north, one block west, and four blocks south.

**a.** Draw a diagram to show your route.




**b.** What is the total distance that you traveled while making the map?

$$d_{total} = d_1 + d_2 + d_3 + d_4 + d_5$$
$$= 3\text{ blocks} + 4\text{ blocks} + 1\text{ block} + 1\text{ block} + 4\text{ blocks}$$
$$= 13\text{ blocks}$$

**13 blocks × 200 m/block = 2600 m**

**c.** Use your diagram to determine your final displacement from your starting point.

**3 blocks × 200 m/block = 600 m**

**The displacement is 600 m east from the starting point.**

**d.** What vector will you follow to return to your starting point?

**600 m toward the west.**

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**Chapter 2 continued**

**6.** An antelope can run 90.0 km/h. A cheetah can run 117 km/h for short distances. The cheetah, however, can maintain this speed only for 30.0 s before giving up the chase.

**a.** Can an antelope with a 150.0-m lead outrun a cheetah?

$d = vt$

$t = 30$ s

$v_{antelope} = (90.0 \text{ km/h})\left(\frac{1 \text{ h}}{3600 \text{ s}}\right)\left(\frac{1000 \text{ m}}{1 \text{ km}}\right)$

$= 25.0$ m/s

$v_{cheetah} = (117 \text{ km/h})\left(\frac{1 \text{ h}}{3600 \text{ s}}\right)\left(\frac{1000 \text{ m}}{1 \text{ km}}\right)$

$= 32.5$ m/s

$d_{antelope} = 25.0 \text{ m/s} \times 30.0 \text{ s}$

$= 750$ m

$d_{cheetah} = 32.5 \text{ m/s} \times 30.0 \text{ s}$

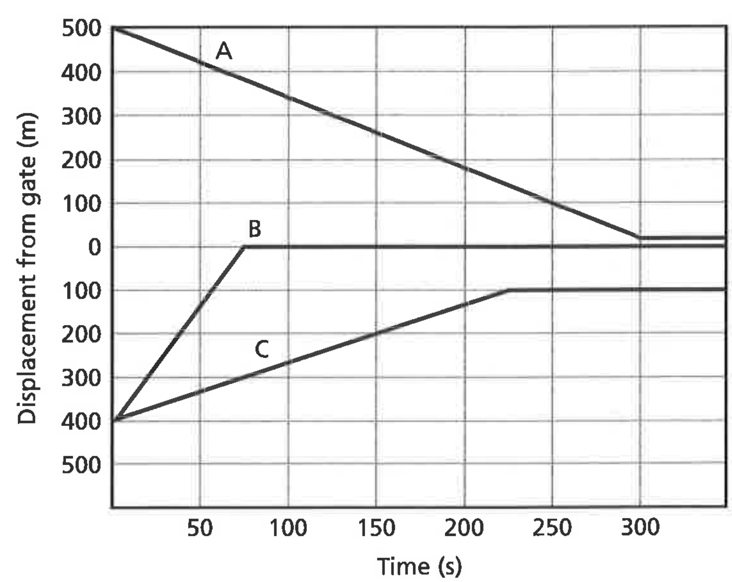
$= 975$ m

**The cheetah can run 225 m farther than the antelope in 30.0 s, so a 150.0-m lead is not sufficient.**

**b.** What is the closest that the antelope can allow a cheetah to approach and remain likely to escape?

**226 m**

**7.** The position-time graph to the right represents the motion of three people in an airport moving toward the same departure gate.




**a.** Which person travels the farthest during the period shown?

**person A**

**b.** Which person travels fastest by riding a motorized cart? How can you tell?

**person B. The magnitude of the slope is largest for line B when the person is traveling.**

**c.** Which person starts closest to the departure gate?

**Person B and person C start 400 m from the gate.**

**d.** Which person appears to be going to the wrong gate?

**person C**

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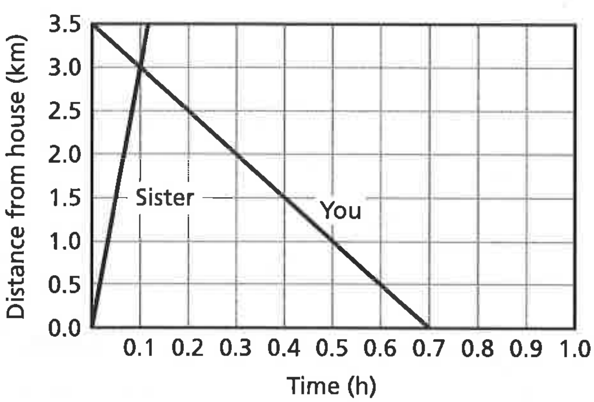
**Chapter 2 continued**

**8.** A radio signal takes 1.28 s to travel from a transmitter on the Moon to the surface of Earth. The radio waves travel at $3.00\times10^8$ m/s. What is the distance, in kilometers, from the Moon to Earth?

$$d = vt$$
$$= (3.00\times10^8 \text{ m/s}) \times 1.28 \text{ s}$$
$$= 3.84\times10^8 \text{ m}$$
$$= (3.84\times10^8 \text{ m}) \times \left(\frac{1 \text{ km}}{1000 \text{ m}}\right)$$
$$= 3.84\times10^5 \text{ km}$$

**9.** You start to walk toward your house eastward at a constant speed of 5.0 km/h. At the same time, your sister leaves your house, driving westward at a constant speed of 30.0 km/h. The total distance from your starting point to the house is 3.5 km.

**a.** Draw a position-time graph that shows both your motion and your sister's motion.




**b.** From the graph, determine how long you travel before you meet your sister.

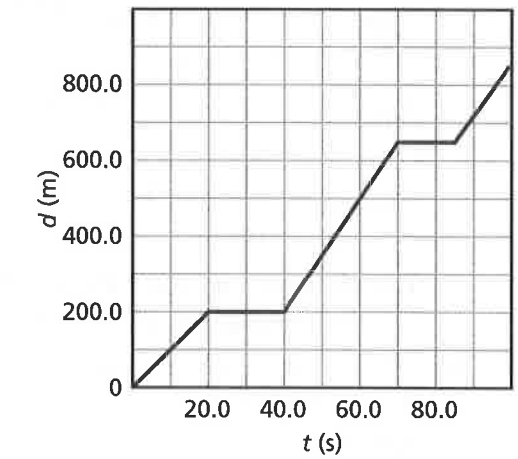
**0.1 h**

**c.** How far do you travel in that time?

**0.5 km**

**10.** A bus travels on a northbound street for 20.0 s at a constant velocity of 10.0 m/s. After stopping for 20.0 s, it travels at a constant velocity of 15.0 m/s for 30.0 s to the next stop, where it remains for 15.0 s. For the next 15.0 s, the bus continues north at 15.0 m/s.

**a.** Construct a *d-t* graph of the motion of the bus.




**b.** What is the total distance traveled?

$$d = v_1t_1 + v_2t_2 + v_3t_3 + v_4t_4 + v_5t_5$$
$$= (10.0 \text{ m/s})(20.0 \text{ s}) + (0.00 \text{ m/s})(20.0 \text{ s}) + (15.0 \text{ m/s})(30.0 \text{ s}) + (0.00 \text{ m/s})(15.0 \text{ s}) + (15.0 \text{ m/s})(15.0 \text{ s})$$
$$= 875 \text{ m}$$

**c.** What is the average velocity of the bus for this period?

$$v_{ave} = \frac{\Delta t}{\Delta d}$$
$$v_{ave} = \frac{875 \text{ m}}{100.0 \text{ s}}$$
$$= 8.75 \text{ m/s}$$

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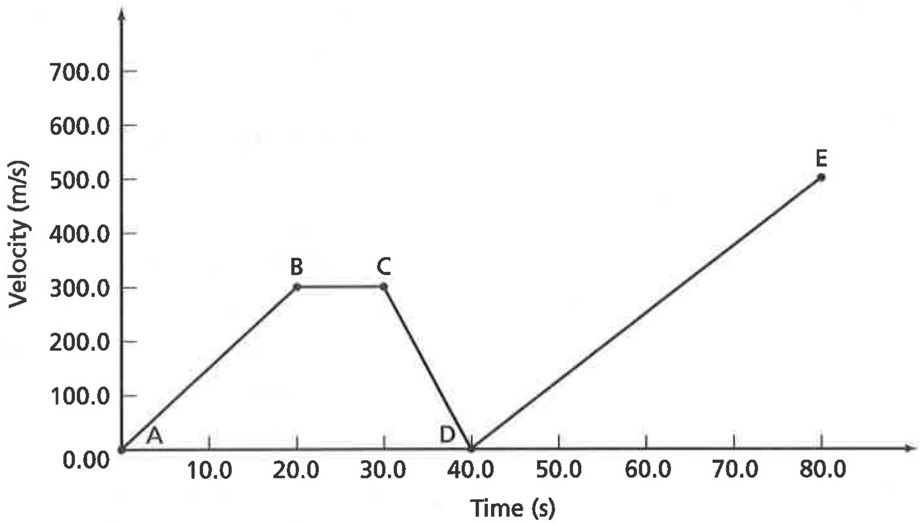
# Chapter 3

1. Use the velocity-time graph below to calculate the velocity of the object whose motion is plotted on the graph.




a. What is the acceleration between the points on the graph labeled A and B?

$$a = \frac{\Delta v}{t} = \frac{(v_f - v_i)}{t}$$

$$= \frac{300.0\ \text{m/s} - 0.0\ \text{m/s}}{20.0\ \text{s}}$$

$$= 15.0\ \text{m/s}^2$$

b. What is the acceleration between the points on the graph labeled B and C?

**$\Delta v = 0$, therefore $a = 0$**
**(no acceleration)**

c. What is the acceleration between the points on the graph labeled D and E?

$$a = \frac{\Delta v}{t} = \frac{(v_f - v_i)}{t}$$

$$= \frac{0.0\ \text{m/s} - 500.0\ \text{m/s}}{40.0\ \text{s}}$$

$$= -125\ \text{m/s}^2$$

d. What is the total distance that the object travels between points B and C?

$$d = vt$$

$$= 300.0\ \text{m/s} \times 10.0\ \text{s}$$

$$= 3.00\times10^3\ \text{m}$$

2. If you throw a ball straight upward, it will rise into the air and then fall back down toward the gound. Imagine that you throw the ball with an initial velocity of 13.7 m/s.

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**a.** How long does it take the ball to reach the top of its motion?

$v_f = v_i + at$

therefore $t_f = \frac{v_f - v_i}{a}$

$t = \frac{13.7 \text{ m/s} - 0.00 \text{ m/s}}{9.80 \text{ m/s}^2}$

$= 1.40 \text{ s}$

**b.** How far will the ball rise before it begins to fall?

$d = \frac{1}{2}(v_f + v_i)t$

$= \frac{1}{2}(13.7 \text{ m/s} + 0.00 \text{ m/s})(1.40 \text{ s})$

$= 9.59 \text{ m}$

**c.** What is its average velocity during this period?

$v_{ave} = \frac{d_f - d_i}{t}$

$= \frac{9.59 \text{ m} - 0.00 \text{ m}}{1.40 \text{ s}}$

$= 6.85 \text{ m/s}$

**3.** A car is traveling at 20 m/s when the driver sees a ball roll into the street. From the time the driver applies the brakes, it takes 2 s for the car to come to a stop.

**a.** What is the average acceleration of the car during that period?

$a = \frac{\Delta v}{t} = \frac{v_f - v_i}{t}$

$= \frac{0 \text{ m/s} - 20 \text{ m/s}}{2 \text{ s}}$

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

**b.** How far does the car travel while the brakes are being applied?

$d = d_i + v_i t + \frac{1}{2}at^2$

$= 0 \text{ m} + (20 \text{ m/s})(2 \text{ s}) + \frac{1}{2}(-10 \text{ m/s}^2)(2 \text{ s})^2$

$= 0 \text{ m} + 40 \text{ m} + (-20 \text{ m/s})$

$= 20 \text{ m}$

**4.** A hot air balloon is rising at a constant speed of 1.00 m/s. The pilot accidentally drops his pen 10.0 s into the flight.

**a.** How far does the pen drop?

**The pen falls from the altitude of the balloon at 10 s.**

$d = vt$

$= (1.00 \text{ m/s})(10.0 \text{ s})$

$= 10.0 \text{ m}$

**b.** How fast is the pen traveling when it hits the ground, ignoring air resistance?

$v_f^2 = v_i^2 + 2a(d_f - d_i)$

$= 0 + 2(9.80 \text{ m/s}^2)(10.0 \text{ m} - 0.00 \text{ m})$

$= 196 \text{ m}^2/\text{s}^2$

$v = 14.0 \text{ m/s}$

**5.** A sudden gust of wind increases the velocity of a sailboat relative to the water surface from 3.0 m/s to 5.5 m/s over a period of 30.0 s.

**a.** What is the average acceleration of the sailboat?

$a = \frac{\Delta v}{t}$

$= \frac{(v_f - v_i)}{t}$

$= \frac{5.5 \text{ m/s} - 3.0 \text{ m/s}}{30.0 \text{ s}}$

$= 0.083 \text{ m/s}^2$

**b.** How far does the sailboat travel during the period of acceleration?

$d_f = d_i + v_i t + \frac{1}{2}at^2$

$= 0.0 \text{ m} + \frac{3.0 \text{ m/s}}{30.0 \text{ s}} + \frac{1}{2}(0.083 \text{ m/s}^2)$

$(30.0 \text{ s})^2$

$= 130 \text{ m}$

**6.** During a serve, a tennis ball leaves a racket at 180 km/h after being accelerated for 80.0 ms.

**a.** What is the average acceleration on the ball during the serve in m/s²?

$v_f = (180 \text{ km/h})\left(\frac{1000 \text{ m}}{1 \text{ km}}\right)\left(\frac{1 \text{ h}}{3600 \text{ s}}\right)$

$= 5.0\times10^1 \text{ m/s}$

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**Chapter 3 continued**

$$a = \frac{\Delta v}{t} = \frac{v_f - v_i}{t}$$
$$= \frac{5.0\times10^{1}\ \text{m/s} - 0.0\ \text{m/s}}{8.0\times10^{-2}\ \text{s}}$$
$$= 630\ \text{m/s}^2$$

**b.** How far does the ball move during the period of acceleration?

$$d_f = d_i + v_i t + \frac{1}{2}at^2$$
$$= 0.0\ \text{m} + (0.0\ \text{m/s})(0.080\ \text{s}) + \frac{1}{2}(630\ \text{m/s}^2)(0.0800\ \text{s})^2$$
$$= 2.0\ \text{m}$$

8

**7.** Anna walks off the end of a 10.0-m diving platform.

**a.** What is her acceleration in $\text{m/s}^2$ toward the pool?

**Her acceleration due to gravity is 9.80 m/s$^2$.**

**b.** How long does it take her to reach the water?

$$d_f = d_i + v_i t + \frac{1}{2}at^2,\ v_i \text{ and } d_i = 0$$

**Solve for $t$:**

$$t = \sqrt{\frac{2d}{a}}$$
$$= \sqrt{\frac{2 \times 10.0\ \text{m}}{9.80\ \text{m/s}^2}}$$
$$= 1.43\ \text{s}$$

**c.** What is her velocity when she reaches the water?

$$v_f = v_i + at$$
$$= 0.0\ \text{m/s} + (9.80\ \text{m/s}^2)(1.43\ \text{s})$$
$$= 14.0\ \text{m/s}$$

9

**8.** A rocket used to lift a satellite into orbit undergoes a constant acceleration of 6.25 m/s$^2$. When the rocket reaches an altitude of 45 km above the surface of Earth, it is traveling at a velocity of 625 m/s. How long does it take for the rocket to reach this speed?

**Solve $d_f = d_i + v_i t + \frac{1}{2}at^2$ for $t$ (let $v_i$ and $d_i = 0$)**

$$t = \sqrt{\frac{2d}{a}}$$
$$= \sqrt{\frac{(2 \times 45\ \text{km})\left(\frac{1000\ \text{m}}{1\ \text{km}}\right)}{6.25\ \text{m/s}^2}}$$
$$= 120\ \text{s}$$

7

**9.** The table below shows the velocity of a student walking down the hallway between classes.

| Time (s) | Velocity (m/s) |
|---|---|
| 0.0 | 0.0 |
| 10.0 | 1.5 |
| 20.0 | 1.5 |
| 30.0 | 1.5 |
| 31.0 | 0.0 |
| 40.0 | 0.0 |
| 50.0 | 3.0 |
| 60.0 | 3.0 |
| 61.0 | 0.0 |

**a.** What is happening to the student's speed during $t = 60.0$ s and $t = 61.0$ s?

**He is slowing down.**

**b.** What is his acceleration between $t = 10$ s and $t = 20$ s?

$$a = \frac{\Delta v}{t}$$
$$= \frac{v_f - v_i}{t_f - t_i}$$
$$= \frac{1.5\ \text{m/s} - 1.5\ \text{m/s}}{200\ \text{s} - 100\ \text{s}}$$
$$= 0.0\ \text{m/s}$$

**c.** What is his acceleration between $t = 60.0$ s and $t = 61.0$ s?

$$a = \frac{\Delta v}{t}$$
$$= \frac{v_f - v_i}{t_f - t_i}$$
$$= \frac{0.0\ \text{m/s} - 3.0\ \text{m/s}}{61.0\ \text{s} - 60.3\ \text{s}}$$
$$= 3.0\ \text{m/s}$$

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**d.** Assuming constant acceleration, how far did he walk during the first 5 s?

$$a = \frac{\Delta v}{t}$$

$$= \frac{v_f - v_i}{t_f - t_i}$$

$$= \frac{1.5\ \text{m/s} - 0.0\ \text{m/s}}{10.0\ \text{s} - 0.0\ \text{s}}$$

$$= 0.15\ \text{m/s}^2$$

$$d = d_i + v_i t + \frac{1}{2}at^2$$

$$= 0.0\ \text{m} + (0.0\ \text{m/s})(5.0\ \text{s}) + \frac{1}{2}(0.15\ \text{m/s}^2)(5.0\ \text{s})^2$$

$$= 1.9\ \text{m}$$

**10.** On the surface of Mars, the acceleration due to gravity is 0.379 times as much as that on the surface of Earth. A robot on Mars pushes a rock over a 500.0-m cliff.

**a.** How long does it take the rock to reach the ground below the cliff?

$$a = 9.80\ \text{m/s}^2 \times 0.379$$

$$= 3.71\ \text{m/s}^2$$

**Solve for** $d_f = d_i + v_i t + \frac{1}{2}at^2$

**for** $t$ **(let** $v_i$ **and** $d_i = 0$**)**

$$t = \sqrt{\frac{2d}{a}}$$

$$= \sqrt{\frac{2(500.0\ \text{m})}{3.71\ \text{m/s}^2}}$$

$$= 16.4\ \text{s}$$

**b.** How fast is the rock traveling when it reaches the surface?

$$v_f = v_i + at$$

$$= 0.0\ \text{m/s} + (3.71\ \text{m/s}^2)(16.4\ \text{s})$$

$$= 60.8\ \text{m/s}$$

**c.** How long would it take the rock to fall the same distance on the surface of Earth?

$$t = \sqrt{\frac{2d}{a}}$$

$$= \sqrt{\frac{2(500.0\ \text{m})}{9.80\ \text{m/s}^2}}$$

$$= 10.1\ \text{s}$$

**11.** A sky diver jumps from an airplane 1000.0 m above the ground. He waits for 8.0 s and then opens his parachute. How far above the ground is the sky diver when he opens his parachute?

$$d_f = d_i + v_i t_f + \frac{1}{2}at^2$$

$$d_f - d_i = v_i t_f + \frac{1}{2}at^2$$

$$v_i = 0$$

$\Delta d = at^2$ **where** $a = -g$

$$\Delta d = \frac{1}{2}gt^2$$

$$= -\frac{1}{2}(9.80\ \text{m/s}^2)(8.0\ \text{s})^2$$

$$= -310\ \text{m}$$

**1000.0 m + (−310 m) = 690 m above the ground**

**12.** A speeding car is traveling at 92.0 km/h toward a police car at rest, facing the same direction as the speeding car. If the police car begins accelerating when the speeding car is 250.0 m behind the police car, what must the police car's acceleration be in order for the police car to reach the speeding car's velocity at the moment the speeding car catches up? Assume that the speeding car does not slow down.

$$\bar{a}_{police} = \frac{\Delta v_{police}}{\Delta t}$$

$$\Delta t = \frac{\Delta d}{\bar{v}_{speeder}}$$

$$\bar{a}_{police} = \Delta v_{police}\left(\frac{\bar{v}_{speeder}}{d}\right)$$

$$\frac{\Delta v_{police}}{\left(\frac{\Delta d}{\bar{v}_{speeder}}\right)} = \frac{v_{f,\ police} - v_{i,\ police}}{\frac{\Delta d}{\bar{v}_{speeder}}}$$

$$= \frac{(25.6\ \text{m/s} - 0.0\ \text{m/s})}{\left(\frac{250.0\ \text{m}}{25.6\ \text{m/s}}\right)}$$

$$= 2.62\ \text{m/s}^2$$

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# Chapter 4

1. You and your bike have a combined mass of 80 kg. How much braking force has to be applied to slow you from a velocity of 5 m/s to a complete stop in 2 s?

$$a = \frac{v_f - v_i}{t_f - t_i} = \frac{0.0\text{ m/s} - 5.0\text{ m/s}}{2.0\text{ s} - 0.0\text{ s}}$$
$$= 2.5\text{ m/s}^2$$
$$F = ma$$
$$= 80\text{ kg} \times (-2.5\text{ m/s}^2)$$
$$= -200\text{ N}$$

2. Before opening his parachute, a sky diver with a mass of 90.0 kg experiences an upward force from air resistance of 150 N.
   a. What net force is acting on the sky diver?

$$F_{gravity} = mg$$
$$= 90.0\text{ kg} \times 9.80\text{ m/s}^2$$
$$= 882\text{ N downward}$$

$$F_{net} = F_{air\ resistance} + F_{gravity}$$
$$F_{net} = 150\text{ N} + (-882\text{ N})$$
$$= -732\text{ N}$$
$$= 730\text{ N downward}$$

   b. What is the sky diver's acceleration?

$$a = \frac{F_{net}}{m}$$
$$= \frac{-730\text{ N}}{90.0\text{ kg}}$$
$$= -8.1\text{ m/s}^2$$
$$= 8.1\text{ m/s}^2\text{ downward}$$

3. A large helicopter is used to lift a heat pump to the roof of a new building. The mass of the helicopter is $5.0\times10^3$ kg and the mass of the heat pump is 1500 kg.
   a. How much force must the air exert on the helicopter to lift the heat pump with an acceleration of 1.5 m/s²?

$$F_{net} = F_{lift} + F_{overcome\ gravity}$$
$$= ma + mg$$
$$= (6.5\times10^3\text{ kg})(1.5\text{ m/s}^2) + (6.5\times10^3\text{ kg})(9.80\text{ m/s}^2)$$
$$= 7.3\times10^4\text{ N upward}$$

   b. Two chains connected to the load each can withstand a tension of 15,000 N. Can the load be safely lifted at 1.5 m/s²?

$$F_{load} = F_{lift} + F_{overcome\ gravity}$$
$$= ma + mg$$
$$= (1.5\times10^3\text{ kg})(1.5\text{ m/s}^2) + (1.5\times10^3\text{ kg})(9.80\text{ m/s}^2)$$
$$= 2.25\times10^3\text{ N} + 1.47\times10^4\text{ N}$$
$$= 1.7\times10^4\text{ N}$$

**The load can be safely lifted because the total force on the chains is less than their combined capability of $3.0\times10^4$ N**

4. In a lab experiment, you attach a 2.0-kg weight to a spring scale. You lift the scale and weight with a constant reading of 22.5 N.
   a. What is the value and direction of the acceleration on the weight?

$$F_{net} = F_{scale} - F_{gravity}$$
$$= 22.5\text{ N} - (2.0\text{ kg})(9.80\text{ m/s}^2)$$
$$= 2.9\text{ N upward}$$

$$a = \frac{m}{F_{net}}$$
$$= \frac{2.0\text{ kg}}{2.9\text{ N}}$$
$$= 0.69\text{ m/s}^2$$
$$= 6.9\times10^{-1}\text{ m/s}^2$$

   b. How far do you lift the weight in the first 2.0-s interval?

$$d_f = d_i + v_i t + \frac{1}{2}at^2$$
$$= 0\text{ m} + (0\text{ m/s})(2.0\text{ s}) + \frac{1}{2}(6.9\times10^{-1}\text{ m/s}^2)(2.0\text{ s})^2$$
$$= 1.4\text{ m}$$

5. As a large jet flies at a constant altitude, its engines produce a forward thrust of $8.4\times10^5$ N. The mass of the plane is $2.6\times10^5$ kg.

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**a.** What is the forward acceleration of the plane, ignoring air resistance?

$$F = ma$$

$$a = \frac{F}{m}$$

$$= \frac{8.4\times10^5\ \text{N}}{2.6\times10^5\ \text{kg}}$$

$$= 3.2\ \text{m/s}^2$$

**b.** How much upward force must the air exert on the plane when it is flying horizontally?

**Because the plane is not changing altitude,**

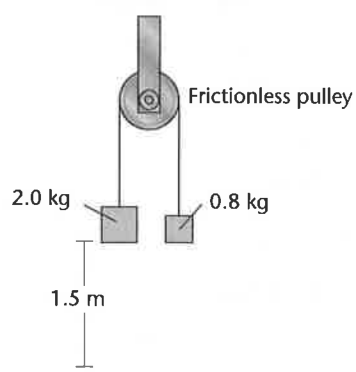
$$F_{net} = 0,\ \text{so}\ F_{lift} = -F_{gravity}$$

$$F_{lift} = -F_{gravity}$$

$$= -(2.6\times10^5\ \text{kg})(-9.80\ \text{m/s}^2)$$

$$= 2.5\times10^6\ \text{N}$$

**6.** Two masses are tied to a rope on a pulley, as shown below.




**a.** When the system is released from this position, what is the acceleration of the 2.00-kg mass?

$$F_{net} = F_{g\text{-large}} - F_{g\text{-small}} + m_{large}g - m_{small}g$$

$$= (2.00\ \text{kg})(9.80\ \text{m/s}^2) - (0.80\ \text{kg})(9.80\ \text{m/s}^2)$$

$$= 11.8\ \text{N downward}$$

$$a = \frac{F}{m}$$

$$= \frac{11.8\ \text{N}}{2.8\ \text{kg}}$$

$$= 4.2\ \text{m/s}^2\ \text{downward}$$

**b.** How long does it take for the 2.0-kg mass to fall to the floor?

**Solve** $d_f = d_i + v_i t + \frac{1}{2}at^2$ **for** $t$ **while** $d_i = 0$ **m,** $v_i = 0$ **m/s**

$$t = \sqrt{\frac{2d}{a}}$$

$$= \sqrt{\frac{(2)(1.5\ \text{m})}{4.2\ \text{m/s}^2}}$$

$$= 0.85\ \text{s}$$

**7.** A man is standing on a scale inside an airplane. When the airplane is traveling horizontally (in other words, the vertical acceleration of the plane is zero) the scale reads 705.6 N. What is the vertical acceleration of the plane in each of the following situations?

**a.** When the scale reads 950.0 N.

$$F_g = mg$$

$$m = \frac{F_g}{g}$$

$$F_{net} = ma$$

$$F_{net} = F_{scale} + (-F_g)$$

$$ma = F_{scale} - F_g$$

$$a = \frac{F_{scale} - F_g}{m}$$

$$= \frac{F_{scale} - F_g}{\left(\frac{F_g}{g}\right)}$$

$$= \frac{g(F_{scale} - F_g)}{F_g}$$

$$= \frac{(9.80\ \text{m/s}^2)(950.0\ \text{N} - 705.6\ \text{N})}{705.6\ \text{N}}$$

$$= 3.39\ \text{m/s}^2$$

**b.** When the scale reads 500.0 N.

$$F_g = mg$$

$$m = \frac{F_g}{g}$$

$$F_{net} = ma$$

$$F_{net} = F_{scale} + (-F_g)$$

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$$ma = F_{scale} - F_g$$

$$a = \frac{F_{scale} - F_g}{m}$$

$$= \frac{F_{scale} - F_g}{\left(\frac{F_g}{g}\right)}$$

$$= \frac{g(F_{scale} - F_g)}{F_g}$$

$$= \frac{(9.80\ \text{m/s}^2)(500.0\ \text{N} - 705.6\ \text{N})}{705.6\ \text{N}}$$

$$= -2.86\ \text{m/s}^2$$

**8.** An airboat glides across the surface of the water on a cushion of air. Perform the following calculations for a boat in which the mass of the boat and passengers is 450 kg.

**a.** If there is no friction, how much force must the propeller fan exert on the air to accelerate the boat at 5.00 $m/s^2$?

$$F = ma$$

$$= (450\ \text{kg})(5.00\ \text{m/s}^2)$$

$$= 2.2\times10^3\ \text{N}$$

**b.** If the actual acceleration with the fan generating the force calculated in part **a** is only 4.95 $m/s^2$, how much friction does the air cushion exert on the boat?

$$a_{friction} = a_{ideal} - a_{actual}$$

$$F_{friction} = ma_{friction}$$

$$m(a_{ideal} - a_{actual})(450\ \text{kg})$$

$$= (5.00\ \text{m/s}^2 - 4.95\ \text{m/s}^2)$$

$$= 22\ \text{N}$$

**c.** What is the upward force exerted by the air cushion on the boat?

$$F_{lift} = -F_{gravity} = -mg$$

$$= -(450\ \text{kg})(-9.80\ \text{m/s}^2)$$

$$= 4.4\times10^3\ \text{N}$$

**9.** A golf ball with a mass of 45 g is struck by a club, leaving the tee with a speed of $1.8\times10^2$ km/h. The period of acceleration was 0.50 m/s.

**a.** What is the average acceleration on the ball as it was struck (in $m/s^2$)?

$$a = \frac{v_f - v_i}{t}, \text{ where } v_i = 0\ \text{km/h}$$

$$a = \frac{(1.8\times10^2\ \text{km/h})\left(\frac{1000\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)}{(0.50\ \text{ms})\left(\frac{1\ \text{s}}{1000\ \text{ms}}\right)}$$

$$= \frac{50\ \text{m/s}}{5.0\times10^{-4}\ \text{s}}$$

$$= 1.0\times10^5\ \text{m/s}^2$$

**b.** What is the force exerted on the club?

$$F = ma$$

$$= (45\ \text{g})\left(\frac{1\ \text{kg}}{1000\ \text{g}}\right) \times (1.0\times10^5\ \text{m/s}^2)$$

$$= 4.5\times10^3\ \text{N}$$

**c.** What is the force exerted on the club by the ball?

$$F_{ball} = -F_{club}$$

$$= -4.5\times10^3\ \text{N}$$

**10.** A package of instruments is attached to a helium-filled weather balloon that exerts an upward force of 45 N.

**a.** If the instrument package weighs 10.0 kg, will the balloon be able to lift it?

$$F_{lift} = ma$$

$$a = \frac{F_{lift}}{m}$$

$$= \frac{45\ \text{N}}{10.0\ \text{kg}}$$

$$= 4.5\ \text{m/s}^2$$

**The balloon cannot lift the package because the upward acceleration is less than the downward acceleration of gravity, 9.80 $m/s^2$.**

**Alternative calculation:**

$$F_{gravity} = (10.0\ \text{kg})(9.80\ \text{m/s}^2)$$

$$= 98.0\ \text{N, which exceeds the upward force}$$

**b.** What is the upward acceleration if the instruments weigh 2.0 kg?

$$F_{net} = F_{lift} - F_{gravity}$$

$$F_{net} = ma - mg$$

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$$= 45\ \text{N} - (2.0\ \text{kg})(9.80\ \text{m/s}^2)$$
$$= 25.4\ \text{N}$$

$$a = \frac{F_{net}}{m}$$
$$= \frac{25.4\ \text{N}}{2.0\ \text{kg}}$$
$$= 13\ \text{m/s}^2 \text{ upward}$$

**11.** A 12-kg block sits on a table. A 10.0-kg block sits on top of the 12-kg block. If there is nothing on top of the 10.0-kg block, what is the force that the table exerts on the 12-kg block?

$$F_{table} = F_{block\ 1} + F_{block\ 2}$$
$$= (12\ \text{kg})(9.80\ \text{m/s}^2) + (10.0\ \text{kg})(9.80\ \text{m/s}^2)$$
$$= 220\ \text{N}$$

**12.** A box experiences a net force of 41 N while it is being lifted. What is the acceleration of the box?

$$F_{net} = ma$$
$$a = \frac{F_{net}}{m}$$
$$= \frac{41\ \text{N}}{9.7\ \text{kg}}$$
$$= 4.2\ \text{m/s}^2$$

**13.** A rope can withstand $1.000\times10^3$ N of tension. If the rope is being used to pull a 10.0-kg package across a frictionless surface, what is the greatest acceleration that will not break the rope?

$$F = ma$$
$$a = \frac{F}{m}$$
$$= \frac{1.000\times10^3\ \text{N}}{10.0\ \text{kg}}$$
$$= 1.00\times10^2\ \text{m/s}^2$$

**14.** A 0.100-kg weight is attached to a spring scale. Find the reading on the scale for each of the following situations.

**a.** When the scale is not moving.

$$F_g = mg$$
$$= (0.100\ \text{kg})(9.80\ \text{m/s}^2)$$
$$= 0.980\ \text{N}$$

**b.** When the scale accelerates at 2.4 m/s$^2$ in the horizontal direction.

**The vertical component of the acceleration is zero, so the reading on the scale is calculated the same way as when the scale is not moving.**

$$F_g = mg$$
$$= (0.100\ \text{kg})(9.80\ \text{m/s}^2)$$
$$= 0.980\ \text{N}$$

**15.** A penny is dropped from the top of a 30.0-m-tall tower. The tower, however, is not located on Earth. The penny has a mass of 2.5 g and experiences a gravitational force of 0.028 N.

**a.** What is acceleration due to gravity on this planet?

$$a_g = \frac{F_g}{m}$$
$$= \frac{0.028\ \text{N}}{0.0025\ \text{kg}}$$
$$= 11\ \text{m/s}^2$$

**b.** After 1.00 s, the penny has a velocity of 10.1 m/s. Assuming the force exerted on the penny by air resistance is uniform and independent of speed, what is the magnitude of the force of air resistance on the penny?

$$F_{net} = m\bar{a}$$
$$= F_g + (-F_a)$$
$$F_a = F_g - ma, \text{ where } a = \bar{a} = \frac{\Delta v}{\Delta t}$$
$$= F_g - m\left(\frac{\Delta v}{\Delta t}\right)$$

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**Chapter 4 continued**

$$= F_g - m\left(\frac{v_f - v_i}{\Delta t}\right)$$

$$= 0.028\ \text{N} - (0.0025\ \text{kg})\left(\frac{10.1\ \text{m/s} - 0.0\ \text{m/s}}{1.00\ \text{s}}\right)$$

$$= 0.0028\ \text{N}$$

**The air resistance is in the opposite direction from the force of gravity and the penny's motion, as it should be.**

**16.** The combined mass of a sled and its rider is 46.4 kg. The sled is pulled across a frozen lake so that the force of friction between the sled and the ice is very small.

**a.** Assuming that friction between the sled and the ice is negligible, what force is required to accelerate the sled at 3.45 m/s$^2$?

$$F = ma$$
$$= (46.4\ \text{kg})(3.45\ \text{m/s}^2)$$
$$= 1.60\times10^2\ \text{N}$$

**b.** A force of 150.0 N is applied to the sled and produces an acceleration of 3.00 m/s$^2$. What is the magnitude of the force of friction that resists the acceleration?

$$F_{net} = ma$$
$$F_{net} = F_{applied} - F_f$$
$$ma = F_{applied} - F_f$$
$$F_f = F_{applied} - ma$$
$$= 150.0\ \text{N} - (46.4\ \text{kg})(3.00\ \text{ms}^2)$$
$$= 10.8\ \text{N}$$

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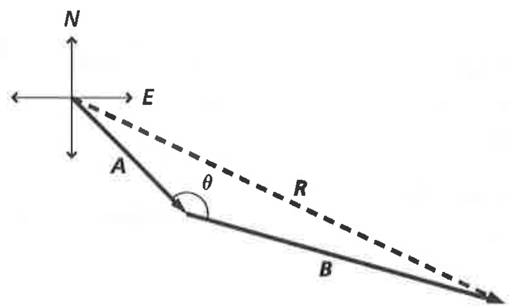
# Chapter 5

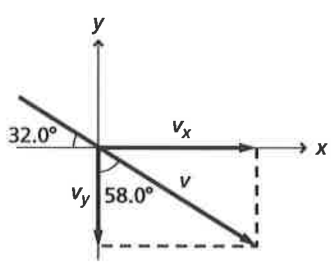
1. A small plane takes off and flies 12.0 km in a direction southeast of the airport. At this point, following the instructions of an air traffic controller, the plane turns 20.0° to the east of its original flight path and flies 21.0 km. What is the magnitude of the plane's resultant displacement from the airport?




$$R^2 = A^2 + B^2 - 2AB\cos\theta$$

$$R = \sqrt{(12.0\text{ km})^2 + (21.0\text{ km})^2 - 2(12.0\text{ km})(21.0\text{ km})(\cos 160.0°)}$$
$$= 32.5\text{ km}$$

2. A hammer slides down a roof that makes a 32.0° angle with the horizontal. What are the magnitudes of the components of the hammer's velocity at the edge of the roof if it is moving at a speed of 6.25 m/s?




**Fourth quadrant: $v_x > 0$ and $v_y < 0$.**

$v_x = v\cos\theta$
$= (6.25\text{ m/s})(\cos -32.0°)$
$= 5.30\text{ m/s}$

$v_y = v\sin\theta$
$= (6.25\text{ m/s})(\sin -32.0°)$
$= -3.31\text{ m/s}$

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**Chapter 5 continued**

**3.** A worker has to move a 17.0-kg crate along a flat floor in a warehouse. The coefficient of kinetic friction between the crate and the floor is 0.214. The worker pulls horizontally on a rope attached to the crate, with a 49.0-N force. What is the resultant acceleration of the crate?

***y*-direction:**

$F_N = F_g = mg$

***x*-direction:**

$$F_{net,\,x} = F_p - F_f = ma_x = ma$$

$$F_f = \mu_k F_N = \mu_k mg$$

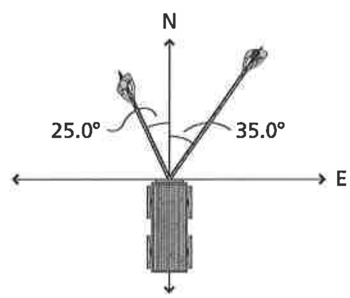
$$ma = F_p - \mu_k mg$$

$$a = \frac{F_p - \mu_k mg}{m}$$

$$= \frac{49.0\text{ N} - (0.214)(17.0\text{ kg})(9.80\text{ m/s}^2)}{17.0\text{ kg}}$$

$$= 0.785\text{ m/s}^2$$

**4.** To get a cart to move, two farmers pull on ropes attached to the cart, as shown below. One farmer pulls with a force of 50.0 N in a direction 35.0° east of north, while the other exerts a force of 30.0 N in a direction 25.0° west of north. What are the magnitude and the direction of the combined force exerted on the cart?




$$R_x = A_x + B_x = A\cos\theta_1 + B\cos\theta_2$$

$$R_y = A_y + B_y = A\sin\theta_1 + B\sin\theta_2$$

$$R = \sqrt{R_x^2 + R_y^2}$$

$$= \sqrt{(A\cos\theta_1 + B\cos\theta_2)^2 + (A\sin\theta_1 + B\sin\theta_2)^2}$$

$$= \sqrt{((50.0\text{ N})(\cos 55.0°) + (30.0\text{ N})(\cos 115.0°))^2 + ((50.0\text{ N})(\sin 55.0°) + (30.0\text{ N})(\sin 115.0°))^2}$$

$$= 70.0\text{ N}$$

$$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right) = \tan^{-1}\left(\frac{A\sin\theta_1 + B\sin\theta_2}{A\cos\theta_1 + B\cos\theta_2}\right)$$

$$= \tan^{-1}\left(\frac{(50.0\text{ N})(\sin 55.0°) + (30.0\text{ N})(\sin 115.0°)}{(50.0\text{ N})(\cos 55.0°) + (30.0\text{ N})(\cos 115.0°)}\right)$$

$$= 76.8°$$

**$R$ = 70.0 N at 76.8° north of east**

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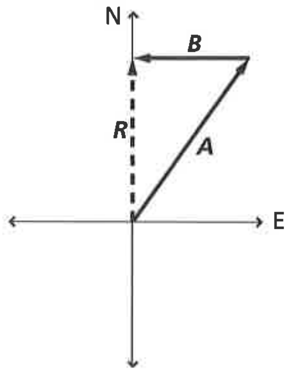
**Chapter 5 continued**

5. Takashi trains for a race by rowing his canoe on a lake. He starts by rowing along a straight path. Then he turns and rows 260.0 m west. If he then finds he is located 360.0 m exactly north of his starting point, what was his displacement along the straight path?




$R_x = 0.0 \text{ m}, R_y = 360.0 \text{ m}$

$B_x = -260.0 \text{ m}, B_y = 0.0 \text{ m}$

$R = A + B, A = R - B$

$A_x = R_x - B_x = 0.0 \text{ m} - (-260.0 \text{ m})$

$= 260.0 \text{ m}$

$A_y = R_y - B_y = 360.0 \text{ m} - 0.0 \text{ m}$

$= 360.0 \text{ m}$

$A = \sqrt{A_x^2 + A_y^2}$

$= \sqrt{(260.0 \text{ m})^2 + (360.0 \text{ m})^2}$

$= 444.1 \text{ m}$

$\theta = \tan^{-1}\left(\frac{A_y}{A_x}\right)$

$= \tan^{-1}\left(\frac{360.0 \text{ m}}{260.0 \text{ m}}\right) = 54.16°$

**$A = 444.1$ m at 54.16° north of east**

6. Mira received a 235-N sled for her birthday. She takes the sled out to a flat snowy field. When she pushes it with a 45.0-N horizontal force, it slides along at a constant speed. What is the coefficient of kinetic friction between the sled and the snow?

***y*-direction:** $F_N = F_g$

***x*-direction:** $F_p - F_f = ma$

$a = 0$ **(since** $v =$ **constant)**

$F_p - F_f = 0$

$F_p = F_f$

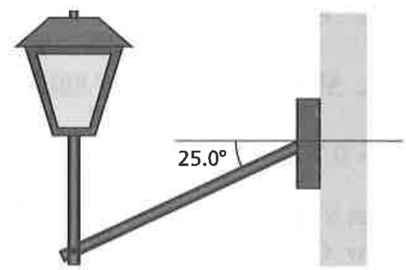
$= \mu_k F_N = \mu_k F_g$

$\mu_k = \frac{F_p}{F_g}$

$= \frac{45.0 \text{ N}}{235 \text{ N}}$

$= 0.191$

7. A rod supports a 2.35-kg lamp, as shown below.




a. What is the magnitude of the tension in the rod?

***y*-direction:**

$T_y = F_g$

$T \sin\theta = mg$

$T = \frac{mg}{\sin\theta}$

$= \frac{(2.35 \text{ kg})(9.80 \text{ m/s}^2)}{\sin 25.0°}$

$= 54.5 \text{ N}$

b. Calculate the components of the force that the bracket exerts on the rod.

***x*-direction:**

$T_x - F_x = 0$

$F_x = T\cos\theta$

$= (54.5 \text{ N})(\cos 25.0°)$

$F_x = 49.4$ **N, inward**

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**Chapter 5 continued**

**9.** A child shoves a small toboggan weighing 100.0 N up a snowy hill, giving the toboggan an initial speed of 6.0 m/s. If the hill is inclined at an angle of 32° above the horizontal, how far along the hill will the toboggan slide? Assume that the coefficient of sliding friction between the toboggan and the snow is 0.15.

**y-direction:**

$F_{net,\,y} = ma_y = 0$

$F_N - F_{gy} = 0$

$F_N = F_{gy} = mg\cos\theta$

**x-direction:**

$F_{net,\,x} = ma_x = ma$

$F_{gx} = mg\sin\theta$

$F_{gx} - F_f = ma$

$F_f = \mu_k F_N = \mu_k mg\cos\theta$

$mg\sin\theta - \mu_k mg\cos\theta = ma$

$a = g(\sin\theta - \mu_k\cos\theta)$

$v_f^2 = v_i^2 + 2a(d_f - d_i)$

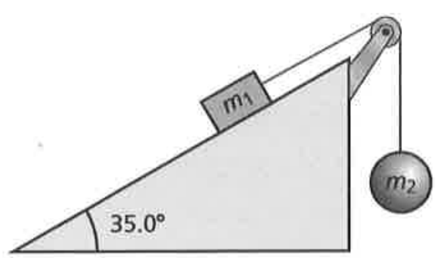
$0 = v_i^2 + 2ad$

$$d = -\frac{v_i^2}{2a} = \frac{v_i^2}{2g(\sin\theta - \mu_k\cos\theta)}$$

$$= \frac{(6.0\text{ m/s}^2)}{(2)(9.80\text{ m/s}^2)(\sin 32° - (0.15)\cos 32°)}$$

**= 4.6 m, up the hill**

**10.** Two objects are connected by a string passing over a frictionless, massless pulley. As shown below, the block is on an inclined plane and the ball is hanging over the top edge of the plane. The block has a mass of 60.0 kg, and the coefficient of kinetic friction between the block and the inclined plane is 0.22. If the block moves at a constant speed down the incline, and the ball rises at a constant speed, what is the mass of the hanging ball?

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**$v$ is constant, so there is no acceleration.**

**Ball ($m_2$):**

**$y$-direction:**

$F_{\text{net}, y} = m_2 a_y = 0$

$F_T - F_g = 0$

$F_T = m_2 g$

**Block ($m_1$):**

**$y$-direction: (parallel to the incline)**

$F_{\text{net}, y} = m_1 a_y = 0$

$F_N = F_{gy} = 0$

$F_N = F_{gy} = m_1 g \cos \theta$

$F_f = \mu_k F_N = \mu_k m_1 g \cos \theta$

**$x$-direction: (perpendicular to the incline)**

$F_{\text{net}, x} = m_1 a_x = 0$

$F_{gx} - F_f - F_T = 0$

$F_{gx} = m_1 g \sin \theta$

$m_1 g \sin \theta - \mu_k m_1 g \cos \theta - F_T = 0$

$m_1 g \sin \theta - \mu_k m_1 g \cos \theta - m_2 g = 0$

$$m_2 = \frac{m_1 g \sin \theta - \mu_k m_1 g \cos \theta}{g}$$

$= m_1 \sin \theta - \mu_k m_1 \cos \theta$

$= (60.0\ \text{kg})(\sin 35.0°) - (0.22)(60.0\ \text{kg})(\cos 35.0°)$

$= 24\ \text{kg}$

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# Chapter 6

1. A busy waitress slides a plate of apple pie along a counter to a hungry customer sitting near the end of the counter. The customer is not paying attention, and the plate slides off the counter horizontally at 0.84 m/s. The counter is 1.38 m high.

   a. How long does it take the plate to fall to the floor?

   **y-direction:**

   $v_{yi} - 0,\ y_i = 0.84\ \text{m}$

   $y_f = y_i + v_{yi}t - \frac{1}{2}gt^2$

   $0 = y_i + 0 - \frac{1}{2}gt^2$

   $t = \sqrt{\frac{2y_i}{g}} = \sqrt{\frac{2(1.38\ \text{m})}{9.80\ \text{m/s}^2}}$

   $= 0.53\ \text{s}$

   b. How far from the base of the counter does the plate hit the floor?

   **x-direction:**

   $v_{xi} = 0.84\ \text{m/s},\ x_i = 0.0\ \text{m}$

   $x_f = x_i + v_{xi}t$

   $= 0.0 + (0.84\ \text{m/s})(0.53\ \text{s})$

   $= 0.45\ \text{m}$

   c. What are the horizontal and vertical components of the plate's velocity just before it hits the floor?

   **horizontal:**

   $v_{xf} = v_{xi} = 0.84\ \text{m/s}$

   **vertical:**

   $v_{yf} = v_{yi} - gt$

   $= 0 - (9.80\ \text{m/s}^2)(0.53\ \text{s})$

   $= -5.2\ \text{m/s}$

2. DuWayne is on his way out to go grocery shopping when he realizes that he has left his wallet at home, so he calls his wife, Yolanda, who opens a high window and throws DuWayne's wallet down at an angle 23° below the horizontal. Yolanda throws the wallet at a speed of 4.2 m/s, and the wallet leaves her hand at a height 2.0 m above the ground. How far from the base of the house does the wallet reach the ground?

   **y-direction:**

   $v_{yi} = v_i \sin \theta_i = (4.2\ \text{m/s}) \sin(-23.0°)$

   $= -1.6\ \text{m/s}$

   $y_f = y_i + v_{yi}t - \frac{1}{2}gt^2$

   $0.0\ \text{m} = 2.0\ \text{m} + (-1.6\ \text{m/s})t - \frac{1}{2}(9.80\ \text{m/s}^2)t^2$

   **This is a quadratic equation in the form $ax^2 + bx + c = 0$, with $a = \frac{1}{2}(9.80\ \text{m/s}^2) = -4.9$, $b = -1.6$, and $c = 2.0$.**

   $t = \frac{-(-1.6) \pm \sqrt{(-1.6)^2 - 4(-4.9)(2.0)}}{2(-4.9)}$

   **The positive solution is $t = 0.50$ s**

   **x-direction:**

   $v_{xi} = v_i \cos \theta_i$

   $x_f = x_i + v_{xi}t = x_i + v_i \cos \theta_i t$

   $= 0.0\ \text{m} + (4.2\ \text{m/s})\cos(-23.0°)(0.50\ \text{s})$

   $= 1.9\ \text{m}$

3. A skateboarder is slowing down at a rate of 0.70 m/s$^2$. At the moment he is moving forward at 1.5 m/s, he throws a basketball upward so that it reaches a height of 3.0 m, and then he catches it at the same level it was thrown without changing his position on the skateboard. Determine the vertical and horizontal components of the ball's velocity relative to the skateboard when the ball left his hand.

   **y-direction:**

   $v_{yf}^2 = v_{yi}^2 - 2g(y_f - y_i)$

   **$y_i = 0$, and, at the highest position, $v_{yf} = 0$**

   $0 = v_{yi}^2 - 2gy_f$

   $v_{yi} = \sqrt{2gy_f} = \sqrt{2(9.80\ \text{m/s}^2)(3.0\ \text{m})}$

   $= 7.7\ \text{m/s}$

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**To find the time the ball is in the air:**

$y_f = y_i + v_{yi}t - \frac{1}{2}gt^2$

**Falling from the highest point, $v_{yi} = 0$, $y_f = 0$, and $y_i = 3.0$ m**

$0 = y_i + 0 - \frac{1}{2}gt_{down}^2$

$t_{down} = \sqrt{\frac{2y_i}{g}} = \sqrt{\frac{2(3.0\text{ m})}{9.80\text{ m/s}^2}}$

$= 0.782$ s

$t = 2t_{down} = 2(0.782\text{ s})$

$= 1.565$ s

***x*-direction:**

**Distance the skateboarder moves:**

$x_s = x_{si} + v_{xsi}t + \frac{1}{2}at^2$

$= 0 + (1.5\text{ m/s})(1.565\text{ s}) + \frac{1}{2}(-0.70\text{ m/s}^2)(1.565\text{ s})^2$

$= 1.490$ m

**Horizontal distance the ball moves:**

$x_b = x_{bi} + v_{xbi}t$

$= 0 + (1.5\text{ m/s})(1.565\text{ s})$

$= 2.348$ m

$x_b + \Delta x = x_s$

**Distance skateboard lags behind ball:**

$\Delta x = x_s - x_b = 1.490\text{ m} - 2.348\text{ m}$

$= -0.848$ m

**Horizontal velocity skateboarder must throw ball relative to skateboard:**

$v_{xi} = \frac{\Delta x}{t} = \frac{-0.848\text{ m}}{1.565\text{ s}}$

$= -0.548$ m/s

$v_{xi} = 0.55$ m/s **opposite the direction of motion of the skateboarder**

**4.** A tennis ball is thrown toward a vertical wall with a speed of 21.0 m/s at an angle of 40.0° above the horizontal. The horizontal distance between the wall and the point where the tennis ball is released is 23.0 m.

**a.** At what height above the point of release does the tennis ball hit the wall?

***x*-direction:**

$v_{xi} = v_i \cos \theta_i =$

$x_f = x_i + v_{xi}t$

$x_f - x_i = v_{xi}t$

$t = \frac{x_f - x_i}{v_{xi}} = \frac{x_f - x_i}{v_i \cos \theta_1} = \frac{23.0\text{ m} - 0.0\text{ m}}{(21.0\text{ m/s}) \cos 40.0°}$

$t_{wall} = 1.43$ s

***y*-direction:**

$v_{yi} = v_i \sin \theta_i$

$y_f = y_i + v_{yi}t - \frac{1}{2}gt^2$

$y_f - y_i = v_{yi}t - \frac{1}{2}gt^2 = v_i \sin \theta_i(t) - \frac{1}{2}gt^2$

$= (21.0\text{ m/s}) \sin 40.0°(1.43\text{ s}) - \frac{1}{2}(9.80\text{ m/s}^2)(1.43\text{ s})^2$

$= 9.28$ m

**b.** Has the tennis ball already passed the highest point on its trajectory when it hits the wall? Justify your answer.

**Method One: Find the time to maximum height.**

$v_{yf} = v_{yi} - gt$

**At maximum height, $v_{yf} = 0$**

$0 = v_{yi} - gt$

$t = \frac{v_{yi}}{g} = \frac{v_i \sin \theta_1}{g} = \frac{(21.0\text{ m/s}) \sin 40.0°}{9.80\text{ m/s}^2}$

$t_{highest} = 1.38$ s

**From part a, $t_{wall} = 1.43$ s**

**Since $t_{wall} > t_{highest}$, the ball has already passed the highest point when it hits the wall.**

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**Method Two: Find $v_{yf}$ component just before the ball hits the wall.**

$$v_{yf,\,wall} = v_{yi} - gt_{wall} = v_i \sin\theta_i - gt_{wall}$$
$$= (21.0\text{ m/s})\sin 40.0° - (9.80\text{ m/s}^2)(1.43\text{ s})$$
$$= -0.515\text{ m/s}$$

**Since $v_{yf,wall} < 0$, the ball is on its way down and has already passed the highest point.**

**5.** The Moon revolves around Earth in a circular orbit with a radius of $3.84\times10^8$ m. It takes 27.3 days for the Moon to complete one orbit around Earth. What is the centripetal acceleration of the Moon?

$$a_c = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$$

$$T = (27.3\text{ days})\left(\frac{24\text{ h}}{1\text{ day}}\right)\left(\frac{3600\text{ s}}{1\text{ h}}\right)$$
$$= 2.3587\times10^6\text{ s}$$

$$a_c = \frac{4\pi^2 r}{T^2} = \frac{4\pi^2(3.84\times10^8\text{ m})}{(2.3587\times10^6\text{ s})^2}$$
$$= 2.72\times10^{-3}\text{ m/s}^2$$

**6.** A clown rides a small car at a speed of 15 km/h along a circular path with a radius of 3.5 m.

**a.** What is the magnitude of the centripetal force on a 0.18-kg ball held by the clown?

$$v = \left(\frac{15\text{ km}}{1\text{ h}}\right)\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)$$
$$= 4.17\text{ m/s}$$
$$F_c = ma_c = m\frac{v^2}{r}$$
$$= (0.18\text{ kg})\frac{(4.17\text{ m/s})^2}{3.5\text{ m}}$$
$$= 0.89\text{ N}$$

**b.** At the point where the car is headed due north, the clown throws the ball vertically upward with a speed of 5.0 m/s relative to the moving car. To where must a second clown run to catch the ball the same distance above the ground as it was thrown?

**$y$-direction:**

$$v_{yf} = v_{yi} - gt$$

**At the highest point, $v_{yf} = 0$**

$$t_{highest} = \frac{v_{yi}}{g}$$

$$t_{total} = 2t_{highest} = \frac{2v_{yi}}{g}$$

**$x$-direction:**

$$R = v_{xi}t = \frac{v_{xi}2_{yi}}{g}$$
$$= \frac{(4.17\text{ m/s})(2)(5.0\text{ m/s})}{9.80\text{ m/s}^2}$$

**= 4.3 m north of the point where the clown threw the ball**

**7.** A 0.45-kg ball is attached to the end of a cord of length 1.4 m. The ball is whirled in a circular path in a horizontal plane. The cord can withstand a maximum tension of 57.0 N before it breaks. What is the maximum speed the ball can have without the cord breaking?

$$F_{net} = ma_c$$

$$F_T = m\frac{v^2}{r}$$

$$v = \sqrt{\frac{F_T r}{m}}$$

$$v_{max} = \sqrt{\frac{F_{T,\,max}r}{m}} = \sqrt{\frac{(57.0\text{ N})(1.4\text{ m})}{(0.45\text{ kg})}}$$
$$= 13\text{ m/s}$$

**8.** The moving sidewalk at an airport has a speed of 0.9 m/s toward the departure gate.

**a.** A man is walking toward the departure gate on the moving sidewalk at a speed of 1.0 m/s relative to the sidewalk. What is the velocity of the man relative to a woman who is standing off the moving sidewalk?

$$v_{m/w} = v_{m/s} + v_{s/gr} + v_{gr/w}$$

**$v_{gr/w} = 0.0$ m/s, since the woman is standing still**

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**Chapter 6 continued**

$v_{m/w} = 1.0\ \text{m/s} + 0.9\ \text{m/s} + 0.0\ \text{m/s}$

$= 1.9\ \text{m/s}$ **toward the departure gate**

**b.** On a similar moving sidewalk that is going in the opposite direction, a child walks toward the terminal at a speed of 0.4 m/s relative to the sidewalk. What is the velocity of the man relative to the child?

$v_{m/c} = v_{m/s1} + v_{s1/gr} + v_{gr/s2} + v_{s2/c}$

$v_{gr/s2} = v_{s2/gr}$

$v_{s2/c} = -v_{c/s2}$

$v_{m/c} = v_{m/s1} + v_{s1/gr} - v_{s2/gr} - v_{c/s2}$

$= 1.0\ \text{m/s} + 0.9\ \text{m/s} - (-0.9\ \text{m/s}) - (-0.4\ \text{m/s})$

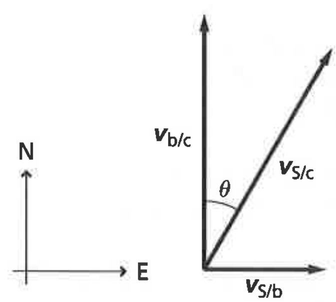
$= 3.2\ \text{m/s}$ **toward the departure gate**

**9.** On a sightseeing trip in Europe, Soraya is riding in a tour bus moving north along a straight section of road at 8.0 m/s. While Soraya looks out at a forest, she hears some passengers on the other side of the bus say they can see a famous castle from their side. Soraya hurries straight across the bus, going east at 4.0 m/s relative to the bus, so that she also can see the castle. What is Soraya's velocity relative to the castle?

$v_{S/c} = v_{S/b} + v_{b/c}$

$v_{S/c} = v_{S/b} + v_{b/c}$

$v_{S/b} = 4.0\ \text{m/s},\ v_{b/c} = 8.0\ \text{m/s},\ v_{S/c} = ?$




**Because the two velocities are at right angles, use the Pythagorean theorem:**

$v_{S/c}^2 = v_{b/c}^2 + v_{S/b}^2$

$v_{S/c} = \sqrt{v_{b/c}^2 + v_{S/b}^2}$

$= \sqrt{(8.0\ \text{m/s})^2 + (4.0\ \text{m/s})^2}$

$= 8.9\ \text{m/s}$

$\theta = \tan^{-1}\left(\frac{v_{S/b}}{v_{b/c}}\right)$

$= \tan^{-1}\left(\frac{4.0\ \text{m/s}}{8.0\ \text{m/s}}\right)$

$= 27°$

$v_{S/c} = 8.9\ \text{m/s}$ **at 27° east of north**

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**Chapter 6 continued**

**10.** A kite is tethered to a stake on a beach. The wind has a constant velocity of 16 km/h at an angle of 15° from the horizontal relative to the beach. Find the components of the kite's velocity relative to the wind.

$$v_{x,\mathrm{w}} = v_{\mathrm{w}} \cos\theta$$

$$v_{y,\mathrm{w}} = v_{\mathrm{w}} \sin\theta$$

$$v_{\mathrm{k/w}} = v_{\mathrm{k/b}} + v_{\mathrm{b/w}}$$

$$v_{\mathrm{b/w}} = -v_{\mathrm{w/b}} = -v_{\mathrm{w}}$$

$$v_{\mathrm{k/w}} = v_{\mathrm{k/b}} - v_{\mathrm{w}}$$

$$v_{x,\mathrm{k/w}} = v_{x,\mathrm{k/b}} - v_{x,\mathrm{w}} = v_{x,\mathrm{k/b}} - v_{\mathrm{w}} \cos\theta$$

$$= 0.0\ \mathrm{km/h} - (16\ \mathrm{km/h})(\cos 15°)$$

$$= -15\ \mathrm{km/h}$$

$$v_{y,\mathrm{k/w}} = v_{y,\mathrm{k/b}} - v_{y,\mathrm{w}} = v_{y,\mathrm{k/b}} - v_{\mathrm{w}} \sin\theta$$

$$= 0.0\ \mathrm{km/h} - (16\ \mathrm{km/h})(\sin 15°) = -4.1\ \mathrm{km/h}$$

**11.** A marble rolls off the edge of a table that is 0.734 m high. The marble is moving at a speed of 0.122 m/s at the moment that it leaves the edge of the table. How far from the table does the marble land?

$$d_{\mathrm{f}} - d_{\mathrm{i}} = v_{\mathrm{i}} + \frac{1}{2}at^2$$

$v_{\mathrm{i}} = 0$ and $a = -g$

$$\Delta d = -\frac{1}{2}gt^2$$

$$t = \sqrt{\frac{-2\Delta d}{g}}$$

$R$ is the range which is equal to $v_{x\mathrm{i}}t$

$$R = v_{x\mathrm{i}}$$

$$= v_{x\mathrm{i}}\sqrt{\frac{-2\Delta d}{g}}$$

$$= v_{x\mathrm{i}}\sqrt{\frac{-2(d_{\mathrm{f}} - d_{\mathrm{i}})}{g}}$$

$$= (0.122\ \mathrm{m/s})\left(\sqrt{\frac{-2(0.0\ \mathrm{m} - 0.734\ \mathrm{m})}{9.80\ \mathrm{m/s^2}}}\right)$$

$$= 0.0472\ \mathrm{m}$$

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**12.** Frank and Carmen are playing catch with a flying disk when it gets stuck in a tree. The disk is lodged between two branches 8.8 m above the ground. If a rock is thrown straight up to hit the disk, what is the minimum speed with which the disk must be thrown?

$v_f^2 = v_i^2 + 2\bar{a}\Delta d$

$v_f = 0$ and $a = -g$

$0 = v_i^2 - 2g\Delta d$

$v_i = \sqrt{2g\Delta d}$

$= \sqrt{2(9.80\ \text{m/s}^2)(8.8\ \text{m})}$

$= 13\ \text{m/s}$

**13.** A baseball player is playing catch with his friend. When the ball leaves his hand it is moving at 29.1 m/s. He throws the ball at an angle of 30.0° above the horizontal. His friend catches the ball at the same height from which it was thrown. How far is the baseball player from his friend?

$v_{fy} = v_{iy} + at$

$v_{fy} = 0$ m/s and $a = -g$

$0 = v_{iy} - gt$

$t = \frac{v_{iy}}{g} = \frac{v_i \sin\theta}{g}$

$= \frac{(29.1\ \text{m/s})\sin 30.0°}{9.80\ \text{m/s}^2}$

$= 1.48\ \text{s}$

$t_{total} = 2t = 2(1.48\ \text{s}) = 2.96\ \text{s}$

$\Delta d = v_{xi}\Delta t$

$\Delta t = t_{total}$

$\Delta d = (v_i \cos\theta)\, t_{total}$

$= (29.1\ \text{m/s})(\cos 30.0°)(2.96\ \text{s})$

$= 74.6\ \text{m}$

**14.** A car moving at 12.67 m/s rounds a bend in the road. The bend is semicircular and has a radius of 60.0 m. What is the centripetal acceleration of the car?

$a_c = \frac{v^2}{r}$

$= \frac{(12.67\ \text{m/s})^2}{60.0\ \text{m}}$

$= 2.68\ \text{m/s}^2$

**15.** A town has a large clock on the hall in the town square. The clock has hands that show the hours, minutes, and seconds. A fly is sitting on the tip of the hand that shows the seconds. If the length of the hand is 1.20 m, what is the fly's centripetal acceleration?

$a_c = \frac{4\pi^2 r}{T^2}$

$= \frac{4\pi^2(1.20\ \text{m})}{(60.0\ \text{s})^2}$

$= 0.0132\ \text{m/s}^2$

**16.** A rock is tied to a string and spun in a horizontal circle. The string is 1.8 m long and the rock has an acceleration of 3.4 m/s$^2$. What is the tangential velocity of the rock?

$a_c = \frac{v^2}{r}$

$v = \sqrt{a_c r}$

$= \sqrt{(3.4\ \text{m/s}^2)(1.8\ \text{m})}$

$= 2.5\ \text{m/s}$

**17.** An airplane flies north at 300.0 km/h relative to the air and the wind is blowing south at 15.0 km/h. What is the airplane's velocity relative to the ground?

$v_{p/g} = v_{p/a} + v_{a/g}$

$= 300.0\ \text{km/h} + (-15.0\ \text{km/h})$

$= 285.0$ km/h northward

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# Chapter 7

1. Titan, the largest moon of Saturn, has a mean orbital radius of $1.22\times10^9$ m. The orbital period of Titan is 15.95 days. Hyperion, another moon of Saturn, orbits at a mean radius of $1.48\times10^9$ m. Use Kepler's third law of planetary motion to predict the orbital period of Hyperion in days.

$$\left(\frac{T_{\text{Hyperion}}}{T_{\text{Titan}}}\right)^2 = \left(\frac{r_{\text{Hyperion}}}{r_{\text{Titan}}}\right)^3$$

$$T_{\text{Hyperion}} = T_{\text{Titan}}\sqrt{\left(\frac{r_{\text{Hyperion}}}{r_{\text{Titan}}}\right)^3}$$

$$= (15.95\text{ days})\sqrt{\left(\frac{1.48\times10^9\text{ m}}{1.22\times10^9\text{ m}}\right)^3}$$

$$= 21.3\text{ days}$$

2. The mass of Earth is $5.97\times10^{24}$ kg, the mass of the Moon is $7.35\times10^{22}$ kg, and the mean distance of the Moon from the center of Earth is $3.84\times10^5$ km. Use these data to calculate the magnitude of the gravitational force exerted by Earth on the Moon.

$$F = G\frac{m_E m_M}{r^2}$$

$$r = 3.84\times10^5\text{ km} = 3.84\times10^8\text{ m}$$

$$F = 6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2\ \frac{(5.97\times10^{24}\text{ kg})(7.35\times10^{22}\text{ kg})}{(3.84\times10^8\text{ m})^2}$$

$$= 1.98\times10^{20}\text{ N}$$

3. Two identical bowling balls are placed 1.00 m apart. The gravitational force between the bowling balls is $3.084\times10^{-9}$ N.

   a. Find the mass of a bowling ball.

$$F_g = G\frac{m_1 m_2}{r^2}$$

$$m_1 = m_2 = m$$

$$F_g = \frac{Gm^2}{r^2}$$

$$m = \sqrt{\frac{F_g r^2}{G}}$$

$$= \sqrt{\frac{(3.084\times10^{-9}\text{ N})(1.00\text{ m})^2}{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)}}$$

$$= 6.80\text{ kg}$$

   b. Compare the weight of the first ball with the gravitational force exerted on it by the second ball.

$$F_g = mg = (6.80\text{ kg})(9.80\text{ m/s}^2)$$

$$F_{g1} = 66.6\text{ N}$$

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$$F_{g2} = 3.084\times10^{-9}\ \text{N}$$

$$\frac{F_{g1}}{F_{g2}} = \frac{66.6\ \text{N}}{3.084\times10^{-9}\ \text{N}}$$

$$= 2.16\times10^{10}$$

**4.** The planet Mercury travels around the Sun with a mean orbital radius of $5.8\times10^{10}$ m. The mass of the Sun is $1.99\times10^{30}$ kg. Use Newton's version of Kepler's third law to determine how long it takes Mercury to orbit the Sun. Give your answer in Earth days.

$$T^2 = \left(\frac{4\pi^2}{Gm_S}\right)r^3$$

$$T = 2\pi\sqrt{\frac{r^3}{Gm_S}}$$

$$= 2\pi\sqrt{\frac{(5.8\times10^{10}\ \text{m})^3}{(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(1.99\times10^{30}\ \text{kg})}}\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)\left(\frac{1\ \text{day}}{24\ \text{h}}\right)$$

$$= 88\ \text{days}$$

**5.** Io, the closest moon to Jupiter, has a period of 1.77 days and a mean orbital radius of $4.22\times10^{8}$ m. Use this information together with Newton's version of Kepler's third law to determine the mass of Jupiter.

$$T_{Io}^{\ 2} = \left(\frac{4\pi^2}{Gm_{Jupiter}}\right)r_{Io}^{\ 3}$$

$$m_{Jupiter} = \left(\frac{4\pi^2}{GT_{Io}^{\ 2}}\right)r_{Io}^{\ 3}$$

$$T_{Io} = (1.77\ \text{days})\left(\frac{24\ \text{h}}{1\ \text{day}}\right)\left(\frac{3600\ \text{s}}{1\ \text{h}}\right)$$

$$= 1.53\times10^{5}\ \text{s}$$

$$m_{Jupiter} = \left(\frac{4\pi^2}{(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(1.53\times10^{5}\ \text{s})^2}\right)(4.22\times10^{8}\ \text{s})^3$$

$$= 1.90\times10^{27}\ \text{kg}$$

**6.** A satellite is placed in a circular orbit 100.0 km above Earth's surface. Earth's mass is $5.97\times10^{24}$ kg and its average radius is $6.38\times10^{6}$ m.

**a.** What is the speed of the satellite?

$$h = 100.0\ \text{km} = 1.000\times10^{5}\ \text{m}$$

$$r = r_E + h = 6.38\times10^{6}\ \text{m} + 1.000\times10^{5}\ \text{m} = 6.48\times10^{6}\ \text{m}$$

$$v = \sqrt{\frac{Gm_E}{r}}$$

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$$= \sqrt{\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(5.97\times10^{24}\ \text{kg})}{(6.48\times10^{6}\ \text{m})}}$$

$$= 7.84\times10^{3}\ \text{m/s}$$

**b.** How many minutes does it take the satellite to complete one orbit?

$$T = 2\pi\sqrt{\frac{r^3}{Gm_E}}$$

$$= 2\pi\sqrt{\frac{(6.48\times10^{6}\ \text{m})^3}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(5.97\times10^{24}\ \text{kg})}}\left(\frac{1\ \text{min}}{60\ \text{s}}\right)$$

$$= 86.6\ \text{min}$$

**7.** You have been hired to do calculations for a consortium that plans to place a space station in orbit around Mars. The mass of Mars is $6.42\times10^{23}$ kg and its radius is $3.40\times10^{6}$ m. In order for the space station to appear to remain over the same spot on Mars at all times, its orbital period must be equal to the length of a day on Mars: $8.86\times10^{4}$ s. At what height above the surface of Mars should the space station be located in order to maintain this orbit? Use Newton's version of Kepler's third law.

$$T^2 = \left(\frac{4\pi^2}{Gm_{\text{Mars}}}\right)r^3$$

$$r = \sqrt[3]{\frac{Gm_{\text{Mars}}T^2}{4\pi^2}}$$

$$= \sqrt[3]{\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(6.42\times10^{23}\ \text{kg})(8.86\times10^{4}\ \text{s})^2}{4\pi^2}}$$

$$= 2.04\times10^{7}\ \text{m}$$

**Height above the surface of Mars:**

$$h = r - r_{\text{Mars}} = 2.04\times10^{7}\ \text{m} - 3.40\times10^{6}\ \text{m} = 1.70\times10^{7}\ \text{m}$$

**8.** The asteroid Vesta has a mass of $3.0\times10^{20}$ kg and an average radius of 510 km.

**a.** What is the acceleration of gravity at its surface?

$$g_{\text{Vesta}} = \frac{Gm_{\text{Vesta}}}{{r_{\text{Vesta}}}^2}$$

$$r_{\text{Vesta}} = 510\ \text{km} = 5.10\times10^{5}\ \text{m}$$

$$g_{\text{Vesta}} = \frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(3.0\times10^{20}\ \text{kg})}{(5.10\times10^{5}\ \text{m})^2}$$

$$= 7.7\times10^{-2}\ \text{m/s}^2$$

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**b.** How much would a 95-kg astronaut weigh at the surface of Vesta?

$$F_g = mg_{Vesta}$$
$$= (95\ kg)(7.7\times10^{-2}\ m/s^2)$$
$$= 7.3\ N$$

**9.** The Moon has an average radius of $1.74\times10^3$ km. At the Moon's surface, $g_{Moon}$ has a value of 1.62 m/s$^2$. What is the value of the acceleration due to gravity at an altitude of $1.00\times10^2$ km above the Moon's surface?

$$r = r_{Moon} + h = 1.74\times10^6\ m + 1.00\times10^5\ m = 1.84\times10^6\ m$$

$$a = g_{Moon}\left(\frac{r_{Moon}}{r}\right)^2$$

$$= (1.62\ m/s^2)\left(\frac{1.74\times10^6\ m}{1.84\times10^6\ m}\right)^2$$

$$= 1.45\ m/s^2$$

**10.** Use data from Table 7-1 in the text.

**a.** Find the Sun's gravitational field strength at Earth's orbit.

$$g_{at\ Earth} = \frac{Gm_S}{(r_{Sun\ to\ Earth})^2}$$

$$= \frac{(6.67\times10^{-11}\ N\cdot m^2/kg^2)(1.99\times10^{30}\ kg)}{(1.50\times10^{11}\ m)^2}$$

$$= 5.90\times10^{-3}\ m/s^2$$

**b.** How does this compare with the Sun's gravitational field strength at the orbit of Pluto?

$$g_{at\ Pluto} = \frac{Gm_S}{(r_{Sun\ to\ Pluto})^2}$$

$$g_{at\ Pluto} = \frac{(6.67\times10^{-11}\ N\cdot m^2/kg^2)(1.99\times10^{30}\ kg)}{(5.87\times10^{12}\ m)^2}$$

$$= 3.85\times10^{-6}\ m/s^2$$

$$\frac{g_{at\ Earth}}{g_{at\ Pluto}} = \frac{5.90\times10^{-3}\ m/s^2}{3.85\times10^{-6}\ m/s^2}$$

$$= 1.53\times10^3$$

**11.** Earth has an orbital period of 365 days and its mean distance from the Sun is $1.495\times10^8$ km. The planet Pluto's mean distance from the Sun is $5.896\times10^9$ km. Using Kepler's third law, calculate Pluto's orbital period in Earth days.

$$\left(\frac{T_P}{T_E}\right)^2 = \left(\frac{r_P}{r_E}\right)^3$$

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$$T_P = T_E\sqrt{\left(\frac{r_P}{r_E}\right)^3}$$

$$= (365\ \text{days})\sqrt{\left(\frac{5.896\times10^9\ \text{km}}{1.495\times10^8\ \text{km}}\right)^3}$$

$$= 9.04\times10^4\ \text{days}$$

**12.** The mass of Earth is $5.98\times10^{24}$ kg and the mass of the Sun is 330,000 times greater than the mass of Earth. If the center of Earth is, on average, $1.495\times10^{11}$ m from the center of the Sun, calculate the magnitude of the gravitational force the Sun exerts on Earth.

$$F = G\frac{m_1m_2}{r^2}$$

$$= \frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(5.98\times10^{24}\ \text{kg})(330{,}000\times5.98\times10^{24}\ \text{kg})}{(1.495\times10^{11}\ \text{m})^2}$$

$$= 3.5\times10^{22}\ \text{N}$$

**13.** Two metal spheres, each weighing 24.0 kg are placed 0.0500 m apart. Calculate the magnitude of the gravitational force the two spheres exert on each other.

$$F = G\frac{m_1m_2}{r^2}$$

$$= (6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)\frac{(24.0\ \text{kg})(24.0\ \text{kg})}{(0.0500\ \text{m})^2}$$

$$= 1.54\times10^{-5}\ \text{N}$$

**14.** A car and a truck are traveling side by side on the highway. The car has a mass of $1.37\times10^3$ kg and the truck has a mass of $9.92\times10^3$ kg. If the cars are separated by 2.10 m, find the force of gravitational attraction between the car and the truck.

$$F = G\frac{m_1m_2}{r^2}$$

$$= (6.67\times10^{-11}\text{N·m}^2/\text{kg}^2)\frac{(1.37\times10^3\ \text{kg})(9.92\times10^3\ \text{kg})}{(2.10\ \text{m})^2}$$

$$= 2.06\times10^{-4}\ \text{N}$$

**15.** A satellite is in orbit $3.11\times10^6$ m from the center of Earth. The mass of Earth is $5.98\times10^{24}$ kg. Calculate the orbital period of the satellite.

$$T = 2\pi\sqrt{\frac{r^3}{Gm_E}}$$

$$= 2\pi\sqrt{\frac{(3.11\times10^6\ \text{m})^3}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(5.98\times10^{24}\ \text{kg})}}$$

$$= 1.72\times10^3\ \text{s}$$

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**Chapter 7 continued**

**16.** The planet Venus orbits the Sun with a mean orbital radius of $1.076\times10^{11}$ m. The mass of the Sun is $1.99\times10^{30}$ kg. Using Newton's version of Kepler's third law, calculate the orbital period of Venus.

$$T^2 = \left(\frac{4\pi^2}{Gm_s}\right)r^3$$

$$T = 2\pi\sqrt{\frac{r^3}{Gm_s}}$$

$$= 2\pi\sqrt{\frac{(1.076\times10^{11}\ \text{m})^3}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(1.99\times10^{30}\ \text{kg})}}$$

$= 1.92\times10^7$ **s or about 222 days**

**17.** A satellite is in orbit at a distance of 6750 km from the center of Earth. The mass of Earth is $5.98\times10^{24}$ kg. What is the orbital speed of the satellite?

$$v = \sqrt{\frac{Gm_E}{r}}$$

$$= \sqrt{\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(5.98\times10^{24}\ \text{kg})}{6.75\times10^6\ \text{m}}}$$

$= 7.69\times10^3$ **m/s**

**18.** Given that the mass of Earth is $5.98\times10^{24}$ kg, what is the orbital radius of a satellite that has an orbital period of exactly one day (assume that a day is exactly 24 hours in length)?

$$T = 2\pi\sqrt{\frac{r^3}{Gm_E}}$$

$$r = \sqrt[3]{Gm_E\left(\frac{T}{2\pi}\right)^2}$$

$$= \sqrt[3]{\begin{array}{l}(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(5.98\times10^{24})\ldots \\ \ldots(24\ \text{h})\left(\frac{60\ \text{min}}{1\ \text{h}}\right)\left(\frac{60\ \text{s}}{1\ \text{min}}\right)\end{array}}$$

$= 4.23\times10^7$ **m**

**19.** The Moon has a mass of $7.349\times10^{22}$ kg and a radius of 1737 km. How much would a 75.0-kg person weigh standing on the surface of the Moon?

$$F_{g,\ \text{Moon}} = mg_{\text{Moon}}$$

$$= m\left(\frac{GM_{\text{Moon}}}{r_{\text{Moon}}^{\ 2}}\right)$$

$$= (75.0\ \text{kg})\left(\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(7.349\times10^{22}\ \text{kg})}{(1.737\times10^6\ \text{m})^2}\right)$$

$= 120$ **N**

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**Chapter 7 continued**

**20.** Jupiter has a mass of $1.90\times10^{27}$ kg and a radius of $7.145\times10^{4}$ km. Earth has a mass of $5.98\times10^{24}$ kg and a radius of $6.38\times10^{6}$ m. How many times their Earth weight would a 75.0-kg person weigh when standing on the surface of Jupiter? (Assume Jupiter has a solid surface to stand on.)

$$\frac{F_J}{F_E} = \frac{mg_J}{mg_E} = \frac{g_J}{g_E}$$

$$= \frac{\frac{GM_J}{r_J^2}}{\frac{GM_E}{r_E^2}} = \frac{M_J(r_E)^2}{M_E(r_J)^2}$$

$$= \frac{(1.90\times10^{27}\text{ kg})(6.38\times10^{6}\text{ m})^2}{(5.98\times10^{24}\text{ kg})(7.145\times10^{7})^2}$$

**= 2.53 times their weight on Earth.**

**21.** A 5.0 kg mass weighs 8.1 N on the surface of the Moon. If the radius of the Moon is 1737 km, what is the mass of the Moon?

$$F_{g,\text{ Moon}} = mg_{\text{Moon}}$$

$$g_{\text{Moon}} = \frac{F_{g,\text{ Moon}}}{m}$$

$$= \frac{GM_{\text{Moon}}}{r^2}$$

$$M_{\text{Moon}} = \frac{r^2F_{g,\text{ Moon}}}{Gm}$$

$$= \frac{(1.737\times10^{6}\text{ m})(8.1\text{ N})}{(6.67\times10^{-11}\text{ N}\cdot\text{m}^2/\text{kg}^2)(5.0\text{ kg})}$$

$$= 7.3\times10^{22}\text{ kg}$$

**22.** Acceleration due to gravity on Earth's surface is $9.80\text{ m/s}^2$. Thus, a 1.00 kg mass weighs 9.80 N on the surface of Earth. If the radius of Earth was cut exactly in half but the mass of Earth remained unchanged, how much would a 1.00-kg mass weigh on the surface of Earth?

**Because the gravitational force is inversely related to $\frac{1}{r^2}$, the 1.00-kg mass would weigh $\frac{1}{\left(\frac{1}{2}r\right)^2} = 4$ times as much.**

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# Chapter 8

**1.** Jupiter, the largest planet in our solar system, rotates around its own axis in 9.84 h. The diameter of Jupiter is $1.43\times10^8$ m.

**a.** What is the angular speed of Jupiter's rotation in rad/s?

$$\left(\frac{1\ \text{rev}}{9.84\ \text{h}}\right)\left(\frac{2\pi\ \text{rad}}{1\ \text{rev}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right) = 1.77\times10^{-4}\ \text{rad/s}$$

**b.** What is the linear speed of a point on Jupiter's equator, due to Jupiter's rotation?

$$r = \frac{d}{2} = \frac{1.43\times10^8\ \text{m}}{2} = 7.15\times10^7\ \text{m}$$

$$\begin{aligned} v &= r\omega \\ &= (7.15\times10^7\ \text{m})(1.77\times10^{-4}\ \text{rad/s}) \\ &= 1.27\times10^4\ \text{m/s} \end{aligned}$$

**2.** A computer disk drive optimizes the data transfer rate by rotating the disk at a constant angular speed of 34.1 rad/s while it is being read. When the computer is searching for one of your files, the disk spins for 0.892 s.

**a.** What is the angular displacement of the disk during this time?

$$\omega = \frac{\Delta\theta}{\Delta t}$$

$$\begin{aligned} \Delta\theta &= \omega\Delta t \\ &= (34.1\ \text{rad/s})(0.892\ \text{s}) \\ &= 30.4\ \text{rad} \end{aligned}$$

**b.** Through how many revolutions does the disk turn during this time?

$$\Delta\theta = (30.4\ \text{rad})\left(\frac{1\ \text{rev}}{2\pi\ \text{rad}}\right) = 4.84\ \text{revolutions}$$

**3.** You are doing your laundry. When the washing machine goes into its spin cycle, the tub starts from an angular speed of 2.30 rad/s, then speeds up smoothly for 8.00 s, until it is turning at 5.00 rev/s. Calculate the angular acceleration of the tub during this time.

$$\omega_i = 2.30\ \text{rad/s}$$

$$\omega_f = \left(\frac{5.00\ \text{rev}}{1\ \text{s}}\right)\left(\frac{2\pi\ \text{rad}}{1\ \text{rev}}\right) = 10.0\pi\ \text{rad/s}$$

$$\begin{aligned} \alpha &= \frac{\Delta\omega}{\Delta t} \\ &= \frac{\omega_f - \omega_i}{\Delta t} \\ &= \frac{10.0\pi\ \text{rad/s} - 2.30\ \text{rad/s}}{8.00\ \text{s}} \\ &= 3.64\ \text{rad/s}^2 \end{aligned}$$

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**4.** One of the beaters of an electric mixer is shown below. What is the centripetal acceleration of the outer part of a blade as it rotates at a rate of 1200 rev/min?


**Method one:** $a_c = \frac{v^2}{r}$

$\omega = 1200$ rev/min

$= \left(\frac{1200 \text{ rev}}{1 \text{ min}}\right)\left(\frac{2\pi \text{ rad}}{1 \text{ rev}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right)$

$= 125.7$ rad/s

$r = \frac{d}{2} = \frac{4.60 \text{ cm}}{2} = \frac{1 \text{ m}}{100 \text{ cm}} = 2.30\times10^{-2}$ m

$v = r\omega$

$= (2.30\times10^{-2} \text{ m})(125.7 \text{ rad/s})$

$= 2.89$ m/s

$a_c = \frac{v^2}{r} = \frac{(2.89 \text{ m/s})^2}{2.30\times10^{-2} \text{ m}}$

$= 3.6\times10^2 \text{ m/s}^2$

**Method two:** $a_c = \frac{4\pi^2 r}{T^2}$

$T = \left(\frac{60 \text{ s}}{1 \text{ min}}\right)\left(\frac{1 \text{ min}}{1200 \text{ rev}}\right)$

$= 5.0\times10^{-2}$ s

$a_c = \frac{4\pi^2 r}{T^2}$

$= \frac{4\pi^2(2.30\times10^{-2} \text{ m})}{(5.0\times10^{-2} \text{ s})^2}$

$= 3.6\times10^2 \text{ m/s}^2$

**5.** A tractor wheel has a radius of 0.84 m. How far does a point on the wheel's edge move when the wheel is rotated through an angle of 67°?

$\theta = 67°\left(\frac{2\pi \text{ rad}}{360°}\right)$

$d = r\theta = (0.84 \text{ m})\frac{67°(2\pi \text{ rad})}{360°}$

$= 0.98$ m

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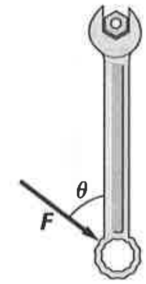
**Chapter 8 continued**

6. In order for a bolt to be tightened, a torque of 45.0 N·m is needed. You use a 0.341-m long wrench, and you exert a maximum force of 189 N at an angle as shown to the right. What is the smallest angle, with respect to the wrench, at which you can exert this force and still tighten the bolt?




**$\tau = Fr \sin \theta$**

**$\sin \theta = \frac{\tau}{Fr}$**

**$\theta_{min} = \sin^{-1}\left(\frac{\tau}{F_{max}r}\right)$**

**$= \sin^{-1}\left(\frac{45.0\ N\cdot m}{(189\ N)(0.341\ m)}\right)$**

**$= 44.3°$**

7. Chloe, whose mass is 56 kg, sits 1.2 m from the center of a seesaw. Josh, whose mass is 84 kg, wants to balance Chloe. Where on the seesaw should Josh sit?

**$\tau_{net} = 0$**

**To balance, torques must be equal and opposite in direction.**

**$\tau_C - \tau_J = 0$**

**$F_{gC}r_C - F_{gJ}r_J = 0$**

**$F_{gJ}r_J = F_{gC}r_C$**

**$r_J = \frac{F_{gC}r_C}{F_{gJ}}$**

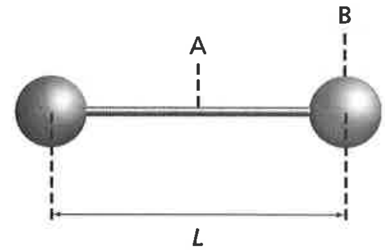
**$= \frac{m_C g r_C}{m_J g} = \frac{m_C r_C}{m_J}$**

**$= \frac{(56\ kg)(1.2\ m)}{(84\ kg)}$**

**$= 0.80\ m$**

**Josh should sit 0.80 m from the center of the seesaw, on the opposite side from Chloe.**

8. An athlete exercises using a dumbbell consisting of a long, thin, lightweight rod with a heavy sphere at each end, as shown below. The length of the rod is $L = 0.78$ m, and the mass of each sphere is 22.0 kg. The mass of the rod can be neglected.




a. Find the moment of inertia of the system for rotation about axis A, at the midpoint between the two spheres.

**For rotation about the center of the rod:**

**$I_{one\ sphere} = mr^2$**

**$r = \frac{L}{2} = \frac{(0.78\ m)}{2}$**

**$= 0.39\ m$**

**$I_{one\ sphere} = (22.0\ kg)(0.39\ m)^2$**

**$I_{system} = 2I_{one\ sphere}$**

**$= 2\left((22.0\ kg)(0.39\ m)^2\right)$**

**$= 6.7\ kg\cdot m^2$**

b. Find the moment of inertia of the system for rotation about axis B, at one end of the rod.

**For rotation about one end of the rod:**

**$I_{one\ sphere} = mr^2$**

**$r = L = 0.78\ m$**

**$I_{one\ sphere} = (22.0\ kg)(0.78\ m)^2$**

**$= 13\ kg\cdot m^2$**

**$I_{system} = I_{one\ sphere}$**

**$= 13\ kg\cdot m^2$**

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$$\alpha = \frac{\Delta\omega}{\Delta t}$$
$$= \frac{\omega_f - \omega_i}{t_f - t_i}$$
$$= \frac{0.524 \text{ rad/s} - 0.0 \text{ rad/s}}{45.0 \text{ s} - 0.0 \text{ s}}$$
$$= 0.012 \text{ rad/s}^2$$

**14.** A 75.0-g mass is attached to a 1.0-m length of string and whirled around in the air at a rate of 4.0 rev/s when the string breaks.

**a.** What was the breaking force of the string?

$$F = ma_c$$
$$= \frac{mv^2}{r} \text{ and } v = r\omega$$
$$= \frac{m(r\omega)^2}{r}$$
$$= mr\omega^2$$
$$= (0.0750 \text{ kg})(1.0 \text{ m})\left(\frac{2\pi \text{ rad}}{1 \text{ rev}}\right)(4.0 \text{ rev/s})^2$$
$$= 47 \text{ N}$$

**b.** What was the linear velocity of the mass as soon as the string broke?

$$v = r\omega$$
$$= (1.0 \text{ m})\left(\frac{2\pi \text{ rad}}{\text{rev}}\right)(4.0 \text{ rev/s})$$
$$= 25 \text{ m/s}$$

**15.** A 2.0-g coin is placed on a flat turntable at a distance of 5.0 cm from the center of rotation. The turntable rotates at a rate of 1.0 rev/s and the coin rides without slipping.

**a.** What is the linear speed of the coin?

$$v = r\omega$$
$$= (0.050 \text{ m})\left(\frac{2\pi \text{ rad}}{\text{rev}}\right)(1.0 \text{ rev/s})$$
$$= 0.31 \text{ m/s}$$

**b.** What is the centripetal acceleration of the coin?

$$a_c = \frac{v^2}{r}$$
$$= \frac{(0.31 \text{ m/s})^2}{(0.050 \text{ m})}$$
$$= 1.9 \text{ m/s}^2$$

**c.** What is the frictional force keeping the coin from slipping?

$$F_f = F_c$$
$$= ma_c$$
$$= (0.0020 \text{ kg})(1.9 \text{ m/s}^2)$$
$$= 3.8\times10^{-3} \text{ N}$$

**16.** A grocer wants to measure out exactly 500.0 g of rice using an old balance scale. The quantity of rice is placed on a pad 4.5 cm from the pivot point and small metal weights are placed on the opposite end 28.0 cm from the pivot point until the scale balances. How much weight should the grocer use to measure out the necessary quantity of rice?

$$\tau_1 - \tau_2 = F_1r_1 - F_2r_2 = m_1gr_1 - m_2gr_2 = 0$$
$$m_1gr_1 = m_2gr_2$$
$$m_2 = \frac{m_1r_1}{r_2}$$
$$= \frac{(0.5000 \text{ kg})(0.045 \text{ m})}{0.28 \text{ m}}$$
$$= 0.080 \text{ kg}$$
$$= 8.0\times10^1 \text{ g}$$

**17.** You have an irregular flat object mounted on a table so it can rotate freely about a central axis. You observe that if you apply a perpendicular force of 5.5 N at a distance of 24.0 cm from the axis of rotation, you can accelerate the object from rest to 3.0 rev/s in just 1.0 s. What is the moment of inertia for this irregular object?

$$\alpha = \frac{\tau_{net}}{I}$$
$$I = \frac{\tau_{net}}{\alpha}$$
$$\alpha = \frac{\Delta\omega}{\Delta\tau}$$
$$\tau_{net} = Fr \sin\theta$$

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**Chapter 8 continued**

Thus,

$$I = \frac{Fr \sin \theta}{\left(\frac{\Delta\omega}{\Delta\tau}\right)}$$

$$= \frac{(5.5\ \text{N})(0.240\ \text{m})(\sin 90.0°)}{\left(\frac{(3.0\ \text{rev/s})(2\pi\ \text{rad})}{1.0\text{s}}\right)}$$

$$= 0.070\ \text{kg·m}^2$$

18. A wagon wheel that is 1.60 m in diameter is mounted vertically so it can turn freely. You grab one of the spokes of the wheel near the outer rim and pull down with 25 N of force. The spoke that you grip on the wheel makes an angle of 40.0° with the horizontal before you apply the force.

**a.** How much torque do you apply to the wheel? Assume that the rim thickness is negligible so that you are applying the force 0.80 m from the center of the wheel.

$$\tau = Fr \sin \theta$$
$$= (25\ \text{N})(0.80\ \text{m})(\sin 40.0°)$$
$$= 13\ \text{N·m}$$

**b.** If this wheel has a mass of 15 kg, what is its moment of inertia? Disregard the mass of the spokes.

$$I = mr^2$$
$$= (15\ \text{kg})(0.80\ \text{m})^2$$
$$= 9.6\ \text{kg·m}^2$$

**c.** What is the angular acceleration of this wheel as you turn it?

$$\alpha = \frac{\tau_{\text{net}}}{I} = \frac{13\ \text{N·m}}{9.6\ \text{kg·m}^2} = 1.4\ \text{rad/s}^2$$

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# Chapter 9

1. A golfer uses a club to hit a 45-g golf ball resting on an elevated tee, so that the golf ball leaves the tee at a horizontal speed of +38 m/s.

   **a.** What is the impulse on the golf ball?

   $\text{Impulse} = F\Delta t = m\Delta v$

   $F\Delta t = mv_f - mv_i$
   $= mv_f - 0$
   $= (0.045 \text{ kg})(+38 \text{ m/s})$
   $= +1.7 \text{ kg·m/s or } +1.7 \text{ N·s}$

   **b.** What is the average force that the club exerts on the golf ball if they are in contact for $2.0\times10^{-3}$ s?

   $F\Delta t = \text{Impulse} = 1.7 \text{ N·s}$

   $F = \frac{\text{Impulse}}{\Delta t}$
   $= \frac{+1.7 \text{ N·s}}{2.0\times10^{-3} \text{ s}}$
   $= +8.5\times10^2 \text{ N}$

   **c.** What average force does the golf ball exert on the club during this time interval?

   $F_{\text{golf ball on club}} = -F_{\text{club on golf ball}}$

   $F_{\text{club on golf ball}} = +8.5\times10^2 \text{ N}$

   $F_{\text{golf ball on club}} = -8.5\times10^2 \text{ N}$

2. A 0.0420-kg hollow racquetball with an initial speed of 12.0 m/s collides with a backboard. It rebounds with a speed of 6.0 m/s.

   **a.** Calculate the total impulse on the ball.

   $\text{impulse} = F\Delta t = m\Delta v$
   $= (0.0420 \text{ kg})$
   $(12.0 \text{ m/s} - 6.0 \text{ m/s})$
   $= 0.25 \text{ kg·m/s}$

   **b.** If the contact time lasts for 0.040 s, calculate the average force on the ball.

   $\text{impulse} = F\Delta t$

   $F = \frac{\text{impulse}}{\Delta t}$
   $= \frac{0.25 \text{ kg·m/s}}{0.040 \text{ s}}$
   $= 6.2 \text{ N}$

3. After dropping from a height of 1.50 m onto a concrete floor, a 50.0-g ball rebounds to a height of 0.90 m.

   **a.** Find the impulse acting on the ball as it dropped.

   $v_f^2 = v_i^2 - 2g(d_f - d_i)$
   $v_i = 0,\ d_f = 0$
   $v_f^2 = \pm 2gd_i$
   $v_f = \pm\sqrt{2gd_i}$
   $= \pm\sqrt{2(9.80 \text{ m/s}^2)(1.50 \text{ m})}$
   $= -5.42$ m/s (negative, since downward)

   $\text{Impulse} = F\Delta t = m\Delta v$

   $F\Delta t = mv_f - mv_i$
   $= mv_f - 0$
   $= (0.050 \text{ kg})(-5.42 \text{ m/s})$
   $= -0.27 \text{ kg·m/s or } -0.27 \text{ N·s}$

   **b.** Find the impulse acting on the ball as it rebounds.

   $v_f^2 = v_i^2 - 2g(d_f - d_i)$
   $v_f = 0,\ d_i = 0$
   $0 = v_i^2 - 2gd_f$
   $v_i = \pm\sqrt{2gd_f}$
   $= \sqrt{2(9.80 \text{ m/s}^2)(0.90 \text{ m})}$
   $= +4.2$ m/s (positive, since upward)

   $\text{Impulse} = F\Delta t = m\Delta v$

   $F\Delta t = mv_f - mv_i$
   $= 0 - mv_i$
   $= -(0.050 \text{ kg})(4.2 \text{ m/s})$
   $= -0.21 \text{ kg·m/s or } -0.21 \text{ N·s}$

   **c.** Find the impulse on the ball while it was in contact with the floor.

   $\text{Impulse} = F\Delta t = m\Delta v$

   $F\Delta t = mv_f - mv_i$
   $= (0.050 \text{ kg})(4.2 \text{ m/s}) - (0.050 \text{ kg})(-5.42 \text{ m/s})$
   $= 0.48 \text{ kg·m/s or } 0.48 \text{ N·s}$

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**Chapter 9 continued**

4. A tennis player receives a shot with the 60.0-g ball traveling horizontally at −50.0 m/s, and returns the shot with the ball traveling horizontally. The tennis ball and the tennis racket are in contact for $1.00\times10^{-3}$ s. The average force exerted on the ball by the tennis racket is $5.70\times10^{3}$ N. Find the speed of the tennis ball after it leaves the racket.

**Impulse** $= F\Delta t = m\Delta v$

$F\Delta t = mv_f - mv_i$

$$v_f = \frac{F\Delta t + mv_i}{m}$$

$$= \frac{(5.70\times10^{3}\text{ N})(1.00\times10^{-3}\text{ s}) + (0.0600\text{ kg})(-50.0\text{ m/s})}{0.0600\text{ kg}}$$

$= +45.0$ **m/s (i.e., traveling in the opposite direction)**

5. A 180-kg crate is sitting on the flatbed of a moving truck. The coefficient of sliding friction between the crate and the truck bed is 0.30. Two taut cables are attached to the crate, one on each side. Each cable can exert a maximum horizontal force of 650 N either forward or backward if the crate begins to slide. If the truck stops in 1.8 s, what is the maximum speed the truck could have been moving without breaking the cables?

***y*-direction:**

$F_N = F_g$

$= mg$

***x*-direction:**

$F_{net} = F_f + 2F_{cable}$

$F_f = \mu_k$

$F_N = \mu_k mg$

$F\Delta t = m\Delta v$

$(F_f + 2F_{cable})\Delta t = mv_f - mv_i$

$= 0 - mv_i$

$$v_i = -\frac{(F_f + 2F_{cable})\Delta t}{m}$$

$$= -\frac{(\mu_k mg + 2F_{cable})\Delta t}{m}$$

$$= -\left(\mu_k g + \frac{2F_{cable}}{m}\right)\Delta t$$

$$= -\left((0.30)(9.80\text{ m/s}^2) + \frac{2(650\text{ N})}{180\text{ kg}}\right)(1.8\text{ s})$$

$= -18$ m/s

**18 m/s in a direction opposite to the forces from the cables and friction**

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**Chapter 9 continued**

6. A single uranium atom has a mass of $3.97\times10^{-25}$ kg. It decays into the nucleus of a thorium atom by emitting an alpha particle at a speed of $2.10\times10^{7}$ m/s. The mass of an alpha particle is $6.68\times10^{-27}$ kg. What is the recoil speed of the thorium nucleus?

**$p_f = p_i$ by conservation of momentum**

$$m_\alpha v_\alpha + m_{Th}v_{Th} = m_U v_U$$

$$v_U = 0 \text{ m/s}$$

$$v_{Th} = \frac{m_\alpha v_\alpha}{m_{Th}}$$

$$m_\alpha + m_{Th} = m_U$$

$$m_{Th} = m_U - m_\alpha$$

$$v_{Th} = -\frac{m_\alpha v_\alpha}{m_U - m_\alpha}$$

$$= -\frac{(6.68\times10^{-27}\text{ kg})(2.10\times10^{7}\text{m/s})}{3.97\times10^{-25}\text{ kg} - 6.68\times10^{-27}\text{ kg}}$$

$$= -3.59\times10^{5}\text{ m/s}$$

7. A 10.0-g bullet is fired into a stationary 5.00-kg block of wood. The bullet lodges inside the block. The speed of the block-plus-bullet system immediately after the collision is measured as 0.600 m/s. What was the original speed of the bullet?

$$p_f = p_i$$

$$= p_{bullet,\,i} + p_{block,\,i}$$

$$(m_{bullet} + m_{block})v_f = m_{bullet}v_{bullet,\,i} + m_{block}v_{block,\,i}$$

$$= m_{bullet}v_{bullet,\,i} + 0$$

$$v_{bullet,\,i} = \frac{(m_{bullet} + m_{block})v_f}{m_{bullet}}$$

$$= \frac{(1.00\times10^{-2}\text{ kg} + 5.00\text{ kg})(0.600\text{ m/s})}{1.00\times10^{-2}\text{ kg}}$$

$$= 301\text{ m/s}$$

8. Aisha is sitting on frictionless ice and holding two heavy ski boots. Aisha weighs 637 N, and each boot has a mass of 4.50 kg. Aisha throws both boots forward at the same time, at a velocity of 6.00 m/s relative to her. What is Aisha's resulting velocity?

$$p_{Af} + p_{Bf} = p_{Ai} + p_{Bi}$$

$$m_{Aisha}v_{Aisha,\,f} + 2m_{boot}v_{boot,\,f} = (m_{Aisha} + 2m_{boot})v_i$$

$$= 0$$

$$v_{Aisha,\,f} = -\frac{2m_{boot}v_{boot,\,f}}{m_{Aisha}}$$

$$m_{Aisha} = \frac{F_{g,\,Aisha}}{g} = \frac{637\text{ N}}{9.80\text{ m/s}^2} = 65.0\text{ kg}$$

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**Chapter 9 continued**

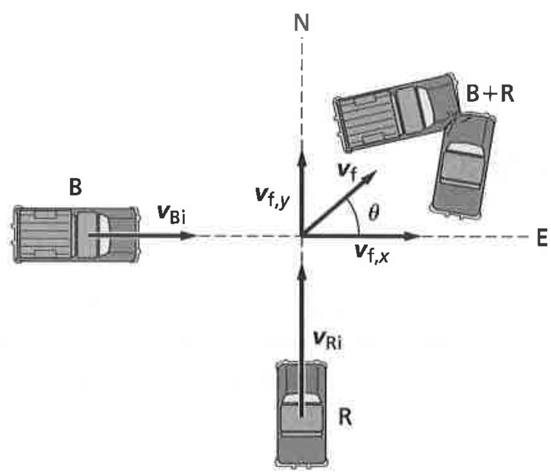
$$v_{\text{Aisha, f}} = -\frac{2(4.50\text{ kg})(6.00\text{ m/s})}{65.0\text{ kg}}$$

$= -0.831$ **m/s**

$=$ **0.831 m/s backward or in the direction opposite to the thrown boots**

**9.** Two cars enter an icy intersection. A blue car with a mass of $2.50\times10^3$ kg is heading east at 20.0 m/s, and a red car with a mass of $1.45\times10^3$ kg is going north at 30.0 m/s. The two vehicles collide and stick together. Determine the speed and direction of the cars as they skid away together just after colliding.

$p_{(B + R)f} = p_{Bi} + p_{Ri}$




***x*-direction:**

$p_{(B + R)f, x} = p_{Bi, x} + p_{Ri, x}$

$m_{(B + R)}v_{f, x} = m_B v_{Bi, x} + m_R v_{Ri, x}$

$$v_{f, x} = \frac{m_B v_{Bi, x} + m_R v_{Ri, x}}{m_{(B + R)}}$$

$v_{Ri, x} = 0$

$$v_{f, x} = \frac{(2.50\times10^3\text{ kg})(20.0\text{ m/s})}{2.50\times10^3\text{ kg} + 1.45\times10^3\text{ kg}}$$

$= 12.66$ m/s

***y*-direction:**

$p_{(B + R)f, y} = p_{Bi, y} + p_{Ri, y}$

$m_{(B + R)}v_{f, y} = m_B v_{Bi, y} + m_R v_{Ri, y}$

$$v_{f, y} = \frac{m_B v_{Bi, y} + m_R v_{Ri, y}}{m_{(B + R)}}$$

$v_{Bi, y} = 0$

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**Chapter 9 continued**

$$v_{f,y} = \frac{(1.45\times10^3\ \text{kg})(30.0\ \text{m/s})}{2.50\times10^3\ \text{kg} + 1.45\times10^3\ \text{kg}}$$
$$= 11.01\ \text{m/s}$$

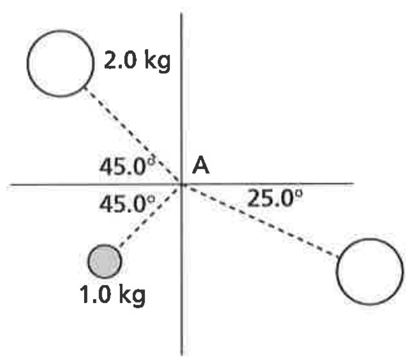
$$v_f = \sqrt{v_{f,x}^{\,2} + v_{f,y}^{\,2}}$$
$$= \sqrt{(12.66\ \text{m/s})^2 + (11.01\ \text{m/s})^2}$$
$$= 16.8\ \text{m/s}$$

$$\tan\theta = \frac{v_{f,y}}{v_{f,x}}$$

$$\theta = \tan^{-1}\left(\frac{v_{f,y}}{v_{f,x}}\right)$$
$$= \tan^{-1}\left(\frac{11.01\ \text{m/s}}{12.66\ \text{m/s}}\right)$$
$$= 41.0°$$

**$v_f$ = 16.8 m/s at 41.0° north of east**

**10.** A 2.00-kg puck moving to the right at a velocity of 6.00 m/s at an angle of 45.0° below the horizontal collides at point A with a 1.00-kg puck traveling to the right at a velocity of 3.00 m/s at an angle of 45.0° above the horizontal, as shown below.
After the collision, the 2.0-kg puck moves toward the right at a velocity of 4.50 m/s at an angle of 25.0° below the horizontal. What is the velocity of the 1.0-kg puck immediately after the collision?




$$p_{Cf} + p_{Df} = p_{Ci} + p_{Di}$$

***x*-direction:**

$$p_{Cf,x} + p_{Df,x} = p_{Ci,x} + p_{Di,x}$$
$$= p_{Ci,x} + p_{Di,x} - p_{Cf,x}$$

$$m_D v_{Df,x} = m_C v_{Ci,x} + m_D v_{Di,x} - m_C v_{Cf,x}$$

$$v_{Df,x} = \frac{m_C v_{Ci,x} + m_D v_{Di,x} - m_C v_{Cf,x}}{m_D}$$

$$m_C v_{Ci,x} = (2.00\ \text{kg})(6.00\ \text{m/s})(\cos(-45.0°))$$
$$= 8.485\ \text{kg·m/s}$$

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$m_D v_{Di,\,x} = (1.00\text{ kg})(3.00\text{ m/s})(\cos 45.0°)$

$= 2.121\text{ kg·m/s}$

$m_C v_{Cf,\,x} = (2.00\text{ kg})(4.50\text{ m/s})(\cos(-25.0°))$

$= 8.157\text{ kg·m/s}$

$$v_{Df,\,x} = \frac{(8.485\text{ kg·m/s}) + (2.121\text{ kg·m/s}) - (8.157\text{ kg·m/s})}{1.00\text{ kg}}$$

$= 2.45\text{ m/s}$

*y*-direction:

$p_{Cf,\,y} + p_{Df,\,y} = p_{Ci,\,y} + p_{Di,\,y}$

$p_{Df,\,y} = p_{Ci,\,y} + p_{Di,\,y} - p_{Cf,\,y}$

$m_D v_{Df,\,y} = m_C v_{Ci,\,y} + m_D v_{Di,\,y} - m_C v_{Cf,\,y}$

$$v_{Df,\,y} = \frac{m_C v_{Ci,\,y} + m_D v_{Di,\,y} - m_C v_{Cf,\,y}}{m_D}$$

$m_C v_{Ci,\,y} = (2.00\text{ kg})(6.00\text{ m/s})(\sin(-45.0°)) = -8.485\text{ kg·m/s}$

$m_D v_{Di,\,y} = (1.00\text{ kg})(3.00\text{ m/s})(\sin 45.0°) = 2.121\text{ kg·m/s}$

$m_C v_{Cf,\,y} = (2.00\text{ kg})(4.50\text{ m/s})(\sin(-25.0°)) = -3.804\text{ kg·m/s}$

$$v_{Df,\,y} = \frac{(-8.485\text{ kg·m/s}) + (2.121\text{ kg·m/s}) - (-3.804\text{ kg·m/s})}{1.00\text{ kg}}$$

$= -2.56\text{ m/s}$

$v_{Df} = \sqrt{v_{Df,\,x}^2 + v_{Df,\,y}^2}$

$= \sqrt{(2.45\text{ m/s})^2 + (-2.56\text{ m/s})^2}$

$= 3.54\text{ m/s}$

$$\tan\theta = \frac{v_{Df,\,y}}{v_{Df,\,x}}$$

$$\theta = \tan^{-1}\left(\frac{v_{Df,\,y}}{v_{Df,\,x}}\right)$$

$$= \tan^{-1}\left(\frac{-2.56\text{ m/s}}{2.45\text{ m/s}}\right)$$

$= -46.3°$

$v_{Df} = 3.54$ m/s to the right, at 46.3° below the horizontal

**11.** At 9.0 s after takeoff, a 250-kg rocket attains a vertical velocity of 120 m/s.

**a.** What is the impulse on the rocket?

$F\Delta t = p_f - p_i$

$= mv_f - mv_i$

$= m(v_f - v_i)$

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$= 250\ \text{kg}(120\ \text{m/s} - 0.0\ \text{m/s})$

$= 3.0\times10^4\ \text{kg·m/s}$

**b.** What is the average force on the rocket?

$$F = \frac{p_f - p_i}{\Delta t} = \frac{3.0\times10^4\ \text{kg·m/s}}{9.0\ \text{s}}$$

$= 3.3\times10^3\ \text{N}$

**c.** What is its altitude?

$v_i = 0.0\ \text{m/s} \qquad d_i = 0.0\ \text{m}$

$v_f^2 = v_i^2 + 2a(d_f - d_i)$ and $a = \dfrac{F}{m}$

$$d_f = \frac{v_f^2 - v_i^2 + 2ad_i}{2a} = \frac{v_f^2 - v_i^2 + 2\left(\frac{F}{m}\right)d_i}{2\left(\frac{F}{m}\right)}$$

$$= \frac{v_f^2 - 0 + 2\left(\frac{F}{m}\right)(0)}{2\left(\frac{F}{m}\right)}$$

$$= \frac{v_f^2}{2\left(\frac{F}{m}\right)}$$

$$= \frac{(120\ \text{m/s})^2}{2\left(\frac{3.3\times10^3\ \text{N}}{250\ \text{kg}}\right)}$$

$= 5.5\times10^2\ \text{m}$

**12.** In a circus act, a 18-kg dog is trained to jump onto a 3.0-kg skateboard moving with a velocity of 0.14 m/s. At what velocity does the dog jump onto the skateboard if afterward the velocity of the dog and skateboard is −0.10 m/s?

$p_{di} + p_{si} = p_f$

$m_d v_{di} + m_s v_{si} = (m_d + m_s)v_f$

$$v_{di} = \frac{(m_d + m_s)v_f - m_s v_{si}}{m_d}$$

$$= \frac{(18\ \text{kg} + 3.0\ \text{kg})(0.10\ \text{m/s}) - (3.0\ \text{kg})(0.14\ \text{m/s})}{18\ \text{kg}}$$

$= -0.14\ \text{m/s}$

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**Chapter 9 continued**

**13.** While sitting in a stationary wagon, a girl catches a 2.6-kg medicine ball moving at a speed of 2.7 m/s.

**a.** If the 11-kg wagon is on frictionless wheels, what is the velocity of the girl, wagon, and ball after she has caught the ball? The girl's mass is 55 kg. Ignore friction between the wheels and the road.

$$p_f = p_{\text{ball, i}} + p_{\text{(girl + wagon) i}}$$

$$(m_{\text{girl}} + m_{\text{wagon}} + m_{\text{ball}})v_f = m_{\text{ball}}v_{\text{ball, i}} + (m_{\text{girl}} + m_{\text{wagon}})v_{\text{girl, wagon, i}}$$

**$v_1 = 0$, assume motion in the direction of the thrown ball as positive**

$$v_f = \frac{m_{\text{ball}}v_{\text{ball i}}}{(m_{\text{girl}} + m_{\text{wagon}} + m_{\text{ball}})}$$

$$= \frac{(2.6\text{ kg})(2.7\text{ m/s})}{(55\text{ kg} + 11\text{ kg} + 2.7\text{ kg})}$$

**= 0.10 m/s, in the direction of the thrown ball**

**b.** The girl then throws the ball back at a speed of 2.7 m/s relative to the wagon. What is the velocity of the girl and the wagon right after she has thrown the ball?

$$v_{\text{f, part a}} = 0.10\text{ m/s} = v_i$$

$$p_{\text{ball, f}} + p_{\text{(girl + wagon) f}} = p_{\text{(girl + wagon + ball) i}}$$

$$m_{\text{ball}}v_{\text{ball, f}} + (m_{\text{girl}} + m_{\text{wagon}})v_{\text{girl, wagon, f}}$$

$$= (m_{\text{girl}} + m_{\text{wagon}} + m_{\text{ball}})v_{\text{(girl + wagon + ball) i}}$$

$$v_{\text{(girl + wagon) f}} = \frac{(m_{\text{girl}} + m_{\text{wagon}} + m_{\text{ball}})v_{\text{(girl + wagon + ball) i}} - m_{\text{ball}}v_{\text{ball, f}}}{m_{\text{girl}} + m_{\text{wagon}}}$$

$$v_{\text{(girl + wagon + ball) i}} = v_f \text{ from part a}$$

$$= 0.10\text{ m/s}$$

$$v_{\text{(girl + wagon) f}}$$

$$= \frac{(55\text{ kg} + 11\text{ kg} + 2.6\text{ kg})(0.10\text{ m/s}) - (2.6\text{ kg})(-2.7\text{ m/s} + 0.10\text{ m/s})}{(55\text{ kg} + 11\text{ kg})}$$

**= 0.21 m/s, in the same direction as part a**

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**Chapter 9 continued**

**14.** A collision between two identical pucks, one moving and the other stationary, takes place on ice. The puck with an initial momentum of 4.0 kg·m/s is deflected 60.0° eastward from its original path. Using the law of conservation of momentum, what is the momentum of the puck that was originally stationary after the collision?

$p_{1i} + p_{2i} = p_{1f} + p_{2f}$

$p_{1i} + 0 = p_{1f} + p_{2f}$

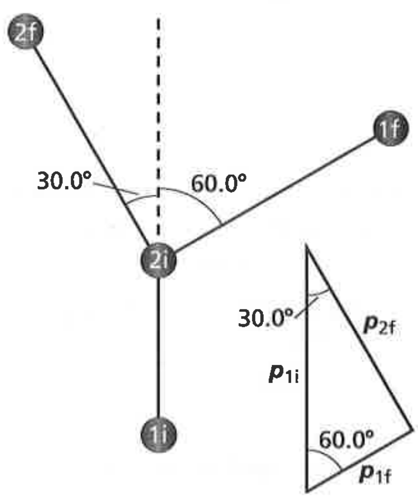
$p_{1i} = p_{1f} + p_{2f}$

$p_{1f} = p_{1i} \sin \theta = (4.0 \text{ kg·m/s})(\sin 60.0°)$

$= 3.5$ **kg·m/s, 60.0° east of north**

$p_{2f} = p_{1i} \cos \theta = (4.0 \text{ kg·m/s})(\cos 60.0°)$

$= 2.0$ **kg·m/s, 30.0° west of north**




# Chapter 10

**1.** A player pushes a 250-g hockey puck over frictionless ice with a constant force, causing it to accelerate at 24 m/s$^2$ over a distance of 50.0 cm.

**a.** Find the work done by the hockey player on the puck.

$W = Fd$

$F = ma$

$W = ma \times d$

$= (0.250 \text{ kg})(24 \text{ m/s}^2)(0.500 \text{ m})$

$= 3.0 \text{ kg·m}^2/\text{s}^2$

$= 3.0 \text{ J}$

**b.** What is the change in the kinetic energy of the puck?

$W = \Delta KE$

$\Delta KE = 3.0 \text{ J}$

**2.** You exert a horizontal force of 4.6 N on a textbook as you slide it 0.60 m across a library table to a friend.

**a.** Calculate the work you do on the book.

$W = Fd$

$= (4.6 \text{ N})(0.60 \text{ m})$

$= 2.8 \text{ J}$

**b.** Your friend returns the book by pushing it with a force of 6.2 N at an angle of 30.0° below the horizontal. What is the work done by your friend on the book?

$W = Fd \cos \theta$

$= (6.2 \text{ N})(0.60 \text{ m})(\cos(-30.0°))$

$= 3.2 \text{ J}$

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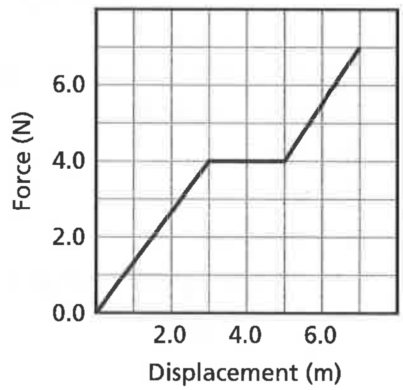
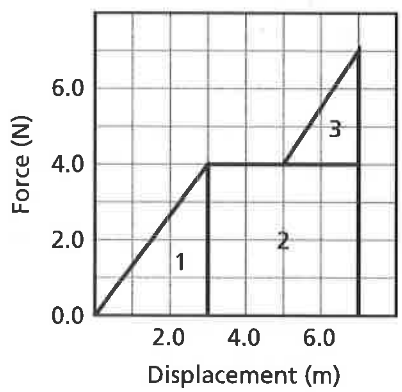
**Chapter 10 continued**

**3.** Shown below is a graph of force versus displacement for an object being pulled. Determine the work done by the force in pulling the object 7.0 m.




**$W$ = area under the curve**




$W = W_1 + W_2 + W_3$

$W_1$: **0.0 m → 3.0 m (triangle)**

$W_2$: **3.0 m → 7.0 m (rectangle)**

$W_3$: **5.0 m → 7.0 m (triangle)**

$$W = \frac{1}{2}(4.0\ \text{N})(3.0\ \text{m}) + (4.0\ \text{N})(4.0\ \text{m}) + \frac{1}{2}(3.0\ \text{N})(2.0\ \text{m})$$

$= 25\ \text{N·m}$

$= 25\ \text{J}$

**4.** A ski lift carries a 75.0-kg skier at 3.00 m/s for 1.50 min along a cable that is inclined at an angle of 40.0° above the horizontal.

**a.** How much work is done by the ski lift?

$F_y = F_g = mg$

$t = 1.50\ \text{min} = 90.0\ \text{s}$

**Length of incline:** $L = vt$

$d_y = L \sin\theta$

$= vt \sin\theta$

$W = F_y d_y$

$= mgvt \sin\theta$

$= (75.0\ \text{kg})(9.80\ \text{m/s}^2)(3.00\ \text{m/s})(90.0\ \text{s})(\sin 40.0°)$

$= 1.28\times10^5\ \text{J}$

**b.** How much power is expended by the ski lift?

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

$= \frac{1.28\times10^5\ \text{J}}{90.0\ \text{s}}$

$= 1.42\times10^3\ \text{W}$

$= 1.42\ \text{kW}$

**5.** An electric motor lifts an elevator at a constant speed of 54.0 km/h. The engine must exert a force of 9.00 kN in order to balance the weight of the elevator and the friction in the elevator cable. What power does the motor produce in kW?

$$v = \left(\frac{54.0\ \text{km}}{1\ \text{h}}\right)\left(\frac{1.000\times10^3\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)$$

$= 15.0\ \text{m/s}$

$P = Fv$

$= (9.00\times10^3\ \text{N})(15.0\ \text{m/s})$

$= 1.35\times10^5\ \text{W}$

$= 135\ \text{kW}$

**6.** Leah is helping to build a water habitat in a neighborhood park. The habitat includes an upper pond connected to a lower pond, 3.2 m below, by a trickling stream with several small cascades. At a home-building store, she finds a 45-W pump that has a maximum circulation rate of 1900 L of water per hour. Can the pump develop enough power to raise the water from the lower to the upper pond? (The mass density of water, $\rho$, is 1.00 kg/L)

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

$m = \rho V$

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**Chapter 10 continued**

$$P = \frac{\rho V g d}{t}$$

$$= \frac{(1.00\ \text{kg/L})(1900\ \text{L})(9.80\ \text{m/s}^2)(3.2\ \text{m})}{3600\ \text{s}}$$

$$= 17\ \text{W}$$

**Yes, the 45-W pump is powerful enough.**

7. Ali uses a pulley system to raise a 30.0-kg carton a vertical distance of 15.3 m. He exerts a force of 211 N and pulls the rope 28.0 m.

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

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

$$F_r = mg$$

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

$$= \frac{(30.0\ \text{kg})(9.80\ \text{m/s}^2)}{(211\ \text{N})}$$

$$= 1.39$$

   b. What is the efficiency of the system?

$$IMA = \frac{d_e}{d_r}$$

$$= \frac{28.0\ \text{m}}{15.3\ \text{m}}$$

$$= 1.83$$

$$e = \frac{MA}{IMA} \times 100$$

$$= \frac{1.39}{1.83} \times 100$$

$$= 76.0\%$$

8. Using a block-and-tackle, a mover takes up 18.5 m of rope to raise a 115-kg stove from the ground to a window ledge 3.7 m high. What force must he exert on the rope if the efficiency of the block-and-tackle is 63 percent?

$$e\ (\%) = \frac{W_o}{W_I} \times 100$$

$$e = \frac{F_r d_r}{F_e d_e} \times 100$$

$$F_e = \frac{F_r d_r}{e d_e} \times 100$$

$$F_r = mg$$

$$F_e = \frac{m g d_r}{e d_e} \times 100$$

$$= \frac{(115\ \text{kg})(9.80\ \text{m/s}^2)(3.7\ \text{m})}{(63\%)(18.5\ \text{m})} \times 100$$

$$= 3.6\times 10^2\ \text{N}$$

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**Chapter 10 continued**

**9.** Rohit lifts a 89-kg crate by exerting a force of 120 N on a lever, through a distance of 1.6 m. The efficiency of the lever is 92 percent. How far is the crate lifted?

$$e\,(\%) = \frac{MA}{IMA} \times 100$$

$$e = \frac{F_r d_r}{F_e d_e} \times 100$$

$$d_r = \frac{eF_e d_e}{100F_r}$$

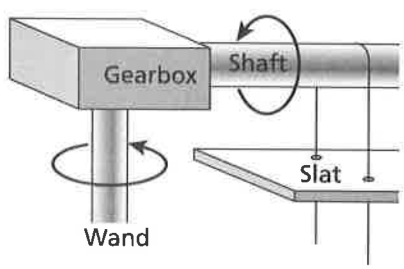
$$F_r = mg$$

$$d_r = \frac{eF_e d_e}{100\,mg}$$

$$= \frac{(92\%)(120\text{ N})(1.6\text{ m})}{(100)(89\text{ kg})(9.80\text{ m/s}^2)}$$

$$= 0.20\text{ m}$$

**10.** While unpacking a blind, Rahul sees that the shaft of the blind, which rotates the horizontal slats, is connected to a small gearbox. The gearbox also is connected to the wand, which is turned to open and close the slats, as shown below. Rahul measures the wand's diameter as 1.00 cm and the shaft's diameter as 1.25 cm. He notices that to rotate the slats 180°, the wand has to make three complete rotations. What ratio of gear teeth does the gearbox contain?




$$IMA = \frac{d_e}{d_r}$$

$$= \frac{\text{teeth on shaft gear}}{\text{teeth on wand gear}} \times \frac{\text{wand radius}}{\text{shaft radius}}$$

$$d_e = 3(2\pi)(\text{wand radius})$$

$$= 6\pi(\text{wand radius})$$

$$d_r = \frac{1}{2}(2\pi)(\text{shaft radius})$$

$$= \pi(\text{shaft radius})$$

$$\frac{d_e}{d_r} = \frac{6\pi(\text{wand radius})}{\pi(\text{shaft radius})}$$

$$= \frac{\text{teeth on shaft gear}}{\text{teeth on wand gear}} \times \frac{\text{wand radius}}{\text{shaft radius}}$$

$$\frac{\text{teeth on shaft gear}}{\text{teeth on wand gear}} = \frac{6}{1}$$

**11.** A gardener lifts a 25-kg bag of sand to a height of 1.1 m, carries it across the yard a distance of 15 m and sets it down against the wall.

**a.** How much work does the gardener do when he lifts the bag of sand?

$$W = Fd = mgd$$

$$= (25\text{ kg})(9.80\text{ m/s}^2)(1.1\text{ m})$$

$$= 270\text{ J}$$

**b.** How much total work is done after the gardener sets down the bag of sand?

**Zero; when the bag of sand is set down, it is returned to its original elevation. The work done in lifting the sand is equal and opposite to the work done in setting the sand back down on the ground. No work is done on the sand while the gardener carries it across the yard.**

**12.** A 0.300-kg baseball is thrown at a speed of 6.5 m/s. The batter hits the ball and it flies into the outfield at a speed of 19.2 m/s. How much work is done in hitting the baseball?

$$W = KE_f - KE_i$$

$$= \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$= \frac{1}{2}m(v_f^2 - v_i^2)$$

$$= \frac{1}{2}(0.300\text{ kg})((19.2\text{ m/s})^2 - (-6.5\text{ m/s})^2)$$

$$= 49\text{ J}$$

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**Chapter 10 continued**

**13.** A worker pushes a lawn mower with a force of 23.0 N, exerted along the direction of the handle and at a speed of 1.25 m/s across a lawn that is 18.5 m wide. The handle of the lawn mower makes an angle of 60.0° with the horizontal.

**a.** How much work is done by the worker?

$$W = Fd\cos\theta$$
$$= (23.0\text{ N})(18.5\text{ m})(\cos 60.0°)$$
$$= 213\text{ J}$$

**b.** If the worker is pushing as hard as possible, how else can the amount of work done be increased?

**Without increasing the force, more work can be done by reducing the angle $\theta$ that the handle of the lawn mower makes with the ground.**

**c.** How much power is exerted by the worker?

$P = \frac{W}{t}$ and $d = vt$

Thus, $t = \frac{d}{v}$ and

$$P = \frac{Wv}{d}$$
$$= \frac{(213\text{ J})(1.25\text{ m/s})}{185\text{ m}}$$
$$= 14.4\text{ kW}$$

**14.** Hoover Dam has a capacity for producing $2.0\times10^6$ kW of power. How much work is done by the turbines each day?

$$W = Pt$$
$$= (2.0\times10^9\text{ W})\left(\frac{3600\text{ s}}{1\text{ h}}\right)\left(\frac{24\text{ h}}{1\text{ day}}\right)$$
$$= 1.7\times10^{14}\text{ J}$$

**15.** Calculate the efficiency of a pulley system when an effort of 200 N of force acting through 10 m lifts a mass of 90 kg a distance of 2.0 m.

$$e = \frac{W_o}{W_I}\times 100$$
$$= \frac{F_rd_r}{F_ed_e}\times 100$$
$$= \frac{(90\text{ kg})(9.80\text{ m/s}^2)(2.0\text{ m})}{(200\text{ N})(10\text{ m})}\times 100$$
$$= 90\%$$

**16.** A particular lever-and-fulcrum system provides a mechanical advantage of 3.5.

**a.** If you are able to exert $4.0\times10^2$ N of force, what is the largest mass you could lift with this lever system?

$$MA = \frac{F_r}{F_e} = \frac{mg}{F_e}$$
$$m = \frac{MA(F_e)}{g}$$
$$= \frac{(3.5)(4.0\times10^2\text{ N})}{9.80\text{ m/s}^2}$$
$$= 140\text{ kg}$$

**b.** Even though this lever system increases the force you are able to exert, it can only lift an object a distance of 5.0 cm even though you move the lever through a distance of 80.0 cm. What is the efficiency of this lever system?

$$IMA = \frac{d_e}{d_r} = \frac{0.800\text{ m}}{0.050\text{ m}} = 16$$
$$e = \frac{MA}{IMA}\times 100 = \frac{3.5}{16}\times 100 = 22\%$$

**17.** The efficiency of an inclined plane is 75 percent. If the length of the plane is 8.0 m and its height is 1.5 m, what force acting parallel to the plane is required to move a 180-kg block up the plane? (Neglect friction.)

$$e = \frac{W_o}{W_i}\times 100 = \frac{F_rd_r}{F_ed_e}\times 100$$
$$= \frac{mgd_r}{F_ed_e}\times 100$$
$$F_e = \frac{mgd_r}{ed_e}\times 100i$$
$$= \frac{(180\text{ kg})(9.80\text{ m/s}^2)(1.5\text{ m})}{(75)(8.0\text{ m})}\times 100$$
$$= 440\text{ N}$$

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# Chapter 11

1. Natasha weighs 530 N. What is her kinetic energy as she swims at a constant speed, covering a distance of 72 m in 1.0 min?

$$v = \frac{d}{t}$$
$$= \left(\frac{72\ \text{m}}{1.0\ \text{min}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)$$
$$= 1.2\ \text{m/s}$$

$$F_g = mg$$
$$m = \frac{F_g}{g}$$
$$KE = \frac{1}{2}mv^2$$
$$= \frac{1}{2}\frac{F_g v^2}{g}$$
$$= \frac{1}{2}\frac{(530\ \text{N})(1.2\ \text{m/s})^2}{9.80\ \text{m/s}^2}$$
$$= 39\ \text{J}$$

2. A 6.00-g block, initially at rest, is pulled to the right along a frictionless horizontal surface by a constant horizontal force of $1.20\times10^{-2}$ N for a distance of 3.00 cm.
   **a.** What is the work done by the force?

$$W = Fd$$
$$= (1.20\times10^{-2}\ \text{N})(3.00\times10^{-2}\ \text{m})$$
$$= 3.60\times10^{-4}\ \text{J}$$

   **b.** What is the change in the kinetic energy of the block?

$$\Delta KE = W$$
$$= 3.60\times10^{-4}\ \text{J}$$

   **c.** What is the speed of the block after the force is removed?

$$\Delta KE = KE_f - KE_i$$
$$KE_i = \frac{1}{2}mv_i^2 = 0$$
$$KE_f = \Delta KE$$
$$\frac{1}{2}mv_f^2 = \Delta KE$$
$$v_f = \sqrt{\frac{2\,\Delta KE}{m}}$$
$$= \sqrt{\frac{2(3.60\times10^{-4}\ \text{J})}{6.00\times10^{-3}\ \text{kg}}}$$
$$= 0.346\ \text{m/s}$$

3. Zeke slides down a snow hill on a rubber mat. Zeke's mass is 76.0 kg and the mass of the mat is 2.00 kg. Zeke starts from rest at the crest of the hill. Frictional forces may be disregarded.
   **a.** What is the change in the gravitational potential energy of Zeke and the mat when they slide to 1.20 m below the crest?

$$m = m_{Zeke} + m_{mat} = 78.0\ \text{kg}$$
$$\Delta PE = PE_f - PE_i$$
$$= mgh_f - mgh_i = mg\Delta h$$
$$= (78.0\ \text{kg})(9.80\ \text{m/s}^2)(-1.20\ \text{m})$$
$$= -917\ \text{J}$$

   **b.** What is the change in the kinetic energy of Zeke and the mat when they slide to 1.20 m below the crest?

$$KE_i + PE_i = KE_f + PE_f$$
$$\Delta KE = KE_f - KE_i = PE_i - PE_f$$
$$= -(PE_f - PE_i) = -\Delta PE$$
$$= +917\ \text{J}$$

   **c.** How fast are Zeke and the mat moving when they are 1.20 m below the crest?

$$\Delta KE = KE_f - KE_i$$
$$KE_i = \frac{1}{2}mv_i^2 = 0$$
$$KE_f = \Delta KE$$
$$\frac{1}{2}mv_f^2 = \Delta KE$$
$$v_f = \sqrt{\frac{2\,\Delta KE}{m}}$$
$$= \sqrt{\frac{2(917\ \text{J})}{78.0\ \text{kg}}}$$
$$= 4.85\ \text{m/s}$$

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**Chapter 11 continued**

**4.** Rohit can consistently throw a 0.200-kg ball at a speed of 12.0 m/s. On one such throw, Rohit throws the ball straight upward and it passes the top of a flagpole when it is 6.00 m above the ball's initial position.

**a.** What is the ball's gravitational potential energy when it passes the top of the flagpole? (Assume the ball's initial gravitational energy is 0 J.)

$$PE_f = mgh_{flagpole}$$
$$= (0.200\ \text{kg})(9.80\ \text{m/s}^2)(6.00\ \text{m})$$
$$= 11.8\ \text{J}$$

**b.** What is the ball's kinetic energy as it passes the top of the flagpole?

$$KE_i + PE_i = KE_f + PE_f$$
$$PE_i = 0$$
$$KE_f = KE_i - PE_f$$
$$= \frac{1}{2}mv_i^2 - PE_f$$
$$= \frac{1}{2}(0.200\ \text{kg})(12.0\ \text{m/s})^2 - 11.8\ \text{J}$$
$$= 2.6\ \text{J}$$

**c.** What is the ball's velocity as it first passes the top of the flagpole?

$$KE_f = \frac{1}{2}mv_f^2$$
$$v_f = \sqrt{\frac{2KE_f}{m}}$$
$$= \sqrt{\frac{2(2.6\ \text{J})}{0.200\ \text{kg}}}$$
$$= 5.1\ \text{m/s, upward}$$

**d.** What is the maximum height to which the ball will rise?

$$KE_i + PE_i = KE_f + PE_f$$

**$PE_i = 0$; $KE_f = 0$ since $v_f = 0$ at maximum height**

$$PE_f = KE_i$$
$$mgh_{max} = \frac{1}{2}mv_i^2$$
$$h_{max} = \frac{v_i^2}{2g}$$
$$= \frac{(12.0\ \text{m/s})^2}{2(9.80\ \text{m/s}^2)}$$
$$= 7.35\ \text{m}$$

**5.** What is the change in gravitational potential energy when a $7.0\times10^2$-kg elevator moves from the second floor (6.0 m above the street) to the top floor (252.0 m above the street) of a building?

$$\Delta PE = PE_f = PE_i$$
$$= mg(h_{top\ floor} - h_{second\ floor})$$
$$= (7.0\times10^2\ \text{kg})(9.80\ \text{m/s}^2)(252.0\ \text{m} - 6.0\text{m})$$
$$= 1.7\times10^6\ \text{J}$$

**6.** In a hardware store, paint cans, which weigh 46.0 N each, are transported from storage to the back of the paint department by placing them on a ramp that is inclined at an angle of 24.0° above the horizontal. The cans slide down the ramp at a constant speed of 3.40 m/s and then slide onto a table made of the same material as the ramp. How far does each can slide on the table's horizontal surface before coming to rest?

**On the ramp, using a coordinate system in which the positive *x*-axis is oriented down the ramp:**

***y*-direction:**

$$F_{net,\ y} = ma_y = 0$$
$$F_N - F_{gy} = 0$$
$$F_N = F_{gy} = mg\cos\theta$$
$$F_f = \mu_k F_N = \mu_k mg\cos\theta$$

***x*-direction:**

$$F_{net,\ x} = ma_x = 0$$
$$F_{gx} = mg\sin\theta$$
$$F_{gx} - F_f = 0$$
$$mg\sin\theta - \mu_k mg\cos\theta = 0$$

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$\mu_k = \frac{\sin\theta}{\cos\theta} = \theta$

**On the table:**

***y*-direction:**

$F_N = mg$

$F_f = \mu_k F_N = \mu_k mg$

$W = \Delta KE$

$F_f d \cos(180°) = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$

$v_f = 0$

$-F_f d = -\frac{1}{2}mv_i^2$

$d = \frac{mv_i^2}{2F_f}$

$= \frac{mv_i^2}{2\mu_k mg}$

$= \frac{mv_i^2}{2(\tan\theta)mg}$

$= \frac{v_i^2}{2(\tan\theta)g}$

$= \frac{(3.40 \text{ m/s})^2}{2(\tan 24.0°)(9.80 \text{ m/s}^2)}$

$= 1.32 \text{ m}$

**7.** Meena releases her 10.5-kg toboggan from rest on a hill. The toboggan glides down the frictionless slope of the hill, and at the bottom of the slope it moves along a rough horizontal surface, which exerts a constant frictional force on the toboggan.

**a.** When the toboggan is released from a height of 15.0 m, it travels 6.0 m along the horizontal surface before coming to rest. How much work does the frictional force do on the toboggan?

**Along the slope:**

$KE_i + PE_i = KE_f + PE_f$

$h_f = 0; PE_f = 0$

$v_i = 0; KE_i = 0$

$PE_i = KE_f$

**Along the horizontal surface:**

$W = \Delta KE = KE_f - KE_i$

$v_f = 0; KE_f = 0$

$W = -KE_i$

$= -PE_i = -mgh_i$

$= -(10.5 \text{ kg})(9.80 \text{ m/s}^2)(15.0 \text{ m})$

$= -1.54\times10^3 \text{ J}$

**b.** From what height should the toboggan be released so that it stops after traveling 10.0 m on the horizontal surface?

$W = -F_f d = -PE_i = mgh$

$d = \frac{mgh}{F_f}$

***d* is proportional to *h*, so to increase *d* from 6.00 m to 10.0 m, *h* must increase from 15.0 m to**

$(15.0 \text{ m})\left(\frac{10.0 \text{ m}}{6.00 \text{ m}}\right)$

$h = 25.0 \text{ m}$

**8.** Kuan stands on the edge of a building's flat roof, 12 m above the ground, and throws a 147.0-g baseball straight down. The ball hits the ground at a speed of 18 m/s. What was the initial speed of the ball?

$KE_i + PE_i = KE_f + PE_f$

$h_f = 0; PE_f = 0$

$KE_i = KE_f - PE_i$

$\frac{1}{2}mv_i^2 = \frac{1}{2}mv_f^2 - mgh_i$

$v_i = \sqrt{v_f^2 - 2gh_i}$

$= \sqrt{(18 \text{ m/s})^2 - 2(9.80 \text{ m/s}^2)(12 \text{ m})}$

$= 9.4 \text{ m/s}$

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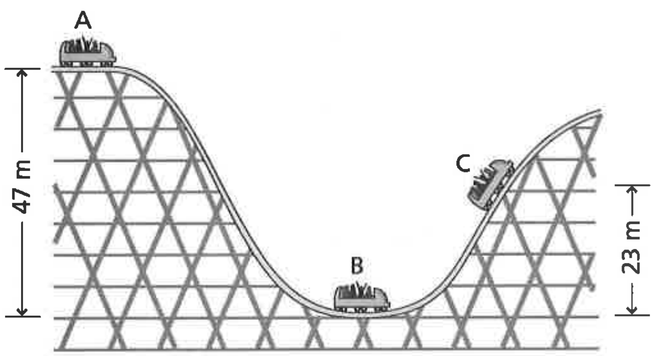
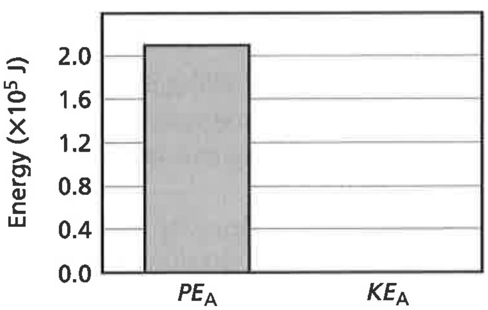
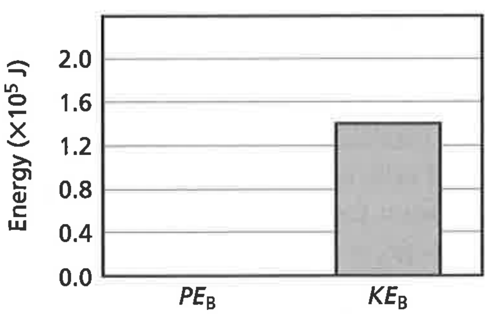
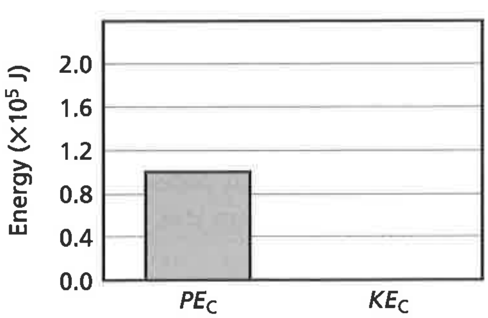
**Chapter 11 continued**

**9.** As shown below, a 450-kg roller-coaster car starts from rest at point A at a height of 47 m, rolls down the track, reaching point B at a speed of 25 m/s, and then rolls up a second hill where it reaches a height of 23 m before coming to rest (at point C). What are the gravitational potential energy and kinetic energy of the car when it is at points A, B, and C?




**Point A:**

$PE_A = 2.1\times10^5$ J

$KE_A = 0$

**Point B:**

$PE_B = 0$

$KE_B = 1.4\times10^5$ J

**Point C:**

$PE_C = 1.0\times10^5$ J

$KE_C = 0$

**10.** Erin holds the 1.20-kg bob of a pendulum at a level at which its gravitational potential energy is 3.00 J, and then releases it.

**a.** Predict the speed of the bob as it passes through its lowest point on the swing.

$$KE_i + PE_i = KE_f + PE_f$$

$$v_i = 0;\ KE_i = 0$$

$$h_f = 0;\ PE_f = 0$$

$$KE_f = PE_i$$

$$\frac{1}{2}mv_f^2 = PE_i$$

$$v_f = \sqrt{\frac{2PE_i}{m}}$$

$$= \sqrt{\frac{2(3.00\text{ J})}{1.20\text{ kg}}}$$

$$= 2.24\text{ m/s}$$

**b.** Erin releases the bob from rest and uses a photogate to measure its speed as it passes through its lowest point. She finds that the actual speed is 93.2 percent of the predicted value. How much work did frictional forces do on the pendulum?

$$v_f' = 0.932v_f$$

$$= (0.932)(2.24\text{ m/s})$$

$$= 2.088\text{ m/s}$$

$$KE_f' = \frac{1}{2}m(v_f')^2$$

$$= \frac{1}{2}(1.20\text{ kg})(2.088\text{ m/s})^2$$

$$= 2.62\text{ J}$$

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$W = KE_f' - KE_f$
$= 2.62\ \text{J} - 3.00\ \text{J}$
$= -0.38\ \text{J}$

c. By what percentage was the pendulum's original energy decreased due to the work done by frictional forces on the pendulum as it moved from its release point to its lowest point?

$$\%\ \text{energy change} = \frac{W}{PE_i} \times 100 = \frac{-0.38\ \text{J}}{3.0\ \text{J}} \times 100 = -13\%$$

**The pendulum's energy decreased by 13 percent.**

11. A loaded freight car of mass $50.0\times10^3$ kg, moving at 18.0 km/h along a straight, level track, collides with a stationary empty freight car of mass $15.0\times10^3$ kg. At the collision, the two boxcars lock together.

a. What is the velocity of the moving pair of boxcars after the collision?

$p_f = p_i$

$p_{(A+B)f} = p_{Ai} + p_{Bi}$

$m_{(A+B)}v_f = m_A v_{Ai} + m_B v_{Bi}$
$= m_A v_{Ai} + 0$

$$v_f = \frac{m_A v_{Ai}}{m_{(A+B)}}$$

$$v_{Ai} = \left(\frac{18.0\ \text{km}}{1\ \text{h}}\right)\left(\frac{10^3\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right) = 5.00\ \text{m/s}$$

$m_{(A+B)} = 5.00\times10^4\ \text{kg} + 1.50\times10^4\ \text{kg}$
$= 6.50\times10^4\ \text{kg}$

$$v_f = \frac{(50.0\times10^3\ \text{kg})(5.00\ \text{m/s})}{(6.50\times10^4\ \text{kg})} = 3.85\ \text{m/s}$$

b. How much energy is lost during the collision?

$E_i = KE_{Ai} + KE_{Bi}$

$= \frac{1}{2}mv_{Ai}^2 + \frac{1}{2}mv_{Bi}^2$

$= \frac{1}{2}(5.00\times10^4\ \text{kg})(5.00\ \text{m/s})^2 + 0$

$= 6.25\times10^5\ \text{J}$

$E_f = KE_{(A+B)f}$

$= \frac{1}{2}m_{(A+B)}v_f^2$

$= \frac{1}{2}(6.50\times10^4\ \text{kg})(3.85\ \text{m/s})^2$

$= 4.82\times10^5\ \text{J}$

$E_{lost} = E_i - E_f$
$= 6.25\times10^5\ \text{J} - 4.82\times10^5\ \text{J}$
$= 1.43\times10^5\ \text{J} = 143\ \text{kJ}$

12. An arrow with a mass of 320 g is shot straight up into the air and reaches a height of 150 m before stopping and falling back to the ground.

a. How much work is done by gravity as the arrow reaches its maximum height?

$W_g = -mgh$
$= -(0.32\ \text{kg})(9.80\ \text{m/s}^2)(150\ \text{m})$
$= -470\ \text{J}$

b. If the arrow's kinetic energy is zero at its maximum height, calculate the initial velocity of this arrow as it is shot from the ground.

$KE_i + W_g = KE_f$, and $KE_f = 0$ J

$\frac{1}{2}mv^2 = -W_g$

$$v = \sqrt{\frac{-2W_g}{m}} = \sqrt{\frac{-2(-470\ \text{J})}{0.32\ \text{kg}}} = 54\ \text{m/s}$$

13. The nucleus of a single atom of uranium U-235 consists of 92 protons and 143 neutrons. How much potential energy is contained within just a single uranium nucleus?

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$$m_{total} = m_p + m_n$$
$$= (92)(1.67\times10^{-27}\text{ kg}) + (143)(1.68\times10^{-27}\text{ kg})$$
$$= 3.9\times10^{-25}\text{ kg}$$

$$E_0 = m_{total}c^2$$
$$= (3.9\times10^{-25}\text{ kg})(3.00\times10^{8}\text{ m/s})^2$$
$$= 3.5\times10^{-8}\text{ J}$$

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# Chapter 12

**1.** In order to cook pasta, 1.8 L of tap water must first be heated from 24°C to boiling at 100°C. If the density of water is 1.00 kg/L, how much heat must be added for the water to reach its boiling point?

$$Q = mC(T_f - T_i)$$
$$= (1.8\ \text{kg})(4180\ \text{J/kg·°C})(100°\text{C} - 24°\text{C})$$
$$= 6\times10^5\ \text{J}$$

**2.** Some of the best pots and pans for cooking are made of copper. To learn why, compare copper pots to aluminum pots. Assume that $5.00\times10^4$ J of heat is added to a copper pot and an aluminum pot. Each pot has a mass of 2.2 kg.

**a.** How much does the temperature of the copper pot increase? (specific heat = 385 J/kg·K)

$$Q = mC\Delta T$$
$$\Delta T = \frac{Q}{mC}$$
$$= \frac{5.00\times10^4\ \text{J}}{(2.2\ \text{kg})(385\ \text{J/kg·C})}$$
$$= 59°\text{C}$$

**b.** How much does the temperature of the aluminum pot increase? (specific heat = 897 J/kg·K)

$$Q = mC\Delta T$$
$$\Delta T = \frac{Q}{mC}$$
$$= \frac{5.00\times10^4\ \text{J}}{(2.2\ \text{kg})(897\ \text{J/kg·C})}$$
$$= 25°\text{C}$$

**3.** There is 32.7 L of water in a bathtub. The temperature of the water is 42.1°C. If 11.3 L of water at 27.0°C is added to the bathtub, what is the new temperature of the bathwater?

$$T_f = \frac{m_a C_a T_a + m_b C_b T_b}{m_a C_a + m_b C_b}$$
$$m_{water} = \rho V$$
$$m_{tub\text{–}water} = (1\ \text{kg/L})(32.7\ \text{L}) = 32.7\ \text{kg}$$
$$m_{added\text{–}water} = (1\ \text{kg/L})(11.3\ \text{L}) = 11.3\ \text{kg}$$
$$T_f = \frac{(32.7\ \text{kg})\cancel{(4180\ \text{J/kg·°C})}(42.1°\text{C}) + (11.3\ \text{kg})\cancel{(4180\ \text{J/kg·°C})}(27.0°\text{C})}{(32.7\ \text{kg})\cancel{(4180\ \text{J/kg·°C})} + (11.3\ \text{kg})\cancel{(4180\ \text{J/kg·°C})}}$$
$$= 38.2°\text{C}$$

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**4.** A 0.098-kg sample of methanol is heated from 34°C until it is completely vaporized. A total of 93.487 kJ is used. If the boiling point of methanol is 65°C, what is the heat of vaporization of methanol?

$$Q_{heating} = mC\Delta T$$
$$Q_{vaporization} = mH_v$$
$$Q_{total} = Q_{heating} + Q_{vaporization}$$
$$Q_{total} = mC\Delta T + mH_v$$
$$H_v = \frac{Q_{total} - mC\Delta T}{m}$$
$$= \frac{(9.3487\times10^4\ \text{J}) - (0.098\ \text{kg})(2450\ \text{J/kg·°C})(65°\text{C} - 34°\text{C})}{(0.098\ \text{kg})}$$
$$= 8.8\times10^5\ \text{J/kg}$$

**5.** A car engine releases $5.6\times10^2$ kJ of energy as it cools. What is the change in temperature for each of the following potential coolants when it absorbs this amount of energy?

**a.** 2.6 kg of antifreeze (specific heat = 2380 J/kg·K)

$$Q = mC\Delta T$$
$$\Delta T = \frac{Q}{mC}$$
$$= \frac{5.6\times10^5\ \text{J}}{(2.6\ \text{kg})(2380\ \text{J/kg·°C})}$$
$$= 9.0\times10^1 °\text{C}$$

**b.** 1.8 kg of methanol

$$Q = mC\Delta T$$
$$\Delta T = \frac{Q}{mC}$$
$$= \frac{5.6\times10^5\ \text{J}}{(1.8\ \text{kg})(2450\ \text{J/kg·°C})}$$
$$= 130°\text{C}$$

**c.** 2.4 kg of water

$$Q = mC\Delta T$$
$$\Delta T = \frac{Q}{mC}$$
$$= \frac{5.6\times10^5\ \text{J}}{(2.4\ \text{kg})(4180\ \text{J/kg·°C})}$$
$$= 56°\text{C}$$

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6. A calorimeter containing 1.2 kg of water at 23.0°C is used to find the specific heat of a number of substances. A 503-g sample of each substance is heated to 250°C and is placed in the calorimeter. For each of the following final temperatures, calculate the specific heat of the substance. Using the table at right, predict what each substance is.

**Table 12-1**

**Specific Heat of Common Substances**

| Material | Specific Heat (J/kg·K) | Material | Specific Heat (J/kg·K) |
|---|---|---|---|
| Aluminum | 897 | Lead | 130 |
| Brass | 376 | Methanol | 2450 |
| Carbon | 710 | Silver | 235 |
| Copper | 385 | Steam | 2020 |
| Glass | 840 | Water | 4180 |
| Ice | 2060 | Zinc | 388 |
| Iron | 450 | | |

**a.** 31.5°C

$$m_w C_w(T_f - T_w) + m_s C_s(T_f - T_s) = 0$$

$$m_s C_s T_f - m_s C_s T_s = m_w C_w T_w - m_w C_w T_f$$

$$C_s = \frac{m_w C_w T_w - m_w C_w T_f}{m_s T_f - m_s T_s}$$

$$= \frac{(1.2\text{ kg})(4180\text{ J/kg·°C})(23.0\text{°C}) - (1.2\text{ kg})(4180\text{ J/kg·C})(31.5\text{°C})}{(0.503\text{ kg})(31.5\text{°C}) - (0.503\text{ kg})(250\text{°C})}$$

$$= 390\text{ J/kg°C}$$

**The substance is zinc.**

**b.** 32.8°C

$$C_s = \frac{m_w C_w T_w - m_w C_w T_f}{m_s T_f - m_s T_s}$$

$$= \frac{(1.2\text{ kg})(4180\text{ J/kg·°C})(23.0\text{°C}) - (1.2\text{ kg})(4180\text{ J/kg·°C})(32.8\text{°C})}{(0.503\text{ kg})(32.8\text{°C}) - (0.503\text{ kg})(250\text{°C})}$$

$$= 450\text{ J/kg·°C}$$

**The substance is iron.**

**c.** 41.8°C

$$C_s = \frac{m_w C_w T_w - m_w C_w T_f}{m_s T_f - m_s T_s}$$

$$= \frac{(1.2\text{ kg})(4180\text{ J/kg·°C})(23.0\text{°C}) - (1.2\text{ kg})(4180\text{ J/kg·°C})(41.8\text{°C})}{(0.503\text{ kg})(41.8\text{°C}) - (0.503\text{ kg})(250\text{°C})}$$

$$= 9.0\times10^2\text{ J/kg·°C}$$

**The substance is aluminum.**

**d.** 28.2°C

$$C_s = \frac{m_w C_w T_w - m_w C_w T_f}{m_s T_f - m_s T_s}$$

$$= \frac{(1.2\text{ kg})(4180\text{ J/kg·°C})(23.0\text{°C}) - (1.2\text{ kg})(4180\text{ J/kg·°C})(28.2\text{°C})}{(0.503\text{ kg})(28.2\text{°C}) - (0.503\text{ kg})(250\text{°C})}$$

$$= 230\text{ J/kg·°C}$$

**The substance is silver.**

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**Chapter 12 continued**

7. A 935-kg car moving at 31 m/s comes to a stop. The brakes, which contain about 18 kg of iron, absorb all of the energy. By how much does the temperature of the brakes increase?

$$KE_{car} = \frac{1}{2}m_{car}v^2$$

$$Q_{brakes} = m_{brakes}C_{iron}\Delta T$$

$$KE_{car} = Q_{brakes}$$

$$\frac{1}{2}m_{car}v^2 = m_{brakes}C_{iron}\Delta T$$

$$\Delta T = \frac{m_{car}v^2}{2m_{brakes}C_{iron}}$$

$$= \frac{(935\ \text{kg})(31\ \text{m/s})^2}{2(18\ \text{kg})(450\ \text{J/kg·°C})}$$

$$= 55°\text{C}$$

8. A 23-g zinc block falling at 18 m/s strikes the ground and comes to a complete stop. All of the block's kinetic energy is converted into thermal energy and none of it leaves the block. By how much does the block's temperature increase?

$$KE_{block} = Q_{block}$$

$$KE_{block} = \frac{1}{2}mv^2$$

$$Q_{block} = mC\Delta T$$

$$\frac{1}{2}mv^2 = mC\Delta T$$

$$\Delta T = \frac{mv^2}{2mC} = \frac{v^2}{2C}$$

$$= \frac{(18\ \text{m/s})^2}{2(388\ \text{J/kg·°C})}$$

$$= 0.42°\text{C}$$

9. How much heat is required to completely vaporize a 23.0-kg block of ice at −8.00°C?

**Raising the ice to 0.00°C**

$$Q_1 = mC\Delta T$$

$$= (23.0\ \text{kg})(2060\ \text{J/kg·°C})(8.00°\text{C})$$

**Melting the ice**

$$Q_2 = mH_f$$

$$= (23.0\ \text{kg})(3.34\times10^5\ \text{J/kg})$$

**Heating the water to 100.0°C**

$$Q_3 = mC\Delta T$$

$$= (23.0\ \text{kg})(4180\ \text{J/kg·°C})(100.0°\text{C})$$

**Vaporizing the water**

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$Q_4 = mH_v$
$= (23.0\ \text{kg})(2.26\times10^6\ \text{J/kg})$

$Q_{total} = Q_1 + Q_2 + Q_3 + Q_4$
$= (23.0\ \text{kg})(2060\ \text{J/kg·°C})(8.00°\text{C}) + (23.0\ \text{kg})(3.34\times10^5\ \text{J/kg}) + (23.0\ \text{kg})(4180\ \text{J/kg·°C})(100.0°\text{C}) + (23.0\ \text{kg})(2.26\times10^6\ \text{J/kg})$
$= 6.97\times10^6\ \text{J}$

**10.** A block of ice at −5.00°C is added to a trough that contains 5.33 kg of water at 34.0°C. Assume that there is no heat loss to the surroundings. If all of the ice melts and the final temperature of the mixture is 6.00°C, what was the original mass of the ice?

**Cooling the water**

$Q = mC_{water}\Delta T$
$= (5.33\ \text{kg})(4180\ \text{J/kg·°C})(28.0°\text{C})$

**Melting the ice and raising its temperature**

$Q = mC_{ice}\Delta T + mH_f + mC_{water}\Delta T$

$$m = \frac{Q}{C_{ice}\Delta T + H_f + C_{water}\Delta T}$$

$$= \frac{(5.33\ \text{kg})(4180\ \text{J/kg·°C})(28.0°\text{C})}{(2060\ \text{J/kg·°C})(5.00°\text{C}) + (3.34\times10^5\ \text{J/kg}) + (4180\ \text{J/kg·C})(6.00°\text{C})}$$

$= 1.69\ \text{kg}$

**11.** A patio is constructed from 360 2.6-kg bricks. What amount of energy is released from the patio as it cools 6.0°C? The specific heat of brick is 920 J/kg·K.

$\Delta E = Q = mC\Delta T$
$= (360\ \text{bricks})(2.6\ \text{kg/brick})(920\ \text{J/kg·K})(6.0\ \text{K})$
$= 5.2\times10^3\ \text{kJ}$

**12.** How much ice at 0.0°C will be melted by 1.0 g of steam condensing at 100.0°C?

**All the energy from the condensing steam is used to melt the ice, so the energy absorbed by the ice should be equal to that evolved by the condensing steam.**

$Q_{f,\ water} = Q_{v,\ water}$

$m_{ice}H_{f,\ water} = m_{steam}H_{v,\ water}$

$$m_{ice} = \frac{m_{steam}H_{v,\ water}}{H_{f,\ water}}$$

$$= \frac{(1.0\ \text{g})(2.26\times10^6\ \text{J/kg})}{(3.34\times10^5\ \text{J/kg})}$$

$= 6.8\ \text{g}$

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**Chapter 12 continued**

**13.** The temperature of 150.0 g of zinc is lowered from 25.0°C to 16.4°C as 2.5 g of liquid nitrogen at its freezing point condenses on its surface. What is the heat of vaporization of nitrogen?

$$C_{\mathrm{Zn}} = 388\ \mathrm{J/kg{\cdot}K} = 388\ \mathrm{J/kg{\cdot}°C}$$

$$\Delta E = Q_{\mathrm{Zn}} + Q_{\mathrm{v,\,N_2}} = 0$$

$$Q_{\mathrm{Zn}} = -Q_{\mathrm{v,\,N_2}}$$

$$m_{\mathrm{Zn}}C_{\mathrm{Zn}}\Delta T_{\mathrm{Zn}} = -m_{\mathrm{N_2}}H_{\mathrm{v,\,N_2}}$$

$$H_{\mathrm{v,\,N_2}} = -\frac{m_{\mathrm{Zn}}C_{\mathrm{Zn}}(T_{\mathrm{f,\,Zn}} - T_{\mathrm{i,\,Zn}})}{m_{\mathrm{N_2}}}$$

$$= -\frac{(150.0\ \mathrm{g})(388\ \mathrm{J/kg{\cdot}°C})(16.4°\mathrm{C} - 25.0°\mathrm{C})}{2.5\ \mathrm{g}}$$

$$= 2.0\times10^{5}\ \mathrm{J/kg}$$

**14.** The head of a jackhammer supplies mechanical energy to a 0.50-kg iron ingot at a rate of 950 W. If this mechanical energy were transferred to the ingot and converted to thermal energy with none transferred to the environment, what would be the temperature rise of the ingot in 2.0 s?

$$W = \Delta KE = \Delta E = Q = mC\Delta T$$

$$P = \frac{W}{t} \qquad W = Pt$$

$$m_{\mathrm{Fe}}C_{\mathrm{Fe}}\Delta T_{\mathrm{Fe}} = Pt$$

$$\Delta T_{\mathrm{Fe}} = \frac{Pt}{m_{\mathrm{Fe}}C_{\mathrm{Fe}}}$$

$$= \frac{(950\ \mathrm{J})(2.0\ \mathrm{s})}{(0.50\ \mathrm{kg})(450\ \mathrm{J/kg{\cdot}°C})}$$

$$= 8.4°\mathrm{C}$$

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**Chapter 12 continued**

**15.** While casting a silver ornament, a silversmith pours 0.12 kg of molten silver at 1010°C into a 2.40-kg iron mold at a temperature of 35°C. What will be the equilibrium temperature of the silver casting and mold? Use information in the following table, and assume no thermal energy is lost to the surrounding environment.

| Table 12-2 | | |
|---|---|---|
| **Material** | **Variable** | **Value** |
| Iron | Heat of fusion | $2.66\times10^5$ J/kg |
| Iron | Melting point | 1535°C |
| Iron (*s*) | Specific heat | 450 J/kg·°C |
| Silver | Heat of fusion | $1.04\times10^5$ J/kg |
| Silver (*s*) | Specific heat | 235 J/kg·°C |
| Silver (*l*) | Specific heat | 290 J/kg·°C |
| Silver | Melting point | 960°C |

$$Q_{Ag(l)} + Q_{Ag(fusion)} + Q_{Ag(s)} + Q_{Fe(s)} = 0$$

$$m_{Ag}C_{Ag(l)}(T_{Ag(mp)} - T_{i,\,Ag}) + m_{Ag}H_{f,\,Ag} + m_{Ag}C_{Ag(s)}(T_f - T_{Ag(mp)}) + m_{Fe}C_{Fe}(T_f - T_{i,\,Fe}) = 0$$

$$T_f(m_{Ag}C_{Ag(s)} + m_{Fe}C_{Fe}) = -m_{Ag}C_{Ag(l)}(T_{Ag(mp)} - T_{i,\,Ag}) - m_{Ag}H_{f,\,Ag} + m_{Ag}C_{Ag(s)}T_{Ag(mp)} + m_{Fe}C_{Fe}T_{i,\,Fe}$$

$$T_f = \frac{-m_{Ag}C_{Ag(l)}(T_{Ag(mp)} - T_{i,\,Ag}) - m_{Ag}H_{f,\,Ag} + m_{Ag}C_{Ag(s)}T_{Ag(mp)} + m_{Fe}C_{Fe}T_{i,\,Fe}}{(m_{Ag}C_{Ag(s)} + m_{Fe}C_{Fe})}$$

$$= \frac{-(0.12\text{ kg})(290\text{ J/kg·°C})(960\text{°C} - 1010\text{°C}) - (0.12\text{ kg})(-1.04\times10^5\text{ J/kg}) \ldots}{(0.12\text{ kg})(235\text{ J/kg·°C}) \ldots}$$

$$\frac{\ldots(0.12\text{ kg})(235\text{ J/kg·°C})(960\text{°C})(2.40\text{ kg})(450\text{ J/kg·°C})(35\text{°C})}{\ldots+(240\text{ kg})(450\text{ J/kg·°C})}$$

$$= 68\text{°C}$$

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# Chapter 13

1. A car with a mass of $1.30\times10^3$ kg has 0.127 $m^2$ of tire in contact with the road.
   a. How much does the car weigh?

$$F_g = mg$$
$$= (1.30\times10^3\ \text{kg})(9.80\ \text{m/s}^2)$$
$$= 1.27\times10^4\ \text{N}$$

   b. How much pressure does the car exert on the road?

$$P = \frac{F}{A}$$
$$= \frac{(1.27\times10^4\ \text{N})}{(0.127\ \text{m}^2)}$$
$$= 1.00\times10^5\ \text{Pa}$$

2. A piston contains 0.102 $m^3$ of gas at an initial pressure of 217 kPa and an initial temperature of 23.0°C. Use these as the starting conditions for the following questions.
   a. What is the new pressure of the gas when the volume of the cylinder is reduced to 0.074 $m^3$ while the temperature remains constant?

$$P_1V_1 = P_2V_2$$
$$P_2 = \frac{P_1V_1}{V_2}$$
$$= \frac{(2.17\times10^5\ \text{Pa})(0.102\ \text{m}^3)}{(0.074\ \text{m}^3)}$$
$$= 3.0\times10^5\ \text{Pa}$$
$$= 3.0\times10^2\ \text{kPa}$$

   b. If the volume remains constant at 0.102 $m^3$, what will be the pressure of the gas at 81°C?

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$
$$P_2 = \frac{P_1V_1T_2}{T_1V_2}$$

and $V_1 = V_2$,

$$\text{so } P_2 = \frac{P_1T_2}{T_1}$$
$$= \frac{(2.17\times10^5\ \text{Pa})(273\ \text{K} + 81\ \text{K})}{(273\ \text{K} + 23\ \text{K})}$$
$$= 2.60\times10^5\ \text{Pa}$$
$$= 2.60\times10^2\ \text{kPa}$$

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**c.** What is the new pressure of the gas when the temperature is reduced to 11°C and the volume of the cylinder is increased to 0.256 m³?

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$P_2 = \frac{P_1V_1T_2}{T_1V_2}$$

$$= \frac{(2.17\times10^5\ \text{Pa})(0.102\ \text{m}^3)(273\ \text{K} + 11°\text{C})}{(273\ \text{K} + 23\ \text{K})(0.256\ \text{m}^3)}$$

$$= 8.30\times10^4\ \text{Pa}$$

$$= 83.0\ \text{kPa}$$

**3.** A certain bicycle tire should be inflated to 250 kPa before it is used. If the tire is at 230 kPa when the air in the tire is at 25°C, what temperature does the air in the tire have to reach for the proper pressure in the tire to be attained? Assume that expansion of the tire itself is negligible.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$T_2 = \frac{P_2T_1}{P_1}$$

$$= \frac{(250\ \text{kPa})(273\ \text{K} + 0\ \text{K})}{230\ \text{kPa}}$$

$$= 297\ \text{K}$$

$$= 24°\text{C}$$

**4.** A $3.22\times10^{-5}$-m³ glass tube filled with xenon is pressurized to 6.00 atm. The temperature of the gas is 22.0°C.

**a.** How many moles of gas are in the tube?

$$PV = nRT$$

$$n = \frac{PV}{RT}$$

$$= \frac{(6.00\ \text{atm})(1.01325\times10^5\ \text{Pa/atm})(3.22\times10^{-5}\ \text{m}^3)}{(8.31\ \text{Pa·m}^3/\text{mol·K})(273\ \text{K} + 22\ \text{K})}$$

$$= 7.99\times10^{-3}\ \text{mol}$$

**b.** What is the mass of the gas in the tube? (Xenon has a molar mass of 131.29 g/mol.)

$$m = nM$$

$$= (7.99\times10^{-3}\ \text{mol})(131.29\ \text{g/mol})$$

$$= 1.05\ \text{g}$$

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**Chapter 13 continued**

**5.** Two pistons are connected to a fluid-filled reservoir. The first piston has an area of 3.002 $cm^2$, and the second has an area of 315 $cm^2$.

**a.** If the first cylinder is pressed inward with a force of 50.0 N, what is the force that the fluid in the reservoir exerts on the second cylinder?

$$F_2 = \frac{F_1 A_2}{A_1}$$

$$= \frac{(50.0\ \text{N})(315\ \text{cm}^2)}{(3.002\ \text{cm}^2)}$$

$$= 5.25\times10^3\ \text{N}$$

**b.** A third cylinder is connected to the reservoir. When the second cylinder is pressed inward with a force of 50.0 N, the fluid in the reservoir exerts a force of 135 N on the third cylinder. What is the area of the third cylinder?

$$\frac{F_2}{A_2} = \frac{F_3}{A_3}$$

$$A_3 = \frac{F_3 A_2}{F_2}$$

$$= \frac{(135\ \text{N})(315\ \text{cm}^2)}{(50.0\ \text{N})}$$

$$= 8.50\times10^2\ \text{cm}^2$$

**6.** A cube of stainless steel, 0.30 m on each side, is completely submerged in water.

**a.** What is the buoyant force on the cube?

$$F_{\text{buoyant}} = \rho_{\text{fluid}} V g$$

$$= (1.00\times10^3\ \text{kg/m}^3)(0.027\ \text{m}^3)(9.80\ \text{m/s}^2)$$

$$= 260\ \text{N}$$

**b.** What is the apparent weight of the cube? (The density of stainless steel is $8.0\times10^3$ kg/$m^3$.)

$$F_{\text{apparent}} = F_g - F_{\text{buoyant}}$$

$$F_g = \rho_{\text{steel}} V g$$

$$F_{\text{apparent}} = \rho_{\text{steel}} V g - F_{\text{buoyant}}$$

$$= (8.0\times10^3\ \text{kg/m}^3)(0.027\ \text{m}^3)(9.80\ \text{m/s}^2) - (260\ \text{N})$$

$$= 1.9\times10^3\ \text{N}$$

**c.** What volume of steel would have to be removed from the center of the cube in order for the cube to float?

$$F_{\text{buoyant}} = F_{\text{g-floating}}$$

$$F_{\text{g-floating}} = F_g - F_{\text{removed}}$$

$$F_{\text{g-floating}} = g(m_1 - m_{\text{removed}})$$

$$F_{\text{g-floating}} = \rho_{\text{steel}} g(V_1 - V_{\text{removed}})$$

$$F_{\text{buoyant}} = \rho_{\text{steel}} g(V_1 - V_{\text{removed}})$$

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$$V_{removed} = \frac{\rho_{steel}V_1 g - F_{buoyant}}{\rho_{steel}g}$$

$$= \frac{(8.0\times10^3\ kg/m^3)(0.027\ m^3)(9.80\ m/s^2) - (260\ N)}{(8.0\times10^3\ kg/m^3)(9.80\ m/s^2)}$$

$$= 0.024\ m^3$$

7. A wooden raft that measures 1.20 m × 0.85 m × 0.10 m has a mass of 9.77 kg. If the raft is to stay afloat in fresh water, what is the maximum amount of additional mass that can be added to the raft?

   $F_g = F_{buoyant}$, so

   $F_g = \rho_{fluid}Vg$

   $mg = \rho_{fluid}Vg$

   $m = \rho_{fluid}V$

   $m = m_{existing} + m_{added}$

   $m_{existing} + m_{added} = \rho_{fluid}V$

   $m_{added} = \rho_{fluid}V - m_{existing}$

   $= (1.00\times10^3\ kg/m^3)(1.2\ m)(0.85\ m)(0.10\ m) - (9.77\ kg)$

   $= 92\ kg$

8. Free diving is a sport in which the contestants attempt to reach the greatest depth possible underwater without using supplemental oxygen. The world record for free diving is 85 m. What is the pressure of water at this depth?

   $P = \rho hg$

   $= (1.00\times10^3\ kg/m^3)(85\ m)(9.80\ m/s^2)$

   $= 8.3\times10^5\ Pa$

9. An aluminum ladder is 3.1 m long.

   a. How much does the ladder expand in length when its temperature rises from 13°C to 42°C?

   $$\alpha = \frac{\Delta L}{L_1\Delta T}$$

   $\Delta L = \alpha L_1\Delta T$

   $= (2.5\times10^{-5}°C^{-1})(3.1\ m)(42°C - 13°C)$

   $= 2.2\times10^{-3}\ m$

   $= 2.2\ mm$

   b. By how much does the ladder's temperature rise if it expands 0.0304 m?

   $$\alpha = \frac{\Delta L}{L_1\Delta T}$$

   $$\Delta T = \frac{\Delta L}{L_1\alpha}$$

   $$= \frac{(0.0304\ m)}{(3.1\ m)(2.5\times10^{-5}°C^{-1})}$$

   $= 390°C$

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**Chapter 13 continued**

**10.** What is the volume of 5.29 L of water at 9.0°C when it is heated to 99.0°C?

$$\beta = \frac{\Delta V}{V_1 \Delta T}$$

$$V = V_1 + \Delta V$$

$$\Delta V = \beta V_1 \Delta T = (210\times10^{-6}\text{°C}^{-1})(5.29\ \text{L})(99.0\text{°C} - 9.0\text{°C}) = 0.10\ \text{L}$$

$$V = 5.29\ \text{L} + 0.10\ \text{L} = 5.39\ \text{L}$$

**11.** Atmospheric pressure at sea level is measured as 101,325 Pa. What is the weight of the column of air above a 1-cm$^2$ patch of ground?

$$P = \frac{F}{A}$$

$$F = PA = (101{,}325\ \text{Pa})(1.0\ \text{cm}^2)\left(\frac{1\ \text{m}^2}{1\times10^4\ \text{cm}^2}\right)$$

$$= 1.0\times10^1\ \text{N}$$

**12.** A 100.0-L chamber contains an ideal gas at a temperature of 20.0°C and a pressure of 15 atm. One wall of the chamber moves as a piston and reduces the volume of the chamber to 75 L while raising the temperature to 27.0°C. What is the new pressure under these conditions?

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$P_2 = \frac{P_1V_1T_2}{V_2T_1}$$

$$= \frac{(15\ \text{atm})(1.013\times10^5\ \text{Pa/atm})(100.0\ \text{L})(293\ \text{K})}{(75\ \text{L})(301\ \text{K})}$$

$$= 2.0\times10^6\ \text{Pa, or about 19 atm}$$

**13.** An ideal gas is trapped in a cylinder 1.0 m long and with a diameter of 12.5 cm. The pressure inside is measured as $3.0\times10^5$ Pa with a temperature of 29°C. How many gas molecules are contained within this cylinder?

$$PV = nRT$$

$$n = \frac{PV}{RT}$$

$$= \frac{(3.0\times10^5\ \text{Pa})(\pi)(0.0625\ \text{m})^2(1.0\ \text{m})}{(8.31\ \text{Pa}\cdot\text{m}^3/\text{mol}\cdot\text{K})(302\ \text{K})}$$

$$= 1.467\ \text{mol}$$

$$1.467\ \text{mol}\left(\frac{6.022\times10^{23}\ \text{molecules}}{1\ \text{mol}}\right) = 8.8\times10^{23}\ \text{molecules}$$

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**Chapter 13 continued**

**14.** What is the volume of 1 mol of an ideal gas under standard temperature and pressure of $1.013\times10^5$ Pa and 0°C?

$$PV = nRT$$

$$V = \frac{nRT}{P}$$

$$= \frac{(1.0\text{ mol})(8.31\text{ Pa·m}^3\text{/mol·K})(273\text{ K})}{1.013\times10^5\text{ Pa}}$$

$$= 0.022\text{ m}^3$$

**15.** A car with a mass of $1.0\times10^3$ kg rests on a hydraulic lift that is 2.0 m wide and 10.0 m long. The lift is connected to a second cylindrical piston with only a 14.0-cm diameter and a hand pump. What force is necessary to lift the car off the ground using only the hand pump?

$$F_2 = \frac{F_1A_2}{A_1}$$

$$= \frac{(1.0\times10^3\text{ kg})(9.80\text{ m/s}^2)(\pi)(0.070\text{ m})^2}{(2.0\text{ m})(10.0\text{ m})}$$

$$= 7.5\text{ N}$$

**16.** A lake is 40.0 m deep. An air bubble with a volume of 18 cm$^3$ emerges from the bottom of the lake and rises to the surface.

**a.** What is the pressure at the bottom of the lake?

$$P = \rho hg$$

$$= (1.00\times10^3\text{ kg/m}^3)(40.0\text{ m})(9.80\text{ m/s}^2)$$

$$= 3.9\times10^5\text{ Pa}$$

**b.** What is the volume of the air bubble just before it reaches the surface? (Assume an ideal gas.)

$$P_1V_1 = P_2V_2$$

$$V_2 = \frac{P_1V_1}{P_2}$$

$$= \frac{(39\times10^5\text{ Pa})(18\text{ cm}^3)}{1.013\times10^5\text{ Pa}}$$

$$= 69\text{ cm}^3$$

**17.** What fraction of an iceberg shows above the water? Use the density of ice as $\rho_{ice} = 920$ kg/m$^3$ and the density of sea water as $\rho_{water} = 1030$ kg/m$^3$.

**The weight of an iceberg is**

$$F_g = \rho_{ice}V_{ice}g$$

**The buoyant force of the iceberg due to the displacement of water is**

$$F_{buoyant} = \rho_{water}V_{water}g$$

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**When the iceberg floats at the surface of the water in equilibrium, the buoyant force is equal to the weight of the object,**

$\rho_{ice} V_{ice} g = \rho_{water} V_{water} g$

$$\frac{V_{water}}{V_{ice}} = \frac{\rho_{ice}}{\rho_{water}} = \frac{920\ \text{kg/m}^3}{1030\ \text{kg/m}^3} = 0.89$$

**The submerged portion of the iceberg accounts for 89% of its volume, so only 11% of the iceberg floats above the surface.**

**18.** The height of a cylindrical concrete support pillar for a bridge is 13.0 m during the winter when the air temperature averages 4°C.

**a.** How much does the pillar grow during the summer when temperatures can reach 30°C?

$$\alpha = \frac{\Delta L}{L_1 \Delta T}$$

$$\Delta L = \alpha L_1 \Delta T$$
$$= (12\times10^{-6}{}^\circ\text{C}^{-1})(13.0\ \text{m})(30^\circ\text{C} - 4^\circ\text{C}) = 0.0041\ \text{m} = 4\ \text{mm}$$

**b.** The pillar is 1.5 m in diameter. How much does its volume increase during the summer?

$$\beta = \frac{\Delta V}{V_1 \Delta T}$$

$$\Delta V = \beta V_1 \Delta T = (36\times10^{-6}{}^\circ\text{C}^{-1})(\pi)(0.75\ \text{m})^2(13.0\ \text{m})(30.0^\circ\text{C} - 4.0^\circ\text{C})$$
$$= 0.022\ \text{m}^3$$

**c.** Besides strength, why is concrete a better choice of materials for bridge support than aluminum?

**Aluminum has a coefficient of linear expansion of $\alpha = 25\times10^{-6}{}^\circ\text{C}^{-1}$, more than twice that of concrete. This value means that aluminum expands much more with fluctuations in temperature than concrete does and places greater strain on connections and joints as it expands.**

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# Chapter 14

**1.** A spring stretches by 25.0 cm when a 0.500-kg mass is suspended from its end.

**a.** Determine the spring constant.

$$F = kx$$

$$k = \frac{F}{x}$$

$$F = mg$$
$$= (0.500\ \text{kg})(9.80\ \text{m/s}^2)$$
$$= 4.90\ \text{N}$$

$$k = \frac{4.90\ \text{N}}{0.250\ \text{m}}$$
$$= 19.6\ \text{N/m}$$

**b.** How much elastic potential energy is stored in the spring when it is stretched this far?

$$PE_{sp} = \frac{1}{2}kx^2$$
$$= \frac{1}{2}(19.6\ \text{N/m})(0.250\ \text{m})^2$$
$$= 0.612\ \text{J}$$

**2.** A spring has a spring constant of 135 N/m. How far must it be compressed so that 4.39 J of elastic potential energy is stored in the spring?

$$PE_{sp} = \frac{1}{2}kx^2$$

$$x = \sqrt{\frac{2PE_{sp}}{k}}$$
$$= \sqrt{\frac{2(4.39\ \text{J})}{135\ \text{N/m}}}$$
$$= 0.255\ \text{m}$$

**3.** On a planet where the gravitational acceleration is five times $g$ on Earth, a pendulum swings back and forth with a period of 1.22 s. What is the length of the pendulum?

$$T = 2\pi\sqrt{\frac{l}{g}}$$

$$l = g\left(\frac{T}{2\pi}\right)^2$$
$$= 5(9.80\ \text{m/s}^2)\left(\frac{1.22\ \text{s}}{2\pi}\right)^2$$
$$= 1.85\ \text{m}$$

**4.** Sonya hears water dripping from the eaves of the house onto a porch roof. She counts 30 drops in 1.0 min.

**a.** What is the frequency of the drops?

$$f = \left(\frac{30\ \text{drops}}{1.0\ \text{min}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)$$
$$= 0.50\ \text{Hz}$$

**b.** What is the period of the drops?

$$T = \frac{1}{f} = \frac{1}{0.50\ \text{Hz}}$$
$$= 2.0\ \text{s}$$

**5.** Hiroshi is generating waves on a rope by flipping the rope up and down. Each motion up or down lasts 0.20 s. The distance from a crest to a trough is 0.40 m.

**a.** What is the amplitude of the wave?

$$A = \frac{1}{2}(\text{distance from crest to trough})$$
$$= \frac{1}{2}(0.40\ \text{m})$$
$$= 0.20\ \text{m}$$

**b.** What is the frequency of the waves?

$$T = t_{up} + t_{down} = (0.20\ \text{s} + 0.20\ \text{s})$$
$$= 0.40\ \text{s}$$

$$f = \frac{1}{T} = \frac{1}{0.40\ \text{s}}$$
$$= 2.5\ \text{Hz}$$

**6.** A water wave travels a distance of 15 m in 1 min. When this wave passes a point where a cork is floating in the water, it causes the cork to move up and down 12 times in 15 s.

**a.** What is the speed of this water wave?

$$v = \frac{d}{t} = \left(\frac{15\ \text{m}}{1.0\ \text{min}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)$$
$$= 0.25\ \text{m/s}$$

**b.** What is the wavelength of this water wave?

$$\lambda = \frac{v}{f}$$

$$f = \frac{12\ \text{times}}{15\ \text{s}} = 0.80\ \text{Hz}$$

$$\lambda = \frac{0.25\ \text{m/s}}{0.80\ \text{Hz}} = 0.31\ \text{m}$$

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**c.** What is the period of this water wave?

$$\mathbf{T = \frac{1}{f} = \frac{1}{0.80\ Hz}}$$
$$\mathbf{= 1.2\ s}$$

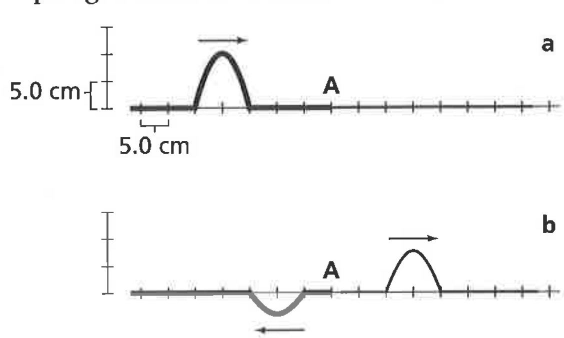
**7.** A Love wave—one of the four types of waves associated with earthquakes—is a transverse wave in which the surface of Earth moves back and forth as the wave passes. What is the speed of a Love wave that has a period of 150 s and a wavelength of 620 km?

$$\mathbf{v = \lambda f}$$
$$\mathbf{f = \frac{1}{T}}$$
$$\mathbf{v = \frac{\lambda}{T}}$$
$$\mathbf{= \frac{6.2\times10^5\ m}{150\ s}}$$
$$\mathbf{= 4.1\times10^3\ m/s = 4.1\ km/s}$$

**8.** A pulse with an amplitude of 0.53 m travels to the right along a rope. Another pulse, with an amplitude of −0.24 m, travels to the left along the same rope. The two pulses approach each other. What is the amplitude of the rope at the point where the midpoints of the pulses pass each other?

$$\mathbf{A = A_1 + A_2}$$
$$\mathbf{= 0.53\ m + (-0.24\ m)}$$
$$\mathbf{= 0.29\ m}$$

**9.** Part **a** of the figure below shows a pulse traveling at a speed of 1.0 m/s in a coil spring to which a second spring is attached at point A. Part **b** of the figure shows the springs a short time later.




**a.** What is the amplitude of the incident pulse?

**0.10 m**

**b.** What is the speed of the reflected pulse?

**The reflected pulse and the incident pulse travel in the same spring, so they have the same speed of 1.0 m/s.**

**c.** What is the speed of the transmitted pulse?

$$\mathbf{v_{reflected} = \frac{d}{t}}$$
$$\mathbf{t = \frac{d}{v_{reflected}}}$$
$$\mathbf{= \frac{0.10\ m}{1.0\ m/s}}$$
$$\mathbf{= 0.10\ s}$$
$$\mathbf{v_{transmitted} = \frac{d}{t} = \frac{0.15\ m}{0.10\ s}}$$
$$\mathbf{= 1.5\ m/s}$$

**10.** A physics teacher attaches an electric oscillator to one end of a 2.0-m horizontal spring and attaches the other end of the spring to a stationary hook in the wall. She adjusts the frequency of the oscillator to produce a standing wave in the spring. Students observe that the standing wave has three nodes and two antinodes. She then doubles the frequency of the oscillations and produces another standing wave. How many nodes and antinodes do the students observe in the new standing wave?

**For $f_1$, there are three nodes and two antinodes, indicating that the standing wave has a wavelength of 2.0 m, the same as the length of the spring.**

$$\mathbf{\lambda_1 = 2.0\ m}$$
$$\mathbf{f_2 = 2f_1}$$
$$\mathbf{v = \lambda_1 f_1 = \lambda_2 f_2}$$
$$\mathbf{\lambda_2 = \frac{f_1}{f_2}\lambda_1}$$
$$\mathbf{= \frac{f_1}{2f_1}\lambda_1}$$

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$= \frac{\lambda_1}{2}$

$= \frac{2.0\ \text{m}}{2} = 1.0\ \text{m}$

**The new standing wave has a wavelength of half the length of the spring. The spring contains two full wavelengths; therefore, the students observe five nodes and four antinodes.**

**11.** What magnitude force will compress a spring so that the spring elastic potential increases by 0.24 J? The spring constant is 18 N/cm.

$PE_{sp} = \frac{1}{2}kx^2$

$x = \sqrt{\frac{2PE_{sp}}{k}}$

$= \sqrt{\frac{2(0.24\ \text{J})}{18\ \text{N/cm}\left(\frac{100\ \text{cm}}{1\ \text{m}}\right)}}$

$= 0.016\ \text{m}$

$= 1.6\ \text{cm}$

$F = kx = (18\ \text{N/cm})(1.6\ \text{cm})$

$= 29\ \text{N}$

**12.** Each back-and-forth movement of the bob in a small pendulum clock releases a cog on a wheel. As the cog is released, the wheel undergoes a slight rotation. If the release of three cogs moves the second hand of the clock forward 1.0 s, what is the length of the pendulum?

$T = 2\pi\sqrt{\frac{l}{g}}$

$l = \frac{gT^2}{4\pi^2}$

$= \frac{(9.80\ \text{m/s}^2)(0.67\ \text{s})^2}{4\pi^2}$

$= 0.11\ \text{m}$

**13.** Calculate the frequency in hertz of each of the following:

**a.** a "new" moon (period = 27.3 days)

$f = \frac{1}{T}$

$= \frac{1}{(27.3\ \text{days})\left(\frac{24\ \text{h}}{1\ \text{day}}\right)\left(\frac{60\ \text{min}}{1\ \text{h}}\right)\left(\frac{60\ \text{s}}{1\ \text{min}}\right)}$

$= 4.24\times10^{-7}\ \text{Hz}$

**b.** a day on Earth

**It takes Earth 1.0 days to rotate on its axis, so the period is 1.0 days.**

$f = \frac{1}{T}$

$= \frac{1}{(1.0\ \text{day})(24\ \text{h/d})(60\ \text{min/h})(60\ \text{s/h})}$

$= 1.2\times10^{-5}\ \text{Hz}$

**c.** a breath (Assume a breathing rate of 8–12 breaths in 60.0 s.)

$T_1 = \frac{60.0\ \text{s}}{8\ \text{breaths}} = 7.50\ \text{s}$

$T_2 = \frac{60.0\ \text{s}}{16\ \text{breaths}} = 3.75\ \text{s}$

$f_1 = \frac{1}{T_1} = \frac{1}{7.50\ \text{s}} = 0.133\ \text{Hz}$

$f_2 = \frac{1}{T_2} = \frac{1}{3.75\ \text{s}} = 0.267\ \text{Hz}$

$f = 0.133 - 0.267\ \text{Hz}$

**d.** a heart beat (Assume a heart rate of 1.0–1.6 beats per second.)

$f_1 = \frac{1}{T_1} = \frac{1}{1.0\ \text{s}} = 1.0\ \text{Hz}$

$f_2 = \frac{1}{T_2} = \frac{1}{1.6\ \text{s}} = 0.63\ \text{Hz}$

$f = 0.63 - 1.0\ \text{Hz}$

**14.** The distance between four consecutive antinodes of a standing wave in a spring is 42 cm. What is the wavelength of the standing wave? *Hint: The distance between two consecutive antinodes in a standing wave represents 0.5 λ.*

**The distance between four antinodes represents 1.5 λ.**

$1.5\ \lambda = 42\ \text{cm}$

$\lambda = \frac{42\ \text{cm}}{1.5} = 28\ \text{cm}$

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# Chapter 15

Assume that the speed of sound in air is 343 m/s, at 20°C, unless otherwise noted.

1. The sound a mosquito makes is produced when it beats its wings at the average frequency of 620 wing beats per second. What is the wavelength of the sound waves produced by the mosquito?

   $f = \frac{\text{620 beats}}{\text{1 s}} = \text{620 Hz}$

   $v = \lambda f$

   $\lambda = \frac{v}{f}$

   $= \frac{\text{343 m/s}}{\text{620 Hz}}$

   $= \text{0.55 m}$

2. You are listening to an outdoor concert on a day when the temperature is 0°C. The sound of a wavelength of 0.490 m is emitted by a flute on the stage 125 m from where you are standing.

   **a.** What is the time elapsed before you hear the sound emitted from the stage?

   $v = \frac{d}{t}$

   $t = \frac{d}{v}$

   **At 0°C, $v = \text{331 m/s}$**

   $t = \frac{\text{125 m}}{\text{331 m/s}}$

   $= \text{0.378 s}$

   **b.** What is the frequency of the sound?

   $v = \lambda f$

   $f = \frac{v}{\lambda}$

   $= \frac{\text{331 m/s}}{\text{0.490 m}}$

   $= \text{676 Hz}$

3. The pulse-echo technique is used in diagnostic medical imaging. A short ultrasound pulse is emitted from the device, and echoes are produced when the pulse is reflected at a tissue interface. The echo signals are received back at the device and then analyzed to build up an image of the organ. The speed of sound in soft tissue is 1540 m/s. If an echo is received $58.2\times10^{-6}$ s after the pulse was emitted, how far is the tissue interface from the ultrasound device?

   $v = \frac{d}{t}$

   $d = vt$

   **Time taken for the pulse to reach interface = $\frac{1}{2}$ (time between pulse and echo)**

   $t = \frac{5.82\times10^{-5}\text{ s}}{2}$

   $= 2.91\times10^{-5}\text{ s}$

   $d = (\text{1540 m/s})(2.91\times10^{-5}\text{ s})$

   $= \text{0.0448 m}$

   $= 4.48\times10^{-2}$ **m or 4.48 cm**

4. The engine of a jet plane taking off produces a sound level of 140 dB, and the sound wave has a pressure amplitude of 200 Pa. A baggage handler working next to a jet plane that is taking off is wearing specially designed hearing protectors that reduce the sound level entering his ear by 40 dB. What is the pressure amplitude of the sound waves entering his ear?

   **The sound level is decreased from 140 dB to 100 dB. For each 20-dB increase in sound level, the pressure amplitude increases by a factor of 10. Therefore, for each decrease of 20 dB in sound level, the pressure amplitude decreases by a factor of 10.**

   **Pressure amplitude of a 120-dB sound = $\frac{1}{10}$ (pressure amplitude of a 140-dB sound)**

   **Pressure amplitude of a 100-dB sound = $\frac{1}{10}$ (pressure amplitude of a 120-dB sound)**

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**Chapter 15 continued**

**Pressure amplitude of a 100-dB sound $= \frac{1}{100}$ (pressure amplitude of a 140-dB sound)**

$$A_2 = \frac{A_1}{100}$$
$$= \frac{200\ \text{Pa}}{100}$$
$$= 2\ \text{Pa}$$

**5.** While fishing from a boat anchored offshore, you see another fishing boat between your boat and the shore. The other boat sounds a 510-Hz horn as it heads toward the shore at a speed of 18 m/s.

**a.** If your fishing boat is stationary, what is the frequency of the sound waves from the horn that reach you?

$$f_d = f_s\frac{(v - v_d)}{(v - v_s)}$$
$$v_d = 0$$
$$f_d = f_s\frac{v}{(v - v_s)}$$
$$= (510\ \text{Hz})\frac{343\ \text{m/s}}{343\ \text{m/s} - (-18\ \text{m/s})}$$
$$= 480\ \text{Hz}$$

**b.** If your fishing boat now heads out to sea at a speed of 15 m/s, what is the frequency of the sound waves from the horn that reach you?

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$
$$= (510\ \text{Hz})\frac{343\ \text{m/s} - 15\ \text{m/s}}{343\ \text{m/s} - (-18\ \text{m/s})}$$
$$= 460\ \text{Hz}$$

**6.** A species of bat navigates by emitting short bursts of sound waves that have a frequency range that peaks at 58.0 kHz.

**a.** If a bat is flying at 4.0 m/s toward a stationary object, what is the frequency of the sound waves reaching the object?

**The frequency of the sound waves reaching the stationary object is $f_{d1}$.**

$$f_{d1} = f_s\left(\frac{v - v_d}{v - v_s}\right)$$
$$v_d = 0$$
$$f_{d1} = f_s\frac{v}{(v - v_s)}$$
$$f_{d1} = (58.0\ \text{kHz})\frac{343\ \text{m/s}}{343\ \text{m/s} - 4.0\ \text{m/s}}$$
$$= 58.7\ \text{kHz}$$

**b.** What is the frequency of the reflected sound waves detected by the bat?

**The frequency of the reflected sound waves from the object is $f_{d1}$ and the frequency of the sound waves detected by the bat is $f_{d2}$.**

$$f_{d2} = f_{d1}\left(\frac{v - v_d}{v - v_s}\right)$$
$$v_s = 0$$
$$f_{d2} = f_{d1}\frac{v - v_d}{v}$$
$$= (58.7\ \text{kHz})\frac{343\ \text{m/s} - (-4.0\ \text{m/s})}{343\ \text{m/s}}$$
$$= 59.4\ \text{kHz}$$

**c.** What is the difference between the frequency of the sound waves emitted by the bat and the frequency of the sound waves detected by the bat if the bat is flying at 4.0 m/s and the object is a moth approaching at 1.0 m/s?

$$f_{d1} = f_s\left(\frac{v - v_d}{v - v_s}\right)$$
$$= (58.0\ \text{kHz})\frac{343\ \text{m/s} - (-1.0\ \text{m/s})}{343\ \text{m/s} - 4.0\ \text{m/s}}$$
$$= 58.86\ \text{kHz}$$
$$f_{d2} = f_{d1}\left(\frac{v - v_d}{v - v_s}\right)$$
$$= (58.86\ \text{kHz})\frac{343\ \text{m/s} - (-4.0\ \text{m/s})}{343\ \text{m/s} - 1.0\ \text{m/s}}$$
$$= 59.7\ \text{kHz}$$
$$\Delta f = f_{d2} - f_s$$
$$= 59.7\ \text{kHz} - 58.0\ \text{kHz}$$
$$= 1.7\ \text{kHz}$$

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**Chapter 15 continued**

7. Hannah places an open, vertical glass tube into a container of water so that the lower end of the tube is submerged. She holds a vibrating tuning fork over the top of the tube while varying the water level in the tube. Hannah notices that the loudest sound is heard when the distance from the water to the top of the tube is 32.7 cm, and again when the distance is 98.2 cm. What is the frequency of the tuning fork?

$$L_B - L_A = \frac{1}{2}\lambda$$

$$\lambda = 2(L_B - L_A) = 2(0.982 \text{ m} - 0.327 \text{ m}) = 1.31 \text{ m}$$

$$v = \lambda f$$

$$f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{1.31 \text{ m}} = 262 \text{ Hz}$$

8. The six strings of a standard guitar are tuned to the following frequencies: 165, 220, 294, 392, 494, and 659 Hz.

   **a.** Find the lengths of the shortest open-ended organ pipes that would produce the same frequencies.

$$f = \frac{v}{2L}$$

$$L = \frac{v}{2f}$$

$$L_1 = \frac{v}{2f_1} = \frac{343 \text{ m/s}}{2(165 \text{ Hz})} = 1.04 \text{ m}$$

$$L_2 = \frac{v}{2f_2} = \frac{343 \text{ m/s}}{2(220 \text{ Hz})} = 0.780 \text{ m}$$

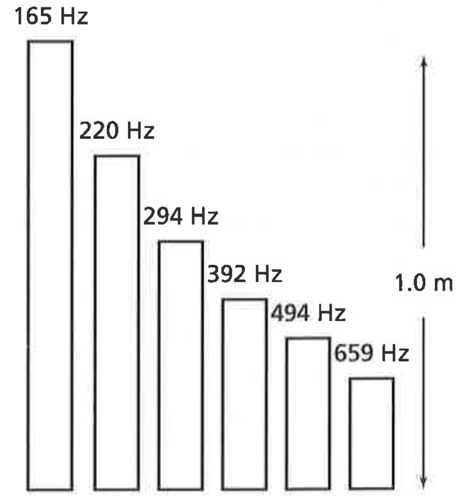
$$L_3 = \frac{v}{2f_3} = \frac{343 \text{ m/s}}{2(294 \text{ Hz})} = 0.583 \text{ m}$$

$$L_4 = \frac{v}{2f_4} = \frac{343 \text{ m/s}}{2(392 \text{ Hz})} = 0.438 \text{ m}$$

$$L_5 = \frac{v}{2f_5} = \frac{343 \text{ m/s}}{2(494 \text{ Hz})} = 0.347 \text{ m}$$

$$L_6 = \frac{v}{2f_6} = \frac{343 \text{ m/s}}{2(659 \text{ Hz})} = 0.260 \text{ m}$$

   **b.** Sketch the pipes, showing their lengths to scale.




9. The fundamental tone of an open-pipe resonator with a length of 48 cm is the same as the second harmonic tone of a closed-pipe resonator. What is the length of the closed-pipe resonator?

**Second harmonic (closed pipe) = fundamental (open pipe)**

$$3f_{1,c} = f_{1,o}$$

$$f_{1,o} = \frac{v}{2L_o}$$

$$f_{1,c} = \frac{v}{4L_c}$$

$$\frac{3v}{4L_c} = \frac{v}{2L_o}$$

$$L_c = \frac{3}{2}L_o = \frac{3}{2}(0.48 \text{ m}) = 0.72 \text{ m}$$

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**10.** You receive a CD with the following note: "The first sound on the CD is the sound of a 238-Hz tuning fork and a second tuning fork being struck simultaneously. The second sound on the CD is the sound of the second tuning fork and a 240.0-Hz tuning fork being struck simultaneously. What is the frequency of the second tuning fork?" Listening to the CD, you hear that the first sound has a beat frequency of 3.00 Hz and the second sound has a beat frequency of 5.00 Hz. Answer the question found in the note.

$f_{\text{beat}} = |f_2 - f_1|$

$(f_2 - f_1) = \pm f_{\text{beat}}$

$f_2 = f_1 \pm f_{\text{beat}}$

$= \mathbf{38.0\ Hz \pm 3.00\ Hz}$

$= \mathbf{241\ Hz\ or\ 235\ Hz}$

$f_{\text{beat}} = |f_2 - f_3|$

$(f_2 - f_3) = \pm f_{\text{beat}}$

$f_2 = f_3 \pm f_{\text{beat}}$

$= \mathbf{240.0\ Hz \pm 5.00\ Hz}$

$= \mathbf{245\ Hz\ or\ 235\ Hz}$

**The frequency of the second tuning fork must be 235 Hz.**

**11.** A radio station broadcasts their signal with a wavelength of 3.5 $\mu$m. Although your radio will translate this signal into audible sound, explain why you cannot hear the radio signal directly.

$$f = \frac{v}{\lambda} = \frac{343\ \text{m/s}}{3.5\times10^{-6}\ \text{m}} = 9.8\times10^{7}\ \text{s}^{-1}$$

$= \mathbf{98\ MHz}$

**The threshold of the human ear is around 20,000 Hz, so the frequency of this radio signal is far higher than what the ear can detect.**

**12.** Antennas are designed to be as long as the wavelengths they are intended to receive. An amateur radio operator sets up an antenna line in his backyard in order to receive a signal from across the country. What length should this antenna line be to receive a signal of $3.0\times10^2$ Hz?

$$\lambda = \frac{v}{f} = \frac{343\ \text{m/s}}{3.0\times10^{2}\ \text{Hz}} = 1.1\ \text{m}$$

**13.** You hear the siren of a fire engine as you stand on the side of the road. As it approaches, the siren which broadcasts at a frequency of 645 Hz is heard by you as being 660 Hz. How fast is the fire engine traveling?

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right),\ v_d = 0\ \text{m/s}$$

$$f_d = \frac{f_s v}{v - v_s}$$

$$v_s = v\left(\frac{f_d - f_s}{f_d}\right)$$

$$= (343\ \text{m/s})\left(\frac{660\ \text{Hz} - 645\ \text{Hz}}{660\ \text{Hz}}\right)$$

$= \mathbf{7.8\ m/s}$

**14.** A friend talks to you as she walks past you at a speed of 2.25 m/s. Why do you not notice a Doppler shift in her voice as she passes?

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right),\ v_d = 0\ \text{m/s}$$

$$f_d = \frac{f_s v}{v - v_s}$$

$$= f_s\left(\frac{343\ \text{m/s}}{343\ \text{m/s} - 2.25\ \text{m/s}}\right)$$

$= \mathbf{1.01}\ f_s$

**When the speed of the source is very low compared with the speed of sound, there is little or no detectable difference in the frequency of the sound emitted.**

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## Chapter 15 continued

**15.** If a submarine emits a sonar "ping" underwater and detects an echo 4.00 s later, how far away is the object that reflected the echo?

$$v = \frac{d}{t}$$

$$d = vt = (1533\ \mathrm{m/s})(4.00\ \mathrm{s}) = 6130\ \mathrm{m}$$

**Since the sound must travel from the source to the object and back to the source, the object detected would be at half that distance, or about 3060 m away.**

**16.** An open tube is filled with water which is slowly drained as a tuning fork of frequency $f = 1.00\times10^3$ Hz is held over the open end. As the water drains, the level of the water is marked as a maximum of sound is heard in the tube. These maxima are detected at distances of 16.7 cm, 33.4 cm and 50.1 cm, measured from the open end of the tube. What is the speed of sound in the air within the tube?

**With resonance points every 16.7 cm,**

$$\lambda = 2L$$
$$= 2(16.7\ \mathrm{cm})$$
$$= 33.4\ \mathrm{cm}$$

$$\lambda = \frac{v}{f}$$

$$v = \lambda f$$
$$= (0.334\ \mathrm{m})(1.00\times10^3\ \mathrm{Hz})$$
$$= 334\ \mathrm{m/s}$$

**17.** A piano tuner is trying to tune one of the piano strings by listening for a beat frequency between the unknown string and a known tuning fork of frequency 262.0 Hz.

**a.** He notices a beat frequency of 4.0 Hz when the string and tuning fork are struck at the same time. What is the frequency of the piano string?

$$f\text{beat} = |f_A - f_B|$$

$$f_A = f_{\text{beat}} + f_B$$
$$= 4.0\ \mathrm{Hz} + 262.0\ \mathrm{Hz}$$
$$= 266.0\ \mathrm{Hz}$$

**b.** After an adjustment, he notices a beat frequency of 0.11 Hz when the string and tuning fork are struck. What is the new frequency of the piano string?

$$f_A = f_{\text{beat}} + f_B$$
$$= 0.11\ \mathrm{Hz} + 262.0\ \mathrm{Hz}$$
$$= 262.1\ \mathrm{Hz}$$

**18.** In music, the middle C has a frequency of 256 Hz. What frequency is a note that is exactly one octave higher than middle C?

**An octave is a frequency ratio of 1:2, so the next highest octave above middle C is**

$$\frac{1}{2} = \frac{256\ \mathrm{Hz}}{f}$$

$$f = 2(256\ \mathrm{Hz}) = 512\ \mathrm{Hz}$$

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# Chapter 16

1. An outdoor lamp has a luminous flux of 2500 lm.

   a. What is the illuminance on the ground if the lamp is mounted at a height of 2.8 m?

   $$E = \frac{P}{4\pi r^2}$$
   $$= \frac{2500\ \text{lm}}{4\pi(2.8\ \text{m})^2}$$
   $$= 25\ \text{lx}$$

   b. What is the illuminance on a house that is 10.7 m from the lamp?

   $$E = \frac{P}{4\pi r^2}$$
   $$= \frac{2500\ \text{lm}}{4\pi(10.7\ \text{m})^2}$$
   $$= 1.7\ \text{lx}$$

   c. What is the luminous intensity of the lamp?

   $$C = \frac{P}{4\pi}$$
   $$= \frac{2500\ \text{lm}}{4\pi}$$
   $$= 2.0\times10^2\ \text{cd}$$

2. A home movie projector has an internal lamp with a luminous flux of 1500 lm.

   a. How far from the screen should the projector be positioned to obtain a screen illuminance of 3.32 lx?

   $$E = \frac{P}{4\pi r^2}$$
   $$r = \sqrt{\frac{P}{4\pi E}}$$
   $$= \sqrt{\frac{1500\ \text{lm}}{4\pi(3.32\ \text{lx})}}$$
   $$= 6.0\ \text{m}$$

   b. What would be the luminous flux of the projector if it produced the same screen illuminance at 4.89 m from the screen?

   $$E = \frac{P}{4\pi r^2}$$
   $$P = 4\pi E r^2$$
   $$= 4\pi(3.32\ \text{lx})(4.89\ \text{m})^2$$
   $$= 998\ \text{lm}$$

3. How many lumens are there per candela?

   $$C = \frac{P}{4\pi}$$
   $$\frac{P}{C} = 4\pi$$
   $$= 12.6\ \text{lm/cd}$$

4. A point source of light provides 4.21 lx at 2.1 m.

   a. What is the luminous intensity of the light source?

   $$C = \frac{P}{4\pi}$$
   $$E = \frac{P}{4\pi r^2}$$
   $$P = 4\pi E r^2$$
   $$C = \frac{4\pi E r^2}{4\pi} = E r^2$$
   $$= (4.21\ \text{lx})(2.1\ \text{m})^2$$
   $$= 19\ \text{cd}$$

   b. What is the luminous flux of the light source?

   $$E = \frac{P}{4\pi r^2}$$
   $$P = 4\pi E r^2$$
   $$= 4\pi(4.21\ \text{lx})(2.1\ \text{m})^2$$
   $$= 230\ \text{lm}$$

5. A certain type of halogen light has a luminous intensity of 15,000 cd. How many times more illuminance does this bulb provide at 1.00 m than a 60-W lightbulb with a luminous flux of 1750 lm?

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$$\frac{E_{\text{halogen}}}{E_{\text{60-W}}} = \frac{\frac{P_{\text{halogen}}}{4\pi r^2}}{\frac{P_{\text{60-W}}}{4\pi r^2}}$$

$$= \frac{P_{\text{halogen}}}{P_{\text{60-W}}}$$

$$C_{\text{halogen}} = \frac{P_{\text{halogen}}}{4\pi}$$

$$P_{\text{halogen}} = 4\pi C_{\text{halogen}}$$

$$\frac{E_{\text{halogen}}}{E_{\text{60-W}}} = \frac{4\pi C_{\text{halogen}}}{P_{\text{60-W}}}$$

$$= \frac{4\pi(15{,}000\ \text{cd})}{1750\ \text{lm}}$$

$$= 110$$

6. What is the observed change in wavelength of orange light ($\lambda = 590$ nm) when the light source is moving toward an observer at $5.66\times10^5$ m/s?

$$\Delta\lambda = -\frac{v}{c}\lambda$$

$$= \left(-\frac{5.66\times10^5\ \text{m/s}}{3.00\times10^8\ \text{m/s}}\right)(5.90\times10^{-7}\ \text{m})$$

$$= -1.00\times10^{-9}\ \text{m}$$

7. The primary colors are red, yellow, and blue. Based on the wavelengths below, calculate the range of frequencies for each color of light.

**a.** blue: 455–492 nm

$$\lambda = \frac{c}{f}$$

$$f_1 = \frac{c}{\lambda_1}$$

$$= \frac{3.00\times10^8}{4.55\times10^{-7}\ \text{m}}$$

$$= 6.59\times10^{14}\ \text{Hz}$$

$$f_2 = \frac{c}{\lambda_2}$$

$$= \frac{3.00\times10^8\ \text{m/s}}{4.92\times10^{-7}\ \text{m}}$$

$$= 6.10\times10^{14}\ \text{Hz}$$

**range = $6.10\times10^{14}$ Hz to $6.59\times10^{14}$ Hz**

**b.** yellow: 577–597 nm

$$\lambda = \frac{c}{f}$$

$$f_1 = \frac{c}{\lambda_1}$$

$$= \frac{3.00\times10^8}{5.77\times10^{-7}\ \text{m}}$$

$$= 5.20\times10^{14}\ \text{Hz}$$

$$f_2 = \frac{c}{\lambda_2}$$

$$= \frac{3.00\times10^8\ \text{m/s}}{5.97\times10^{-7}\ \text{m}}$$

$$= 5.03\times10^{14}\ \text{Hz}$$

**range = $5.03\times10^{14}$ Hz to $5.20\times10^{14}$ Hz**

**c.** red: 622–780 nm

$$\lambda = \frac{c}{f}$$

$$f_1 = \frac{c}{\lambda_1}$$

$$= \frac{3.00\times10^8}{6.22\times10^{-7}\ \text{m}}$$

$$= 4.82\times10^{14}\ \text{Hz}$$

$$f_2 = \frac{c}{\lambda_2}$$

$$= \frac{3.00\times10^8\ \text{m/s}}{7.80\times10^{-7}\ \text{m}}$$

$$= 3.8\times10^{14}\ \text{Hz}$$

**range = $3.8\times10^{14}$ Hz to $4.82\times10^{14}$ Hz**

8. Visible light has a frequency that ranges from about $4.0\times10^{14}$ Hz to about $7.5\times10^{14}$ Hz. What is the range of wavelengths for visible light?

$$\lambda_1 = \frac{c}{f_1}$$

$$= \frac{(3.00\times10^8)}{(4.0\times10^{14}\ \text{Hz})}$$

$$= 7.5\times10^{-7}\ \text{m}$$

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$\lambda_2 = \frac{c}{f_2}$

$= \frac{(3.00\times10^8 \text{ m/s})}{(7.5\times10^{14})}$

$= 4.0\times10^{-7}$ m

range $= 4.0\times10^{-7}$ m to $7.5\times10^{-7}$ m

**9.** Find the velocity of the observer for each of the following situations. Assume the light source is stationary in each situation.

**a.** An observer approaches a light source at a velocity that makes red light ($\lambda$ = 670 nm) appear yellow ($\lambda$ = 585 nm).

$\lambda_{obs} - \lambda = \pm \frac{v}{c}\lambda$

$v = (c)\frac{\lambda_{obs} - \lambda}{\lambda}$

$= (3.00\times10^8 \text{ m/s})\left(\frac{5.85\times10^{-7} \text{ m} - 6.7\times10^{-7} \text{ m}}{6.7\times10^{-7} \text{ m}}\right)$

$= -3.8\times10^7$ m/s

**b.** An observer approaches a light source at a velocity that makes yellow light ($\lambda$ = 585 nm) appear blue ($\lambda$ = 470 nm).

$\lambda_{obs} - \lambda = \pm \frac{v}{c}\lambda$

$v = (c)\frac{\lambda_{obs} - \lambda}{\lambda}$

$= (3.00\times10^8 \text{ m/s})\left(\frac{4.7\times10^{-7} \text{ m} - 5.85\times10^{-7} \text{ m}}{5.85\times10^{-7} \text{ m}}\right)$

$= -5.9\times10^7$ m/s

**c.** An observer approaches a light source at a velocity that makes red light ($\lambda$ = 670 nm) appear blue ($\lambda$ = 470 nm).

$\lambda_{obs} - \lambda = \pm \frac{v}{c}\lambda$

$v = (c)\frac{\lambda_{obs} - \lambda}{\lambda}$

$= (3.00\times10^8 \text{ m/s})\left(\frac{4.7\times10^{-7} \text{ m} - 6.7\times10^{-7} \text{ m}}{6.7\times10^{-7} \text{ m}}\right)$

$= -9.0\times10^7$ m/s

**10.** A source of green light ($\lambda$ = 545 nm) moves toward an observer at 345,000 m/s. What is the frequency of the light from the observer's perspective?

$f = \frac{c}{\lambda}$

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$$f_{obs} = \frac{f}{\left(1 - \frac{v}{c}\right)}$$

$$= \frac{c}{\lambda\left(1 - \frac{v}{c}\right)}$$

$$= \frac{3.00\times10^{8}\text{ m/s}}{(5.45\times10^{-7}\text{ m})\left(1 - \frac{3.45\times10^{5}\text{ m/s}}{3.00\times10^{8}\text{ m/s}}\right)}$$

$$= 5.51\times10^{14}\text{ Hz}$$

**11.** Two polarizing filters are placed so that the angle between the polarizing axes is 45°. Find the ratio of the intensity of the light exiting the second filter to the intensity of the light exiting the first filter.

$$I_2 = I_1 \cos^2\theta$$

$$\frac{I_2}{I_1} = \cos^2\theta$$

$$= \cos^2 45°$$

$$= 0.50$$

**12.** How fast do you have to approach a source of yellow light ($\lambda$ = 585 nm) to reduce the observed wavelength to 575 nm?

$$\Delta\lambda = \pm\frac{v}{c}\lambda$$

$$v = \frac{\Delta\lambda c}{\lambda}$$

$$= \frac{(574\times10^{-9}\text{ m} - 585\times10^{-9}\text{ m})(3.00\times10^{8}\text{ m/s})}{585\times10^{-9}\text{ m}}$$

$$= -5.6\times10^{6}\text{ m/s}$$

**The negative sign means that you must be approaching the source.**

**13.** A light source has a luminous intensity of 375 cd.

**a.** What is its luminous flux?

$$\text{luminous intensity} = \frac{P}{4\pi}$$

$$P = 4\pi(\text{luminous intensity})$$

$$= 4\pi(375\text{ cd})$$

$$= 4.71\times10^{3}\text{ lm}$$

**b.** What illuminance does this light source provide at 2.50 m from the source?

$$E = \frac{P}{4\pi r^2}$$

$$P = 4\pi(\text{luminous intensity})$$

$$P = \frac{4\pi(\text{luminous intensity})}{4\pi r^2} = \frac{\text{luminous intensity}}{r^2}$$

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$$= \frac{375\ \text{cd}}{(2.50\ \text{m})^2}$$

$$= 60.0\ \text{lx}$$

**14.** A light source emits light with a wavelength of 490 nm. This light is observed to have a wavelength 15 nm greater than the original wavelength. Find the relative speed of the source and the observer. Make sure you specify whether they are moving toward or away from each other.

$$\Delta\lambda = \pm\frac{v}{c}\lambda$$

$$v = \frac{\Delta\lambda c}{\lambda}$$

$$= \frac{(1.5\times10^{-8}\ \text{m})(3.00\times10^{8}\ \text{m/s})}{4.9\times10^{-7}\ \text{m}}$$

$$= 9.2\times10^{6}\ \text{m/s}$$

**Since the sign is positive, they are moving away from each other.**

**15.** Two polarizing filters are set up so that light from a source passes through both of them. The intensity of the light leaving the second filter is 0.750 times the intensity of the light leaving the first filter. What is the angle between the filters?

$$I_2 = I_1 \cos^2\theta$$

$$\frac{I_2}{I_1} = \cos^2\theta$$

$$\theta = \cos^{-1}\left(\sqrt{\frac{I_2}{I_1}}\right)$$

$$I_2 = (0.750)I_1$$

$$\frac{I_2}{I_1} = 0.750$$

$$\theta = \cos^{-1}\left(\sqrt{0.750}\right)$$

$$= 30.0°$$

**16.** A light source generates light with a frequency of $5.45\times10^{12}$ Hz. What is the observed frequency of this light if the observer is moving away from the source at $2.60\times10^{4}$ m/s?

$$f_{\text{obs}} = f\left(1 \pm \frac{v}{c}\right)$$

$$= (5.45\times10^{12}\ \text{Hz})\left(1 - \frac{2.60\times10^{6}\ \text{m/s}}{3.00\times10^{8}\ \text{m/s}}\right)$$

$$= 5.40\times10^{12}\ \text{Hz}$$

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# Chapter 17

1. A light ray strikes a plane mirror at an angle of 23° to the normal. Find the angle of reflection for each of the following scenarios.

   a. The light source moves so that the angle of incidence decreases by 11°.

   $$\theta_i = \theta_r$$
   $$(23° - 11°) = \theta_r$$
   $$\theta_r = 12°$$

   b. The light source moves so that the angle of incidence increases by 29°.

   $$\theta_i = \theta_r$$
   $$(23° + 29°) = \theta_r$$
   $$\theta_r = 52°$$

   c. The mirror rotates 20.0° around the point where the beam strikes the mirror so that the angle of incidence increases. The mirror rotates on an axis that is perpendicular to the plane of the incident and reflected rays.

   $$\theta_{\text{i-final}} = \theta_{\text{i-initial}} + \Delta\theta$$
   $$\theta_{\text{i-final}} = \theta_{\text{i-final}}$$
   $$\theta_{\text{r-final}} = \theta_{\text{i-initial}} + \Delta\theta$$
   $$\theta_{\text{r-final}} = (23°) + (+20.0°)$$
   $$\theta_{\text{r-final}} = 43°$$

2. A light ray strikes a plane mirror at an angle of 41° to the normal. How many degrees must the mirror be rotated so that the angles of incidence and reflection are both zero and the reflected light follows the same path as the incident light?

   $$\theta_{\text{i-initial}} - \theta_{\text{rotation}} = \theta_{\text{i-final}}$$
   $$\theta_{\text{rotation}} = \theta_{\text{i-initial}} - \theta_{\text{i-final}}$$
   $$= (41°) - (0°)$$
   $$= 41°$$

3. In a curved mirror, a child appears to be 1.00 m tall. The child's actual height is 1.31 m.

   a. What is the magnification of the image?

   $$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$
   $$= \frac{h_i}{h_o}$$
   $$= \frac{(1.00\text{ m})}{(1.31\text{ m})}$$
   $$= 0.763$$

   b. If the child's position is 6.0 m from the mirror, what is the child's image position?

   $$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$
   $$d_i = -\frac{d_o h_i}{h_o}$$
   $$= -\frac{(6.0\text{ m})(1.00\text{ m})}{(1.31\text{ m})}$$
   $$= -4.6\text{ m}$$

4. A concave mirror magnifies images by a factor of 2.6.

   a. What is the height of an image formed by a 0.89-m-tall object?

   $$m = \frac{h_i}{h_o}$$
   $$h_i = mh_o$$
   $$= (2.6)(0.89\text{ m})$$
   $$= 2.3\text{ m}$$

   b. What is height of an object that has a 1.8-m-tall image?

   $$m = \frac{h_i}{h_o}$$
   $$h_o = \frac{h_i}{m}$$
   $$= \frac{1.8\text{ m}}{2.6}$$
   $$= 0.69\text{ m}$$

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**c.** What is the object distance of an image that has a position of −2.00 m?

$$m = \frac{-d_i}{d_o}$$

$$d_o = \frac{-d_i}{m}$$

$$= \frac{-(-2.00\text{ m})}{(2.6)}$$

$$= 0.77\text{ m}$$

**5.** An object is 10.0 cm from a concave mirror with a focal length of 7.00 cm. The object is 5.00 cm tall.

**a.** What is the image position?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_i = \frac{fd_o}{d_o - f}$$

$$= \frac{(7.00\text{ cm})(10.0\text{ cm})}{(10.0\text{ cm}) - (5.00\text{ cm})}$$

$$= 14.0\text{ cm}$$

**b.** What is the magnification of the image?

$$m = \frac{-d_i}{d_o}$$

$$= \frac{-(14.0\text{ cm})}{(10.0\text{ cm})}$$

$$= -1.40$$

**c.** What is the image height?

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{h_o}$$

$$= \frac{-(14.0\text{ cm})(5.00\text{ cm})}{(10.0\text{ cm})}$$

$$= -7.00\text{ cm}$$

**6.** An image in a concave mirror has a position of 18.0 cm, and its object has a position of 15.0 cm. What is the focal length of the mirror?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$f = \frac{d_i d_o}{d_o + d_i}$$

$$= \frac{(18.0\text{ cm})(15.0\text{ cm})}{(15.0\text{ cm}) + (18.0\text{ cm})}$$

$$= 8.18\text{ cm}$$

**7.** A concave mirror has a focal length of 5.00 cm. An image from the mirror has a position of 12.0 cm. What is the magnification of the image?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_o = \frac{fd_i}{d_i - f}$$

$$m = \frac{-d_i}{d_o}$$

$$= \frac{-d_i(d_i - f)}{fd_i}$$

$$= \frac{(-12.0\text{ cm})(12.0\text{ cm} - 5.00\text{ cm})}{(5.00\text{ cm})(12.0\text{ cm})}$$

$$= -1.40$$

**8.** An image in a concave mirror has a position of 10.0 cm. What is the focal length of the mirror if it has a magnification of $-\frac{1}{5}$?

$$m = \frac{-d_i}{d_o}$$

$$d_o = \frac{-d_i}{m}$$

$$= \frac{-(10.0\text{ cm})}{-0.20}$$

$$= 50.0\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$f = \frac{d_i d_o}{d_i + d_o}$$

$$= \frac{(10.0\text{ cm})(50.0\text{ cm})}{(10.0\text{ cm}) + (50.0\text{ cm})}$$

$$= 8.33\text{ cm}$$

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## Chapter 17 continued

**9.** A concave mirror has a radius of 40.0 cm. An object is placed 25.0 cm from the mirror.

**a.** What is the focal length of the mirror?

$$f = \frac{r}{2}$$
$$= \frac{(40.0\ \text{cm})}{2}$$
$$= 20.0\ \text{cm}$$

**b.** What is the image position?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$
$$d_i = \frac{f d_o}{d_o - f}$$
$$= \frac{(20.0\ \text{cm})(25.0\ \text{cm})}{(25.0\ \text{cm} - 20.0\ \text{cm})}$$
$$= 1.00\times10^2\ \text{cm}$$

**c.** What is the magnification of the image?

$$m = \frac{-d_i}{d_o}$$
$$= \frac{-(1.00\times10^2\ \text{cm})}{(25.0\ \text{cm})}$$
$$= -4.00$$

**10.** A convex mirror has a focal length of 10.0 cm and a magnification of $\frac{1}{2}$.

**a.** What is the image position for an object placed 20.0 cm from the mirror?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$
$$d_i = \frac{f d_o}{d_o - f}$$
$$= \frac{(10.0\ \text{cm})(20.0\ \text{cm})}{(20.0\ \text{cm} - 10.0\ \text{cm})}$$
$$= 20.0\ \text{cm}$$

**b.** If the object is 2.3 cm tall, how tall is its image in the mirror?

$$m = \frac{h_i}{h_o}$$
$$h_i = m h_o$$
$$= (0.5)(2.3\ \text{cm})$$
$$= 1.2\ \text{cm}$$

**11.** A concave mirror with a 30.0-cm radius of curvature produces an image that is 24.0 cm in front of the mirror and inverted. Where is the object that produced the image located?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$
$$d_o = \frac{f d_i}{d_i - f}$$
$$= \frac{(15.0\ \text{cm})(24.0\ \text{cm})}{24.0\ \text{cm} - 15.0\ \text{cm}}$$
$$= 40.0\ \text{cm}$$

**12.** An object that is 10.0 cm from a concave mirror has an image located 15.0 cm from the mirror. What is the focal length of the mirror?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$
$$f = \frac{d_i d_o}{d_i + d_o}$$
$$= \frac{(15.0\ \text{cm})(10.0\ \text{cm})}{15.0\ \text{cm} + 10.0\ \text{cm}}$$
$$= 6.00\ \text{cm}$$

**13.** An object located 15.0 cm in front of a concave mirror produces an image 60.0 cm in front of the mirror. What is the focal length of the mirror?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$
$$f = \frac{d_i d_o}{d_i + d_o}$$
$$= \frac{(60.0\ \text{cm})(15.0\ \text{cm})}{60.0\ \text{cm} + 15.0\ \text{cm}}$$
$$= 12.0\ \text{cm}$$

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**Chapter 17 continued**

**14.** A concave mirror with a focal length of 25.0 cm produces an image at 75.0 cm. What is the object distance for the object that produced the image?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_o = \frac{fd_i}{d_i - f}$$

$$= \frac{(25.0\text{ cm})(75.0\text{ cm})}{75.0\text{ cm} - 25.0\text{ cm}}$$

$$= 37.5\text{ cm}$$

**15.** A 5.00-cm-tall object is reflected in a convex mirror with a −40.0-cm focal length. The image is located 20.0 cm behind the mirror.

**a.** Where is the object located?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_o = \frac{fd_i}{d_i - f}$$

$$= \frac{(-40.0\text{ cm})(-20.0\text{ cm})}{(-20.0\text{ cm}) - (-40.0\text{ cm})}$$

$$= 40.0\text{ cm}$$

**b.** What is the height of the image?

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-h_o d_i}{d_o}$$

$$= \frac{-(5.00\text{ cm})(-20.0\text{ cm})}{40.0\text{ cm}}$$

$$= 2.50\text{ cm}$$

**16.** In a convex mirror, a 15.0-cm-tall object forms a 7.5-cm-tall image. What is the object distance if the image is located at −8.00 cm?

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$d_o = \frac{-d_i h_o}{h_i}$$

$$= \frac{-(-8.00\text{ cm})(15.0\text{ cm})}{7.5\text{ cm}}$$

$$= 16\text{ cm}$$

# Chapter 18

**1.** A beam of light traveling through air strikes flint glass at an angle of 31.0° to the normal. At what angle does the beam enter the flint glass?

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.00)(\sin 31.0°)}{(1.62)}\right)$$

$$= 18.5°$$

**2.** Light has a speed of $2.00\times10^8$ m/s in clear acrylic.

**a.** What is the index of refraction of clear acrylic?

$$n = \frac{c}{v}$$

$$= \frac{(3.00\times10^8\text{ m/s})}{(2.00\times10^8\text{ m/s})}$$

$$= 1.50$$

**b.** What is the wavelength of yellow light ($\lambda$ = 589 nm) in clear acrylic?

$$\lambda = \lambda_o n$$

$$= (5.89\times10^{-7}\text{ m})(1.50)$$

$$= 8.84\times10^{-7}\text{ m}$$

**c.** A beam of light traveling through air strikes a block of clear acrylic at an angle of 29° to the normal. At what angle does the light enter the block of clear acrylic?

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.00)(\sin 29°)}{(1.50)}\right)$$

$$= 18.9°$$

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3. A beam of light traveling through water is incident upon an unknown type of glass at an angle of 45.0° to the normal and is refracted at an angle of 33.6° to the normal.
   a. What is the index of refraction for the unknown type of glass?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2}$$

$$= \frac{(1.33)(\sin 45.0°)}{(\sin 33.6°)}$$

$$= 1.70$$

   b. What is the speed of light in the unknown type of glass?

$$n = \frac{c}{v}$$

$$v = \frac{c}{n}$$

$$= \frac{(3.00\times10^8 \text{ m/s})}{(1.70)}$$

$$= 1.77\times10^8 \text{ m/s}$$

4. A beam of yellow light has a wavelength of $1.425\times10^{-6}$ m in an unknown medium.
   a. What is the index of refraction of the unknown medium?

$$\lambda = \lambda_o n$$

$$n = \frac{\lambda}{\lambda_o}$$

$$= \frac{(1.425\times10^{-6} \text{ m})}{(5.89\times10^{-7} \text{ m})}$$

$$= 2.42$$

   b. Based on Table 18-1 on page 486 of your textbook, what do you think the unknown substance is?
   **diamond**

5. An even layer of oil floats on top of water ($n_{oil} = 1.15$). A beam of light strikes the oil at an angle of 32.1° to the normal. What is the beam's angle of refraction in the water?

**air to oil**

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.00)(\sin 32.1°)}{(1.15)}\right)$$

$$= 27.5°$$

**Oil to Water**

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.15)(\sin 27.5°)}{(1.33)}\right)$$

$$= 23.5°$$

6. Calculate the critical angles for each of the following situations.
   a. a beam of light passing from crown glass into air

$$\sin \theta_c = \frac{n_2}{n_1}$$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{1.00}{1.52}\right)$$

$$= 41.1°$$

   b. a beam of light passing from diamond into flint glass

$$\sin \theta_c = \frac{n_2}{n_1}$$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{1.62}{2.42}\right)$$

$$= 42.0°$$

   c. a beam of light passing from quartz into water

$$\sin \theta_c = \frac{n_2}{n_1}$$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{1.33}{1.54}\right)$$

$$= 59.7°$$

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**d.** a beam of light passing from water into air

$$\sin \theta_c = \frac{n_2}{n_1}$$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{1.00}{1.33}\right)$$

$$= 48.8°$$

**7.** A beam of light passing from an unknown substance into ethanol has a critical angle of 63.5°.

**a.** What is the index of refraction of the unknown substance?

$$\sin \theta_c = \frac{n_2}{n_1}$$

$$n_1 = \frac{n_2}{\sin \theta_c}$$

$$= \frac{(1.36)}{(\sin 63.5°)}$$

$$= 1.52$$

**b.** Use Table 18-1 on page 486 of your textbook to identify the unknown substance.

**crown glass**

**8.** A magnifying glass forms a 25.0-mm image of a 4.50-mm thread when the thread is placed 30.0 mm from the lens. What is the focal length of the magnifying glass?

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$d_i = -\frac{d_o h_i}{h_o}$$

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$\frac{1}{f} = \frac{1}{d_o} - \frac{h_o}{d_o h_i}$$

$$f = \frac{d_o^2 h_i}{d_o h_i - d_o h_o}$$

$$= \frac{(30.0\text{ cm})^2(25.0\text{ cm})}{(30.0\text{ cm})(25.0\text{ cm}) - (30.0\text{ cm})(4.50\text{ cm})}$$

$$= 36.6\text{ cm}$$

**9.** A student views a friend through a concave lens. The friend is 1.83 m tall and stands 5.00 m from the student with the lens. If the focal length of the lens is 1.00 m, how tall is the virtual image of the friend?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$h_i = \frac{-d_o h_o f}{d_o^2 - d_o f}$$

$$= \frac{-(5.00\text{ m})(1.83\text{ m})(-1.00\text{ m})}{(5.00\text{ m})^2 - (5.00\text{ m})(-1.00\text{ m})}$$

$$= 0.305\text{ m}$$

**10.** A convex lens with a focal length of 22.5 cm is used to create a real image of an object placed 51.0 cm from the lens. The height of the object is 20.0 cm.

**a.** What is the image position?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(51.0\text{ cm})(22.5\text{ cm})}{(51.0\text{ cm}) - (22.5\text{ cm})}$$

$$= 40.3\text{ cm}$$

**b.** What is the height of the image?

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(40.3\text{ cm})(20.0\text{ cm})}{(51.0\text{ cm})}$$

$$= -15.8\text{ cm}$$

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**Chapter 18 continued**

**11.** A beam of light has a wavelength of 550 nm. While traveling through an unknown substance, the light has a wavelength of $5.00\times10^{-7}$ m. What is the index of refraction of the unknown substance?

$$n = \frac{c}{v}$$

$$v = f\lambda_2$$

$$f = \frac{c}{\lambda_1}$$

$$v = \frac{c\lambda_2}{\lambda_1}$$

$$n = \frac{c}{\left(\frac{c\lambda_2}{\lambda_1}\right)} = \frac{\lambda_1}{\lambda_2}$$

$$= \frac{5.5\times10^{-7}\text{ m}}{5.00\times10^{-7}\text{ m}}$$

$$= 1.1$$

**12.** A beam of light traveling through water strikes the boundary between the water and air at an angle of 25° to the normal. At what angle does the light enter the air?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.33)(\sin 25°)}{1.00}\right)$$

$$= 34°$$

**13.** Light travels at a speed of $1.85\times10^8$ m/s through an unknown medium.

**a.** What is the index of refraction of the medium?

$$n = \frac{c}{v}$$

$$= \frac{3.00\times10^8\text{ m/s}}{1.85\times10^8\text{ m/s}}$$

$$= 1.62$$

**b.** Based on Table 18-1 on page 486 of your textbook, what do you think the medium is?

**According to the table, flint glass has an index of refraction of 1.62 and therefore the medium is most likely flint glass.**

**14.** What is the critical angle for light traveling from quartz into crown glass?

$$\sin \theta_c = \frac{n_2}{n_1}$$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{1.52}{1.54}\right)$$

$$= 80.8°$$

**15.** An object is located 18.0 cm from a convex lens that has a focal length of 6.0 cm.

**a.** Where is the image located?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(18.0\text{ cm})(6.0\text{ cm})}{18.0\text{ cm} - 6.0\text{ cm}}$$

$$= 9.0\text{ cm}$$

**b.** What is the orientation of the image?

**The object will be inverted.**

**16.** An object is located 24.0 cm from a convex lens. The object is 4.0 cm tall and its image is −1.0 cm tall. Where is the image located?

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$d_i = \frac{-h_i d_o}{h_o}$$

$$= \frac{-(-1.0\text{ cm})(24.0\text{ cm})}{(4.0\text{ cm})}$$

$$= 6.0\text{ cm}$$

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# Chapter 19

1. Yellow light of a certain wavelength is incident upon two slits separated by 22.5 $\mu$m. A screen is placed 1.20 m away from the slits. The distance to the first-order bright line is 31.4 mm. What is the wavelength of the light?

$$\lambda = \frac{xd}{L}$$
$$= \frac{(3.14\times10^{-2}\ \text{m})(2.25\times10^{-5}\ \text{m})}{(1.20\ \text{m})}$$
$$= 589\ \text{nm}$$

2. A certain laser emits light with a wavelength of 696 nm. The laser is directed at a double slit and a screen is placed 0.900 m from the slits. The first-order bright line appears 36.5 mm from the central bright line. What is the distance between the slits?

$$\lambda = \frac{xd}{L}$$
$$d = \frac{\lambda L}{x}$$
$$= \frac{(6.96\times10^{-7}\ \text{m})(0.900\ \text{m})}{(3.65\times10^{-2}\ \text{m})}$$
$$= 1.72\times10^{-5}\ \text{m}$$

3. Green light with a wavelength of 545 nm is incident upon two slits separated by 18.0 $\mu$m. A screen is set up to view the interference pattern produced and the first-order bright line is 26.4 mm from the central bright line. How far is the screen from the double slit?

$$\lambda = \frac{xd}{L}$$
$$L = \frac{xd}{\lambda}$$
$$= \frac{(2.64\times10^{-2}\ \text{m})(1.80\times10^{-5}\ \text{m})}{(5.45\times10^{-7}\ \text{m})}$$
$$= 0.872\ \text{m}$$

4. A wire coat hanger and a mild solution of soap and water can be used to create large soap bubbles. These bubbles have a multicolored appearance due to thin-film interference. If the index of refraction of the soapy water is 1.4 m what is the minimum thickness of the soap bubble when blue light with a wavelength of 488 nm is reflected?

$$d = \frac{\lambda_{\text{vacuum}}}{4n_{\text{soapy water}}}$$
$$= \frac{(4.88\times10^{-7}\ \text{m})}{4(1.4)}$$
$$= 8.7\times10^{-8}\ \text{m}$$

5. A single-slit diffraction experiment is set up using light from a He-Cd laser ($\lambda = 442$ nm). A screen is placed 0.980 m from the slit and the central bright line produced by the experiment has a width of 21.2 cm. What is the width of the slit?

$$2x_1 = \frac{2\lambda L}{w}$$
$$w = \frac{\lambda L}{x_1}$$
$$= \frac{(4.42\times10^{-7}\ \text{m})(0.980\ \text{m})}{(0.1065\ \text{m})}$$
$$= 4.07\times10^{-6}\ \text{m}$$

6. A single-slit diffraction experiment is set up using a slit with a width of 10.0 cm. The screen is placed 0.900 cm from the slit and the distance from the central bright band to the first dark line is 0.55 cm. What is the wavelength of the light used?

$$x_1 = \frac{\lambda L}{w}$$
$$\lambda = \frac{x_1 w}{L}$$
$$= \frac{(5.5\times10^{-3}\ \text{m})(1.0\times10^{-4}\ \text{m})}{(0.900\ \text{m})}$$
$$= 611\ \text{nm}$$

7. A single-slit diffraction experiment is performed using a He-Ne laser ($\lambda = 633$ nm) and the setup in the figure below. What will be the width of the central bright band?

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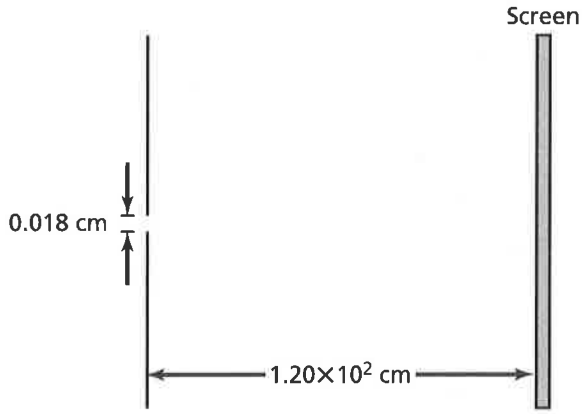


$$2x_1 = \frac{2\lambda L}{w}$$
$$= \frac{2(6.33\times10^{-7}\text{ m})(1.20\text{ m})}{(1.8\times10^{-4}\text{ m})}$$
$$= 8.4\times10^{-3}\text{ m}$$

**8.** A grating spectroscope is used to analyze light of an unknown wavelength. The slits of the grating are 2.4 $\mu$m apart and the angle between the central bright line and the first-order bright line is 15.8°. What is the wavelength of the light?

$$\lambda = d\sin\theta$$
$$= (2.4\times10^{-6}\text{ m})(\sin 15.8°)$$
$$= 653\text{ nm}$$

**9.** A spectroscope uses a grating with 11,500 lines/cm. At what angle will light of wavelength 485 nm have its first-order bright line?

$$\lambda = d\sin\theta$$
$$\theta = \sin^{-1}\left(\frac{\lambda}{d}\right)$$
$$\left(\frac{11{,}500\text{ lines}}{\text{cm}}\right)\left(\frac{100\text{ cm}}{1\text{ m}}\right)$$
$$= 1.15\times10^{6}\text{ lines/m}$$
$$\frac{(1\text{ m})}{(1.15\times10^{6}\text{ lines})} = 8.7\times10^{-7}\text{ m/line}$$
$$= \sin^{-1}\left(\frac{4.85\times10^{-7}\text{ m}}{8.7\times10^{-7}\text{ m}}\right)$$
$$= 33.9°$$

**10.** The aperture through which light enters the human eye is called the iris. The average human iris has a diameter of 5.0 mm. What is the physical limit of the height of an object viewed from 6.0 m away?

$$x_{obj} = \frac{1.22\lambda L_{obj}}{D}$$
$$= \frac{1.22(5.89\times10^{-7}\text{ m})(6.0\text{ m})}{(5.0\times10^{-3}\text{ m})}$$
$$= 8.6\times10^{-4}\text{ m}$$

**11.** Coherent light of wavelength 642 nm is incident upon a pair of slits separated by 21 $\mu$m. If a screen is placed 0.550 m from the slits, how far from the central bright band is the second-order bright band?

$$m\lambda = \frac{xd}{L}$$
$$x = \frac{m\lambda L}{d}$$
$$= \frac{2(6.42\times10^{-7}\text{ m})(0.550\text{ m})}{2.1\times10^{-5}\text{ m}}$$
$$= 0.034\text{ m}$$

**12.** Light of an unknown wavelength falls on two slits separated by $1.90\times10^{-5}$ m. A first-order bright band appears 12.4 mm from the central bright band on a screen that is placed 0.450 m from the slits. Find the wavelength of the light.

$$m\lambda = \frac{xd}{L}$$
$$\lambda = \frac{xd}{mL}$$
$$= \frac{(1.24\times10^{-2}\text{ m})(1.90\times10^{-5}\text{ m})}{(1)(0.450\text{ m})}$$
$$= 524\text{ nm}$$

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**Chapter 19 continued**

**13.** A thin layer of oil floats on water. When light strikes the oil, colored bands are produced. One of the colors is blue ($\lambda$ = 490 nm). If the index of refraction of oil is 1.45, what is the minimum thickness that could have produced this color?

$$2d = (m + \frac{1}{2})\frac{\lambda}{n_{oil}}$$

**For the thinnest layer, $m = 0$**

$$d = \frac{\lambda}{4n_{oil}}$$

$$= \frac{(4.9\times10^{-7}\text{ m})}{4(1.45)}$$

$$= 84\text{ nm}$$

**14.** Light of wavelength 612 nm falls on a single slit $8.5\times10^{-5}$ m wide. The slit is 81 cm from a screen. How wide is the central bright band?

$$2x_1 = \frac{2\lambda L}{w}$$

$$= \frac{2(6.12\times10^{-7}\text{ m})(0.81\text{ m})}{8.5\times10^{-5}\text{ m}}$$

$$= 12\text{ mm}$$

**15.** Light of an unknown wavelength falls on a single slit $9.00\times10^{-5}$ m wide. A 14.1 mm wide bright band is produced on a screen 85 cm away. What is the wavelength of the light?

$$2x_1 = \frac{2\lambda L}{w}$$

$$\lambda = \frac{2x_1 w}{2L}$$

$$= \frac{(1.41\times10^{-2}\text{ m})(9.00\times10^{-5}\text{ m})}{2(0.85\text{ m})}$$

$$= 750\text{ nm}$$

**16.** When light of wavelength 540 nm shines on a diffraction grating, lines spaced at 0.54 m are produced on a screen 95 cm away. What is the spacing between the slits in the diffraction grating?

$$\lambda = d\sin\theta$$

$$d = \frac{\lambda}{\sin\theta}$$

$$\tan\theta = \frac{x}{L}$$

$$\theta = \tan^{-1}\left(\frac{x}{L}\right)$$

$$d = \frac{\lambda}{\sin\left(\tan^{-1}\left(\frac{x}{L}\right)\right)}$$

$$= \frac{540\times10^{-9}\text{ m}}{\sin\left(\tan^{-1}\left(\frac{0.54\text{ m}}{0.95\text{ m}}\right)\right)}$$

$$= \frac{540\times10^{-9}\text{ m}}{\sin(\tan^{-1}(.057))}$$

$$= \frac{540\times10^{-9}\text{ m}}{\sin 30°}$$

$$= 1.1\times10^{-6}\text{ m}$$

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# Chapter 20

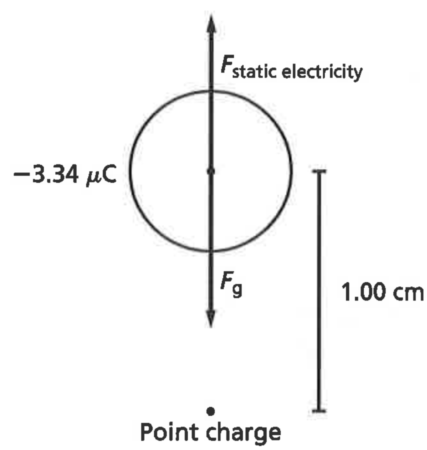
1. A point charge of $+1.23\times10^{-8}$ C and a point charge of $-2.0\times10^{-6}$ C are separated by 30.0 cm. What is the attractive force between the charges?

$$F = K\frac{q_A q_B}{r^2}$$
$$= (9.0\times10^{9}\ \mathrm{N{\cdot}m^2/C^2})\left(\frac{(1.23\times10^{-8}\ \mathrm{C})(2.0\times10^{-6}\ \mathrm{C})}{(0.300\ \mathrm{m})^2}\right)$$
$$= 2.5\times10^{-3}\ \mathrm{N}$$

2. Two identical positive charges separated by 12.5 cm exert a repulsive force of 1.24 N on each other. What is the magnitude of the charges?

$$F = K\frac{2q}{r^2}$$
$$q = \frac{r^2F}{2K}$$
$$= \frac{(0.125\ \mathrm{m})^2(1.24\ \mathrm{N})}{2(9.0\times10^{9}\ \mathrm{N{\cdot}m^2/C^2})}$$
$$= 1.08\times10^{-12}\ \mathrm{C}$$

3. A metal sphere has a mass of 1.22 kg and carries a charge of $-3.34$ nC. Determine the size of the charge required to levitate the sphere 1.00 cm above the charge.




$$F_{\text{static electricity}} = F_{\text{gravity}}$$
$$= K\frac{q_{\text{sphere}}q_{\text{charge}}}{r^2}$$
$$F_{\text{gravity}} = mg$$
$$mg = K\frac{q_{\text{sphere}}q_{\text{charge}}}{r^2}$$
$$q_{\text{charge}} = \frac{mgr^2}{q_{\text{sphere}}K}$$

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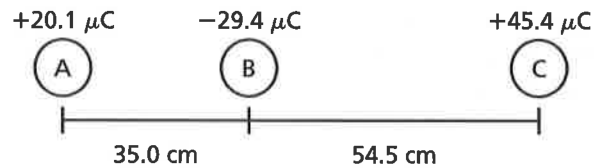
$$= \frac{(1.22\ \text{kg})(9.80\ \text{m/s}^2)(0.010\ \text{m})^2}{(3.34\times10^{-9}\ \text{C})(8.99\times10^{9}\ \text{N·m}^2/\text{C}^2)}$$

$$= 3.98\times10^{-5}\ \text{C}$$

**4.** Three charged particles are placed in a line, as shown in the figure below.




**a.** Find the magnitude and direction of the force on particle A.

$$F_{\text{total}} = F_{\text{AB}} + F_{\text{AC}}$$

$$F_{\text{AB}} = K\frac{q_{\text{A}}q_{\text{B}}}{r^2}$$

$$= (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\left(\frac{(2.01\times10^{-5}\ \text{C})(2.94\times10^{-5}\ \text{C})}{(0.350\ \text{m})^2}\right)$$

$$= 43.4\ \text{N to the right}$$

$$F_{\text{AC}} = K\frac{q_{\text{A}}q_{\text{C}}}{r^2}$$

$$= (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\left(\frac{(2.01\times10^{-5}\ \text{C})(4.54\times10^{-5}\ \text{C})}{(0.895\ \text{m})^2}\right)$$

$$= 10.3\ \text{N to the left or } -10.3\ \text{N}$$

$$F_{\text{total}} = 43.4\ \text{N} - 10.3\ \text{N} = 33.1\ \text{N to the right}$$

**b.** Find the magnitude and direction of the force on particle B.

$$F_{\text{total}} = F_{\text{AB}} + F_{\text{BC}}$$

$$F_{\text{AB}} = K\frac{q_{\text{A}}q_{\text{B}}}{r^2}$$

$$= (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\left(\frac{(2.01\times10^{-5}\ \text{C})(2.94\times10^{-5}\ \text{C})}{(0.350\ \text{m})^2}\right)$$

$$= 43.4\ \text{N to the left or } -43.4\ \text{N}$$

$$F_{\text{BC}} = K\frac{q_{\text{B}}q_{\text{C}}}{r^2}$$

$$= (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\left(\frac{(2.94\times10^{-5}\ \text{C})(4.54\times10^{-5}\ \text{C})}{(0.545\ \text{m})^2}\right)$$

$$= 40.4\ \text{N to the right}$$

$$F_{\text{total}} = -43.4\ \text{N} + 40.4\ \text{N} = 3.0\ \text{N to the left}$$

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**Chapter 20 continued**

**5.** Two negatively charged particles are separated by 89.0 cm. One particle has 4.2 times the charge of the other particle. If the repulsive force between the particles is 0.097 N, what is the magnitude of the charge on each particle?

$$F = K\frac{q_A q_B}{r^2}$$

$$q_A = 4.2q_B$$

$$F = K\frac{4.2{q_B}^2}{r^2}$$

$$q_B = \sqrt{\frac{r^2F}{4.2K}}$$

$$= \sqrt{\frac{(0.89\ \text{m})^2(0.097\ \text{N})}{4.2(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)}}$$

$$= 1.4\times10^{-6}\ \text{C}$$

**6.** A particle with a charge of 1.01 $\mu$C and a particle with a charge of 0.907 $\mu$C exert a force of 4.56 N on each other. What is the distance between the two particles?

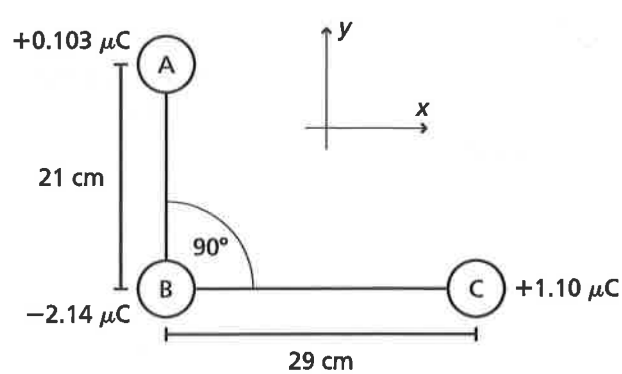
$$F = K\frac{q_A q_B}{r^2}$$

$$r = \sqrt{K\frac{q_A q_B}{F}}$$

$$= \sqrt{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{(1.01\times10^{-6}\ \text{C})(9.07\times10^{-7}\ \text{C})}{(4.56\ \text{N})}\right)}$$

$$= 4.25\ \text{cm}$$

**7.** Three charged particles are arranged as shown in the figure below. Calculate the magnitude and direction of the force experienced by particle B.




$$F_{\text{total}} = F_{\text{A on B}} + F_{\text{C on B}}$$

$$F_{\text{A on B}} = K\frac{q_A q_B}{r^2}$$

$$= (9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{(1.03\times10^{-7}\ \text{C})(2.14\times10^{-6}\ \text{C})}{(0.21\ \text{m})^2}\right)$$

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**Chapter 20 continued**

$= 0.045\ \text{N upward}$

$$F_{\text{C on B}} = K\frac{q_C q_B}{r^2}$$

$$= (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\left(\frac{(1.10\times10^{-6}\ \text{C})(2.14\times10^{-6}\ \text{C})}{(0.29\ \text{m})^2}\right)$$

$$= 0.25\ \text{N to the right}$$

$$F_{\text{total}} = \text{vector sum of } F_{\text{A on B}} \text{ and } F_{\text{C on B}}$$

$$= \sqrt{(0.045\ \text{N})^2 + (0.25\ \text{N})^2}$$

$$= 0.26\ \text{N}$$

$$\tan\theta = \frac{(0.26\ \text{N})}{(0.045\ \text{N})}$$

$$\theta = \tan^{-1}\left(\frac{0.26\ \text{N}}{0.045\ \text{N}}\right)$$

$$= 80°\ \text{clockwise from the } y\text{-axis}$$

**8.** A tiny metal sphere carrying a charge of −43.6 nC is touched to an identical neutral metal sphere. The spheres are then placed 1.02 cm apart. What is the magnitude of the repulsive force between the two spheres?

$$F = K\frac{q_A q_B}{r^2}$$

$$q_A = q_B = \frac{(4.36\times10^{-8}\ \text{C})}{2}$$

$$q = 2.18\times10^{-8}\ \text{C}$$

$$F = (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\left(\frac{(2.18\times10^{-8}\ \text{C})^2}{(0.0102\ \text{m})^2}\right)$$

$$= 0.0411\ \text{N}$$

**9.** Two point charges are separated by a distance of 23 cm. One of the charges has a magnitude of +1.23 $\mu$C, and there is an attractive force of 1.8 N between the charges. What is the magnitude of the negative charge?

$$F = K\frac{q_{pos} q_{neg}}{r^2}$$

$$q_{neg} = \frac{r^2 F}{q_{pos} K}$$

$$= \frac{(0.23\ \text{m})^2(1.8\ \text{N})}{(1.23\times10^{-6}\ \text{C})(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)}$$

$$= 8.6\times10^{-6}\ \text{C}$$

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**10.** What is the force of attraction between an electron and a proton separated by 27.0 nm?

$$F = K\frac{q_{\text{electron}}q_{\text{proton}}}{r^2}$$

$$= (9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{(1.60\times10^{-19}\ \text{C})^2}{(2.70\times10^{-8}\ \text{m})^2}\right)$$

$$= 3.16\times10^{-13}\ \text{C}$$

**11.** Two electrons are located only 2.5 nm apart.

**a.** What is the magnitude of the force between these charged particles?

$$F = K\frac{q_e q_e}{r^2}$$

$$= (9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{(2.5\times10^{-9}\ \text{m})^2}\right)$$

$$= 3.7\times10^{-11}\ \text{N}$$

**b.** Is the force attractive or repulsive?

**The electrons are both negatively charged, so the force is repulsive.**

**12.** Calculate the repulsive force between two protons in the nucleus of an atom of iron separated by only $4.0\times10^{-15}$ m.

$$F = K\frac{q_p q_p}{r^2}$$

$$= (9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{(4.0\times10^{-15}\ \text{m})^2}\right)$$

$$= 14\ \text{N}$$

**13.** The electron and proton in a hydrogen atom exert an electric force of $8.1\times10^{-8}$ N on each other. What is the distance between them?

$$r = \sqrt{K\frac{q_e q_p}{F}}$$

$$= \sqrt{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{8.1\times10^{-8}\ \text{N}}\right)}$$

$$= 5.3\times10^{-11}\ \text{m}$$

**14.** Two protons are located 1.0 cm apart. Which force has the greater magnitude, $\frac{1}{m}$: force due to charge or gravitational force?

$$F_{\text{elec}} = K\frac{q_p q_p}{r^2}$$

$$= (9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{(0.010\ \text{m})^2}\right)$$

$$= 2.3\times10^{-24}\ \text{N}$$

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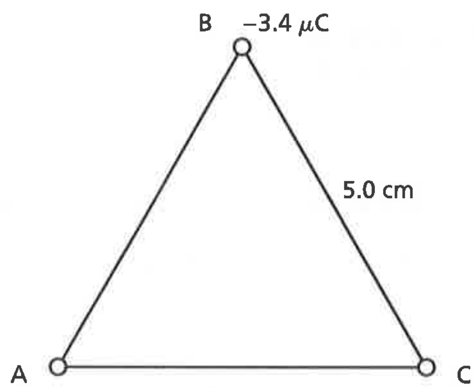
$$F_{grav} = G\frac{m_p m_p}{r^2}$$

$$= (6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)\left(\frac{(1.67\times10^{-27}\ \text{kg})(1.67\times10^{-27}\ \text{kg})}{(0.010\ \text{m})^2}\right)$$

$$= 1.9\times10^{-60}\ \text{N}$$

**The force due to charge is more than $10^{36}$ times stronger than the gravitational force at this distance.**

15. Three point charges of $-3.4\ \mu C$ each are arranged at the points of an equilateral triangle with sides of length 5.0 cm, as shown in the figure below. What is the magnitude of the force acting on one of the charges?




**Since the triangle is uniform, start with any charge (A) and calculate the forces of the other charges using this point as the origin.**

$$F_{C\ on\ A} = K\frac{q_C q_A}{r^2}$$

$$= (9.0\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{(3.4\times10^{-6}\ \text{C})(3.4\times10^{-6}\ \text{C})}{(0.050\ \text{m})^2}\right)$$

$$= 42\ \text{N}$$

$$F_{B\ on\ A} = K\frac{q_B q_A}{r^2}$$

$$= (9.0\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{(3.4\times10^{-6}\ \text{C})(3.4\times10^{-6}\ \text{C})}{(0.050\ \text{m})^2}\right)$$

$$= 42\ \text{N}$$

**The force of $F_{C\ on\ A}$ acts along the $x$-axis but the force of $F_{B\ on\ A}$ needs to be resolved into its $x$- and $y$-components to find the total force.**

$$F_{B\ on\ A,\ x} = (F_{B\ on\ A}) \cos\theta$$

$$= (42\ \text{N})(\cos 60.0°)$$

$$= 21\ \text{N}$$

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**Chapter 20 continued**

$$F_{\text{B on A}, y} = (F_{\text{B on A}}) \sin \theta$$
$$= (42\ \text{N})(\sin 60.0°)$$
$$= 36\ \text{N}$$

$$F_x = F_{\text{C on A}} + F_{\text{B on A}, x} = 42\ \text{N} + 21\ \text{N} = 63\ \text{N}$$

$$F_y = F_{\text{B on A}, y} = 36\ \text{N}$$

$$F_{\text{total}} = \sqrt{F_x^2 + F_y^2}$$
$$= \sqrt{(63\ \text{N})^2 + (36\ \text{N})^2}$$
$$= 72\ \text{N}$$

**16.** Two point charges of different values exert a repulsive force of 0.175 N when they are 0.50 m apart. One of the charges is exactly 10 times as large as the other. What are the values of these point charges?

$$F = K\frac{q_1q_2}{r^2} = K\frac{q_1(10q_1)}{r^2} = 10K\frac{q_1^2}{r^2}$$

$$q_1 = \sqrt{\frac{Fr^2}{10K}}$$
$$= \sqrt{\frac{(0.175\ \text{N})(0.50\ \text{m})^2}{10(9.0\times10^9\ \text{N·m}^2/\text{C}^2}}$$
$$= 7.0\times10^{-7}\ \text{C}$$

$$q_2 = 10q_1 = (10)(7.0\times10^{-7}\ \text{C})$$
$$= 7.0\times10^{-6}\ \text{C}$$

**17.** How far apart will two electrons need to be to exert a repulsive force of exactly 1.0 N upon one another?

$$r = \sqrt{K\frac{q_eq_e}{F}}$$
$$= \sqrt{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)\left(\frac{(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{1.0\ \text{N}}\right)}$$
$$= 1.5\times10^{-14}\ \text{m}$$

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**Chapter 20 continued**

**18.** How far apart will two protons need to be to exert a repulsive force equal to the weight of one of the protons?

$$F = K\frac{q_p q_p}{r^2} = m_p g$$

$$r = \sqrt{K\frac{q_p{}^2}{m_p g}}$$

$$= \sqrt{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{(1.60\times10^{-19}\ \text{C})^2}{(1.67\times10^{-27}\ \text{kg})(9.80\ \text{m/s}^2)}\right)}$$

$$= 0.12\ \text{m}$$

**19.** The distance between the oxygen and hydrogen atoms in a molecule of water is about $2.70\times10^{-10}$ m. If the oxygen atom has a net charge of $-2e^-$ and the hydrogen atom has a net charge of $+1e^-$, what is the force of the electric attraction between them?

$$F = K\frac{q_O q_H}{r^2}$$

$$= (9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{(2)(1.60\times10^{-19}\ \text{C})(1)(1.60\times10^{-19}\ \text{C})}{(2.70\times10^{-10}\ \text{m})^2}\right)$$

$$= 6.3\times10^{-9}\ \text{N}$$

**Because the atoms are opposite in charge, the force is attractive.**

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# Chapter 21

**1.** A test charge in an electric field of strength 21.45 N/C experiences a force of 5.10 N. What is the magnitude of the test charge?

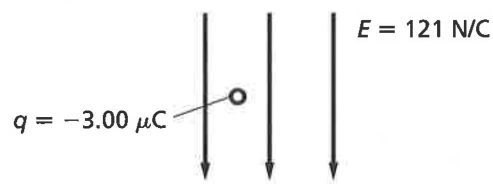
$$E = \frac{F}{q}$$

$$q = \frac{F}{E}$$

$$= \frac{5.10\ \text{N}}{21.45\ \text{N/C}}$$

$$= 0.238\ \text{C}$$

**2.** A test charge of $-3.00\ \mu C$ is placed in an electric field of 121 N/C, as shown in the figure below. What are the magnitude and direction of the force on the test charge?




$$E = \frac{F}{q}$$

$$F = Eq$$

$$= (121\ \text{N/C})(3.00\times10^{-6}\ \text{C})$$

**$= 3.63\times10^{-4}$ N upward (Charge is negative and will thus experience a force in the opposite direction as the electric field lines.)**

**3.** What is the magnitude of an electric field that exerts 39.0 N of force on a $4.5\times10^{-5}$-C test charge?

$$E = \frac{F}{q}$$

$$= \frac{39.0\ \text{N}}{4.5\times10^{-5}\ \text{C}}$$

$$= 8.7\times10^{5}\ \text{N/C}$$

**4.** The potential difference between the two plates below is 520 V.

**a.** What is the strength and direction of the electric field between the two plates?

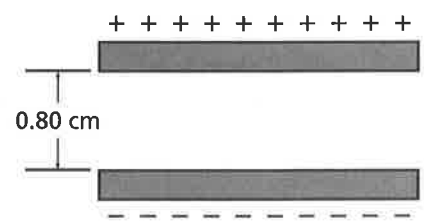
$$\Delta V = Ed$$

$$E = \frac{\Delta V}{d}$$

$$= \frac{520\ \text{V}}{0.008\ \text{m}}$$

$$= 6.5\times10^{4}\ \text{N/C}$$

**b.** How much work is required to move one more electron to the negative plate?




$$\Delta V = \frac{W}{q}$$

$$W = q\Delta V$$

$$= (1.60\times10^{-19}\ \text{C})(520\ \text{V})$$

$$= 8.3\times10^{-17}\ \text{J}$$

**5.** A 3.3-mC charge is moved through a 150-V potential difference.

**a.** How much work is required to move the charge?

$$\Delta V = \frac{W}{q}$$

$$W = q\Delta V$$

$$= (3.3\times10^{-3}\ \text{C})(150\ \text{V})$$

$$= 0.50\ \text{J}$$

**b.** If the charge is moved 0.750 cm, what is the strength of the electric field where the charge is moved?

$$\Delta V = Ed$$

$$E = \frac{\Delta V}{d}$$

$$= \frac{150\ \text{V}}{0.00750\ \text{m}}$$

$$= 2.0\times10^{4}\ \text{N/C}$$

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**Chapter 21 continued**

6. A point charge of unknown magnitude is moved through a 210-N/C electric field.

   a. If the charge is negative and positive work is done on the system, in what direction relative to the electric field lines is the charge moved?

   **If positive work is done on the system, then potential energy has been added and the negative charge must be in a location with a higher energy. An electron will naturally move against electric field lines to a location of lower energy, and thus, the negative charge must have been moved with the field lines.**

   b. If the charge is positive and negative work is done on the system, in what direction relative to the electric field lines is the charge moved?

   **If negative work has been done on the system, the system has lost potential energy and thus, the positive charge must be at a location of lower energy. A positive charge will naturally move with electric field lines to a position of lower energy and thus, the charge must have moved with the field lines.**

   c. Through what potential difference has the charge moved if it is moved 1.9 cm?

   $$\Delta V = Ed$$
   $$= (210\ \text{N/C})(0.019\ \text{m})$$
   $$= 4.0\ \text{V}$$

   d. If +98 J of work is required to move the charge 1.9 cm against the electric field lines, what is the sign and magnitude of the charge?

   $$\Delta V = \frac{W}{q}$$
   $$q = \frac{W}{\Delta V}$$
   $$= \frac{98\ \text{J}}{4.0\ \text{V}} = 24\ \text{C}$$

   **The charge must be positive if it requires positive work to move it against field lines.**

7. A positive test charge is moved 5.6 cm against a 75-N/C electric field. Through what potential difference has the charge been moved?

   $$\Delta V = Ed$$
   $$= (75\ \text{N/C})(0.056\ \text{m})$$
   $$= 4.2\ \text{V}$$

8. What is the capacitance of a capacitor that requires a potential difference of 54 V to store 67.8 $\mu$C of charge?

   $$C = \frac{q}{\Delta V}$$
   $$= \frac{6.78\times10^{-5}\ \text{C}}{54\ \text{V}}$$
   $$= 1.3\ \mu\text{F}$$

9. How much voltage is required for a capacitor with a capacitance of 0.750 $\mu$F to store 2.3 $\mu$C of charge?

   $$C = \frac{q}{\Delta V}$$
   $$\Delta V = \frac{q}{C}$$
   $$= \frac{2.3\times10^{-6}\ \text{C}}{7.50\times10^{-7}\ \text{F}}$$
   $$= 3.1\ \text{V}$$

10. The same voltage is applied to both capacitors A and B, but capacitor A stores three times more charge than capacitor B. What is the ratio of the capacitance of capacitor A to the capacitance of capacitor B?

   $$q_A = 3q_B$$
   $$\frac{q_A}{q_B} = \frac{3}{1}$$
   $$C_A = \frac{q_A}{\Delta V}$$
   $$C_B = \frac{q_B}{\Delta V}$$
   $$\frac{C_A}{C_B} = \left(\frac{\frac{q_A}{\Delta V}}{\frac{q_B}{\Delta V}}\right)$$
   $$= \frac{q_A}{q_B}$$
   $$= \frac{3}{1}$$

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**11.** A helium nucleus consisting of two protons and two neutrons passes through a detector with an electric field strength of $1.50\times10^6$ N/C. What is the magnitude of the force experienced by the helium nucleus?

**The charge on a single proton is $q_p = 1.60\times10^{-19}$ C, and the neutrons contribute nothing to the net charge.**

$$E = \frac{F}{q}$$

$$F = Eq$$

$$= 2Eq_p$$

$$= (1.50\times10^6 \text{ N/C})(2)(1.60\times10^{-19} \text{ C})$$

$$= 4.80\times10^{-13} \text{ N}$$

**12.** An unknown charge is brought within 8.0 cm of a standard test charge of $-5.0\times10^{-9}$ C. At this distance, an electric field strength of $4.65\times10^{-2}$ N/C is measured. What is the value of the unknown charge?

**Combining Coulomb's law with the equation for electric field strength,**

$$E = \frac{F}{q} = K\frac{q_1q_2}{d^2q_1} = \frac{Kq_2}{d^2}$$

$$q_2 = \frac{Ed^2}{K} = \frac{(4.65\times10^{-2} \text{ N/C})(0.080 \text{ m})^2}{9.0\times10^9 \text{ N}\cdot\text{m}^2/\text{C}^2}$$

$$= 3.3\times10^{-14} \text{ C}$$

**(With the value of the electric field strength known, the value of the test charge is not necessary.)**

**13.** In 1 s, $2.50\times10^{18}$ electrons pass from one charged plate to another parallel charged plate.

**a.** If the potential difference between the parallel plates is 1.0 $\mu$V, how much work is done moving this quantity of electrons between the two plates?

$$\Delta V = \frac{W}{q}$$

$$W = q\Delta V = (2.50\times10^{18})(1.60\times10^{-19} \text{ C})(1.0\times10^{-6} \text{ V})$$

$$= 4.0\times10^{-7} \text{ J}$$

**b.** With an electric field strength of $6.0\times10^{-4}$ N/C measured between the plates, how far apart are these parallel plates?

$$\Delta V = Ed$$

$$d = \frac{\Delta V}{E} = \frac{1.0\times10^{-6} \text{ V}}{6.0\times10^{-4} \text{ N/C}}$$

$$= 1.7\times10^{-3} \text{ m} = 1.7 \text{ mm}$$

**14.** An oil drop is suspended in an electric field of $1.92\times10^5$ N/C between two charged plates as part of a Millikan oil-drop experiment. The oil drop has a mass of $1.57\times10^{-11}$ g and the charged plates of the apparatus are exactly 1.00 cm apart.

**a.** What is the potential difference between the two charged plates?

$$\Delta V = Ed$$

$$= (1.92\times10^5 \text{ N/C})(0.0100 \text{ m})$$

$$= 1920 \text{ V}$$

**b.** What is the net charge on the oil drop? How many excess electrons are on this oil drop?

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{mg}{E}$$

$$= \frac{(1.57\times10^{-14} \text{ kg})(9.80 \text{ m/s}^2)}{1.92\times10^5 \text{ N/C}}$$

$$= 8.01\times10^{-19} \text{ C}$$

$$n = \frac{q}{q_e} = \frac{8.01\times10^{-19} \text{ C}}{1.60\times10^{-19} \text{ C}}$$

$$= 5 \text{ electrons}$$

**c.** Which plate is positively charged and which plate is negatively charged? What would happen if the charges were reversed?

**Because the oil drop is suspended between the plates, the top plate must be positive and the bottom plate must be negative. Only an attractive force above and a repulsive force below would offset the downward force of gravity. If the**

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**charges on the plates were reversed, the droplet would accelerate downward since all forces then act in the same direction as gravity.**

**15.** A 0.5-$\mu$F capacitor is able to store $7.2\times10^{-10}$ C of charge with an electric field strength of 0.33 N/C between its plates. How far apart are these plates?

$$C = \frac{q}{\Delta V} = \frac{q}{Ed}$$

$$d = \frac{q}{EC} = \frac{7.2\times10^{-10}\ \text{C}}{(0.33\ \text{N/C})(0.5\times10^{-6}\ \text{F})}$$

$$= 4.4\times10^{-3}\ \text{m} = 4.4\ \text{mm}$$

**16.** Most capacitors are measured in terms of microfarads, $\mu$F, or picofarads, pF, because the unit of capacitance, the farad, is a relatively large unit. Given a 1-F capacitor with plates separated by 1.0 mm and an electric field strength of 1 N/C, calculate the number of electrons resting on the plates of this capacitor.

$$C = \frac{q}{\Delta V} = \frac{q}{Ed}$$

$$q = CEd = (1\ \text{F})(1\ \text{N/C})(0.0010\ \text{m})$$

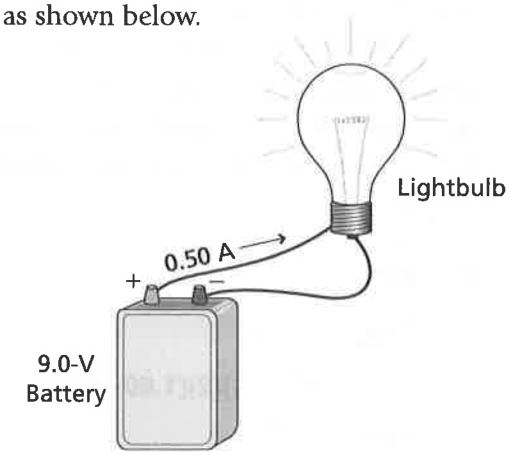
$$= 0.0010\ \text{C}$$

$$n = \frac{q}{q_e} = \frac{0.0010\ \text{C}}{1.60\times10^{-19}\ \text{C}}$$

$$= 6.2\times10^{15}\ \text{electrons}$$

# Chapter 22

**1.** A 9.0-V battery is connected to a lightbulb, as shown below.




**a.** How much power is delivered to the lightbulb?

$$P = IV$$

$$= (0.50\ \text{A})(9.0\ \text{V})$$

$$= 4.5\ \text{W}$$

**b.** How much energy will the bulb use in 1 h?

$$E = Pt$$

$$P = IV$$

$$E = IVt$$

$$= (0.50\ \text{A})(9.0\ \text{V})(1\ \text{h})\left(\frac{60\ \text{min}}{1\ \text{h}}\right)\left(\frac{60\ \text{s}}{1\ \text{min}}\right)$$

$$= 16{,}000\ \text{J}$$

**c.** How long would the bulb have to stay on to use 1 kWh of energy?

$$E = Pt$$

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

$$P = IV$$

$$t = \frac{E}{IV}$$

$$E = (1\ \text{kWh})\left(\frac{1000\ \text{W}}{1\ \text{kW}}\right)\left(\frac{3600\ \text{s}}{1\ \text{h}}\right)$$

$$= 3.6\times10^{6}\ \text{J}$$

$$t = \frac{3.6\times10^{6}\ \text{J}}{(0.50\ \text{A})(9.0\ \text{V})}$$

$$= 800{,}000\ \text{s}$$

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**Chapter 22 continued**

2. A 60-W lightbulb is connected to a 115-V power source.

   a. What is the current through the lightbulb?

   $P = IV$

   $I = \frac{P}{V}$

   $= \frac{60\ W}{115\ V}$

   $= 0.5\ A$

   b. What is the resistance of the lightbulb?

   $P = \frac{V^2}{R}$

   $R = \frac{V^2}{P}$

   $= \frac{(115\ V)^2}{60\ W}$

   $= 200\ \Omega$

3. A circuit is set up as shown in the diagram at the top right.

   a. What should the reading on the ammeter be?

   $R = \frac{V}{I}$

   $I = \frac{V}{R}$

   $= \frac{36\ V}{24\ \Omega}$

   $= 1.5\ A$

   b. What should the reading on the voltmeter be?

   $R = \frac{V}{I}$

   $V = IR$

   $= (1.5\ A)(24\ \Omega)$

   $= 36\ V$

   c. How much power is delivered to the resistor?

   $P = IV$

   $= (1.5\ A)(36\ V)$

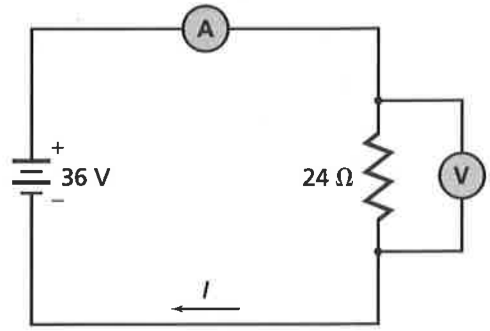
   $= 54\ W$

   d. How much energy is delivered to the resistor per hour?

   $E = Pt$

   $= (54\ W)(3600\ s)$

   $= 1.9\times10^5\ J$




4. A microwave draws a 15.0-A current from a 120-V power source.

   a. How much power is delivered to the microwave?

   $P = IV$

   $= (15.0\ A)(120\ V)$

   $= 1800\ W$

   b. How much energy does the microwave use to heat food for 1 min?

   $E = Pt$

   $= (1800\ W)(60\ s)$

   $= 100{,}000\ J$

5. A circuit is set up as shown in the diagram below.

   a. What is the resistance of the resistor in the circuit?

   $R = \frac{V}{I}$

   $= \frac{115\ V}{2.7\ A}$

   $= 43\ \Omega$

   b. What should be the reading on the voltmeter?

   $R = \frac{V}{I}$

   $V = IR$

   $= (2.7\ A)(43\ V)$

   $= 120\ V$

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**c.** How much power is delivered to the resistor?

$P = IV$

$= (2.7\ \text{A})(115\ \text{V})$

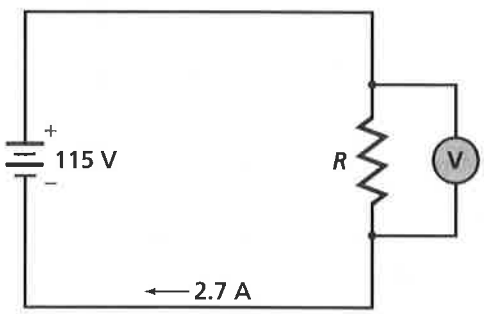
$= 310\ \text{W}$

**d.** How much energy is delivered to the resistor per hour?

$E = Pt$

$= (310\ \text{W})(3600\ \text{s})$

$= 1.1\times10^6\ \text{J}$




**6.** A 100-W lightbulb is turned on for two-fifths of the time for 30 days. At a price of \$0.090 per kWh, how much does the lightbulb cost to run during the 30 days?

$E = Pt$

$(30\ \text{days})\left(\frac{2}{5}\right)(24\ \text{h/day})(3600\ \text{s/h})$

$= 1{,}036{,}800\ \text{s}$

$E = (100\ \text{W})(1{,}036{,}800\ \text{s})$

$= 1.0368\times10^8\ \text{J}$

$(1.0368\times10^8\ \text{J})\left(\frac{1\ \text{kWh}}{3.6\times10^6\ \text{J}}\right) = 28.8\ \text{kWh}$

$(28.8\ \text{kWh})(\$0.090/\text{kWh}) = \$2.59$

**7.** A current of 0.85 A is measured through a 27-Ω resistor for 1.00 h. How much heat does the resistor generate?

$E = Pt$

$P = I^2R$

$E = I^2Rt$

$= (0.85\ \text{A})^2(27\ \Omega)(3600\ \text{s})$

$= 7.0\times10^4\ \text{J}$

**8.** A 60-W lightbulb has a resistance of 240 Ω. What is the current in the lightbulb?

$P = I^2R$

$I = \sqrt{\frac{P}{R}}$

$= \sqrt{\frac{(60\ \text{W})}{(240\ \Omega)}}$

$= 0.5\ \text{A}$

**9.** What is the current through an 80.0-Ω resistor if the voltage drop across the resistor is 20.0 V?

$R = \frac{V}{I}$

$I = \frac{V}{R}$

$= \frac{20.0\ \text{V}}{80.0\ \Omega}$

$= 0.250\ \text{A}$

**10.** A 60-W lightbulb and a 100-W lightbulb both are connected to a 120-V power source. Which bulb has the greater resistance?

$P = \frac{V^2}{R}$

$R = \frac{V^2}{P}$

$R_{60} = \frac{(120\ \text{V})^2}{60\ \text{W}} = 200\ \Omega$

$R_{100} = \frac{(120\ \text{V})^2}{100\ \text{W}} = 100\ \Omega$

**The 60-W lightbulb has the greater resistance.**

**11.** A 12-V battery is used to power a $3.0\times10^2$ mA video camera.

**a.** How much power does the battery provide to the camera?

$3.0\times10^2\ \text{mA} = 0.30\ \text{A}$

$P = IV = (0.30\ \text{A})(12\ \text{V}) = 3.6\ \text{W}$

**b.** How much energy does the camera use in 1.0 s?

$E = Pt = (3.6\ \text{W})(1.0\ \text{s}) = 3.6\ \text{J}$

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**Chapter 22 continued**

**c.** How much energy does the camera use in 1.0 h?

$$E = Pt = (3.6\ \text{J})(1.0\ \text{h})\left(\frac{60\ \text{min}}{1\ \text{h}}\right)\left(\frac{60\ \text{s}}{1\ \text{min}}\right)$$
$$= 1.3\times10^{4}\ \text{J}$$

**d.** How long would it take the video camera to use 1 kWh of energy?

$$E = Pt$$
$$t = \frac{E}{P}$$
$$P = IV$$
$$t = \frac{E}{IV}$$
$$1\ \text{kWh} = (1000\ \text{J/s})(3600\ \text{s})$$
$$= 3.6\times10^{6}\ \text{J}$$
$$t = \frac{(3.6\times10^{6}\ \text{J})}{(0.30\ \text{A})(12\ \text{V})}$$
$$= 1.0\times10^{6}\ \text{s or about 280 h}$$

**12.** A 60-W bulb powered by a 120.0-V source has a resistance of 5.0 Ω at room temperature and 100.0 Ω at operating temperature.

**a.** What is the current when a 60-W bulb is turned on at room temperature?

$$I = \frac{V}{R} = \frac{120.0\ \text{V}}{5.0\ \Omega} = 24\ \text{A}$$

**b.** What is the power of this room-temperature bulb?

$$P = \frac{V^2}{R} = \frac{(120.0\ \text{V})^2}{5.0\ \Omega} = 2.9\ \text{kW}$$

**c.** What is the current when the 60-W bulb is at operating temperature?

$$I = \frac{V}{R} = \frac{(120.0\ \text{V})}{(100.0\ \Omega)} = 1.200\ \text{A}$$

**d.** What is the power of the bulb at operating temperature?

$$P = \frac{V^2}{R} = \frac{(120.0\ \text{V})^2}{100.0\ \Omega} = 144.0\ \text{W}$$

**13.** A 240-V water heater has a resistance of 15 Ω.

**a.** What is the power of the heater?

$$P = \frac{V^2}{R} = \frac{(240.0\ \text{V})^2}{15\ \Omega} = 3.8\ \text{kW}$$

**b.** What thermal energy is supplied by the heater in 15 min?

$$E = Pt$$
$$= (3.8\ \text{kW})(15\ \text{min})\left(\frac{60\ \text{s}}{1\ \text{min}}\right)$$
$$= 3.4\times10^{3}\ \text{kJ}$$

**c.** Compare the power of the same 240-V water heater to a 120-V water heater, also with a resistance of 15 Ω.

$$P = \frac{V^2}{R} = \frac{(120\ \text{V})^2}{15\ \Omega} = 960\ \text{W} = 0.96\ \text{kW}$$
$$\frac{3.8\ \text{kW}}{0.96\ \text{kW}} = 4.0$$

**The power of the 240-V water heater is four times greater than the power of the 120-V heater.**

**d.** Compare the thermal energy of the 240-V water heater to a 120-V heater in a 15-min period.

$$E = Pt = (0.96\ \text{kW})(15\ \text{min})\left(\frac{60\ \text{s}}{1\ \text{min}}\right)$$
$$= 860\ \text{kJ}$$
$$\frac{3.4\times10^{3}\ \text{kJ}}{860\ \text{kJ}} = 4.0$$

**The energy of the 240-V water heater is four times greater than that of the 120-V heater.**

**14.** How much power is dissipated in wires that have a current of 50.0 A and a resistance of 0.015 Ω?

$$P = I^2R = (50.0\ \text{A})^2(0.015\ \Omega) = 38\ \text{W}$$

**15.** A long-distance high-tension wire uses 500,000 V.

**a.** What is the power output of these wires in watts, kilowatts, and megawatts if the current is 20 A?

$$P = IV$$
$$= (20\ \text{A})(500{,}000\ \text{V})$$
$$= 1\times10^{7}\ \text{W}$$
$$= 1\times10^{4}\ \text{kW}$$
$$= 10\ \text{MW}$$

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**Chapter 22 continued**

**b.** What is the power dissipated in the wires if the resistance is 0.015 Ω?

$$P = I^2R = (20\ \text{A})^2(0.015\ \Omega) = 6\ \text{W}$$

**16.** Photovoltaic panels provide power to a home each sunny day. The resistance of the wires in this system is 0.5 Ω. If the power consumption of a computer in the home is 200 W, what current does the computer cause through the wires?

$$P = I^2R$$

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{200\ \text{W}}{0.5\ \Omega}} = 20\ \text{A}$$

**17.** Compare the energy a 120-W bulb uses per hour with the energy use in 1.0 hour of a 60-W bulb.

$$E_{120} = Pt$$

$$= (120\ \text{W})(1.0\ \text{h})\left(\frac{60\ \text{min}}{1\ \text{h}}\right)\left(\frac{60\ \text{s}}{1\ \text{min}}\right)$$

$$= 4.3\times10^5\ \text{J}$$

$$E_{60} = Pt = (60\ \text{W})(1.0\ \text{h})\left(\frac{60\ \text{min}}{1\ \text{h}}\right)\left(\frac{60\ \text{s}}{1\ \text{min}}\right)$$

$$= 2\times10^5\ \text{J}$$

$$\frac{E_{120}}{E_{60}} = \frac{4.3\times10^5\ \text{J}}{2\times10^5\ \text{J}} = 2$$

**The 120-W bulb uses twice the energy in an hour.**

**18.** How much money would be saved by turning off one 100.0-W lightbulb 3.0 h/day for 365 days if the cost of electricity is $0.12 per kWh?

$$E = Pt$$

$$= (100.0\ \text{W})\left(\frac{3.0\ \text{h}}{\text{day}}\right)\left(\frac{60\ \text{min}}{1\ \text{h}}\right)\left(\frac{60\ \text{s}}{1\ \text{min}}\right)$$

$$= 1.1\times10^6\ \text{J/day}$$

$$\left(\frac{1.1\times10^6\ \text{J}}{\text{day}}\right)\left(\frac{1\ \text{kWh}}{3.6\times10^6\ \text{J}}\right) = 0.31\ \text{kWh/day}$$

$$\left(\frac{0.31\ \text{kWh}}{\text{day}}\right)\left(\frac{\$0.12}{1\ \text{kWh}}\right) = \$0.04/\text{day}$$

$$\left(\frac{\$0.04}{\text{day}}\right)(365\ \text{days}) = \$14.60$$

**19.** How much money can be saved by turning off a 500.0-W television set for 3.0 h/day for 365 days at $0.12 per kWh?

$$E = Pt$$

$$= (500.0\ \text{W})\left(\frac{3.0\ \text{h}}{\text{day}}\right)\left(\frac{60\ \text{min}}{1\ \text{h}}\right)\left(\frac{60\ \text{s}}{1\ \text{min}}\right)$$

$$= 5.4\times10^6\ \text{J/day}$$

$$(5.4\times10^6\ \text{J})\left(\frac{1\ \text{kWh}}{3.6\times10^6\ \text{J}}\right) = 1.5\ \text{kWh/day}$$

$$\left(\frac{1.5\ \text{kWh}}{\text{day}}\right)\left(\frac{\$0.12}{\text{kWh}}\right) = \$0.18/\text{day}$$

$$\left(\frac{\$0.18}{\text{day}}\right)(365\ \text{days}) = \$65.70$$

**20.** How much does it cost to operate a 1000.0-W blow dryer for 10.0 minutes at $0.12 per kWh?

$$E = Pt$$

$$= (1000.0\ \text{W})(10.0\ \text{min})\left(\frac{60\ \text{s}}{1\ \text{min}}\right)$$

$$= 6.00\times10^5\ \text{J}$$

$$(6.00\times10^5\ \text{J})\left(\frac{1\ \text{kWh}}{3.6\times10^6\ \text{J}}\right) = 0.17\ \text{kWh}$$

$$(0.17\ \text{kWh})\left(\frac{\$0.12}{\text{kWh}}\right) = \$0.02$$

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# Chapter 23

**1.** Three 12.0-Ω resistors are connected in series to a 50.0-V power source.

**a.** What is the equivalent resistance of the circuit?

$$R = R_1 + R_2 + R_3$$
$$= 12.0\ \Omega + 12.0\ \Omega + 12.0\ \Omega$$
$$= 36.0\ \Omega$$

**b.** What is the current in the circuit?

$$R = \frac{V}{I}$$
$$I = \frac{V}{R}$$
$$= \frac{50.0\ \text{V}}{36.0\ \Omega}$$
$$= 1.39\ \text{A}$$

**c.** What is the voltage drop across each resistor?

$$R = \frac{V}{I}$$
$$V = IR$$
$$= (1.39\ \text{A})(12.0\ \Omega)$$
$$= 16.7\ \text{V}$$

**2.** Three 15.0-Ω resistors are connected in parallel to a 45.0-V power source.

**a.** What is the equivalent resistance of the circuit?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
$$= \frac{1}{15.0\ \Omega} + \frac{1}{15.0\ \Omega} + \frac{1}{15.0\ \Omega}$$
$$= \frac{3}{15} = \frac{1}{5}$$
$$R = 5.00\ \Omega$$

**b.** What is the current in the circuit?

$$R = \frac{V}{I}$$
$$I = \frac{V}{R}$$
$$= \frac{45.0\ \text{V}}{5.00\ \Omega}$$
$$= 9.00\ \text{A}$$

**c.** What is the current through each resistor?

$$R = \frac{V}{I}$$
$$I = \frac{V}{R}$$
$$= \frac{45.0\ \text{V}}{15.0\ \Omega}$$
$$= 3.00\ \text{A}$$

**3.** Two resistors are connected in series to a power source. The voltage drop across the first resistor is 5.40 V and the voltage drop across the second resistor is 9.80 V. The current through the circuit is 1.20 A.

**a.** What is the resistance of each of the resistors?

$$R_{5.40V} = \frac{V}{I}$$
$$= \frac{5.40\ \text{V}}{1.20\ \text{A}}$$
$$= 4.50\ \Omega$$
$$R_{9.80V} = \frac{V}{I}$$
$$= \frac{9.80\ \text{V}}{1.20\ \text{A}}$$
$$= 8.17\ \Omega$$

**b.** What is the equivalent resistance of the circuit?

$$R = R_1 + R_2$$
$$= 4.50\ \Omega + 8.17\ \Omega$$
$$= 12.7\ \Omega$$

**4.** What is the equivalent resistance of the circuit shown below? What is the current in the circuit? What is the voltage drop across the two resistors wired in parallel?

**Find the equivalent resistance of the resistors in parallel.**

$$\frac{1}{R_{eq1}} = \frac{1}{R_2} + \frac{1}{R_3}$$
$$= \frac{1}{12\ \Omega} + \frac{1}{12\ \Omega}$$
$$R_{eq1} = 6.0\ \Omega$$

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**Using the equivalent resistance of the resistors in parallel, find the resistance of the resistors in series.**

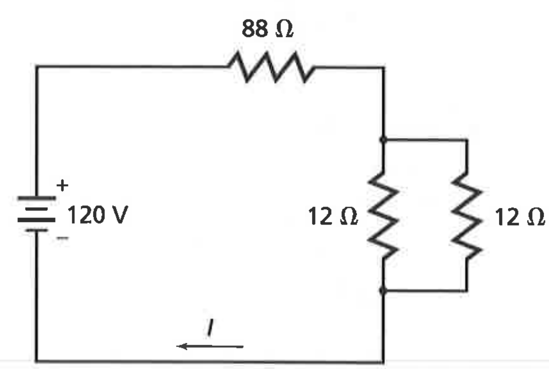
$$R_{eq2} = R_1 + R_{eq1}$$
$$= 88\ \Omega + 6.0\ \Omega$$
$$= 94\ \Omega$$

**The current in the circuit:**

$$R_{eq2} = \frac{V}{I}$$
$$I = \frac{V}{R_{eq2}}$$
$$= \frac{120\ V}{94\ \Omega}$$
$$= 1.3\ A$$

**The voltage drop across the two resistors:**

$$R_{eq1} = \frac{V}{I}$$
$$V = IR_{eq1}$$
$$= (1.3\ A)(6.0\ \Omega)$$
$$= 7.8\ V$$




**5.** A 10.0-Ω resistor, a 20.0-Ω resistor, and a 30.0-Ω resistor are wired in parallel and connected to a 15.0-V power source. What is the equivalent resistance of the circuit?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
$$= \frac{1}{10.0\ \Omega} + \frac{1}{20.0\ \Omega} + \frac{1}{30.0\ \Omega}$$
$$= \frac{11}{60}$$
$$R = 5.45\ \Omega$$

**6.** A 12-Ω and an 18-Ω resistor are connected to a 48-V power source.

**a.** What is the equivalent resistance of the circuit if the resistors are connected in series?

$$R = R_1 + R_2$$
$$= 12\ \Omega + 18\ \Omega$$
$$= 3.0\times10^1\ \Omega$$

**b.** What is the equivalent resistance of the circuit if the resistors are connected in parallel?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$= \frac{1}{12.0\ \Omega} + \frac{1}{18.0\ \Omega}$$
$$= \frac{5}{36}$$
$$R = 7.2\ \Omega$$

**7.** A voltage divider is made from a 9.0-V battery. Two resistors are connected in series to the battery. If one resistor has a resistance of 24 Ω and the voltage drop across the other resistor must be 4.0 V, what is the resistance of the second resistor?

**Find the current in the circuit.**

**Let R be the unknown resistance.**

**Then** $(9.0\ V) = V_R + V_{24}$
$$= (4.0\ V) + I(24\ \Omega)$$

$$I = \frac{5.0\ V}{24\ \Omega} = 0.21\ A$$

**Find the resistance of the second resistor.**

$$R = \frac{V}{I}$$
$$= \frac{4.0\ V}{0.21\ A}$$
$$= 19\ \Omega$$

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8. A circuit is constructed, as shown in the figure below. The voltmeter reads 63.0 V.

a. Which resistor dissipates the most energy per second?

$$R = \frac{V}{I}$$

$$I = \frac{V}{R}$$

$$= \frac{63.0\ \text{V}}{36\ \Omega}$$

$$= 1.8\ \text{A}$$

$$P = I^2R$$

$$= (1.8\ \text{A})^2R$$

**Thus, the resistor with the highest resistance will dissipate the most energy per second. So, the 54-Ω resistor dissipates the most energy per second.**

b. What is the voltage of the power source?

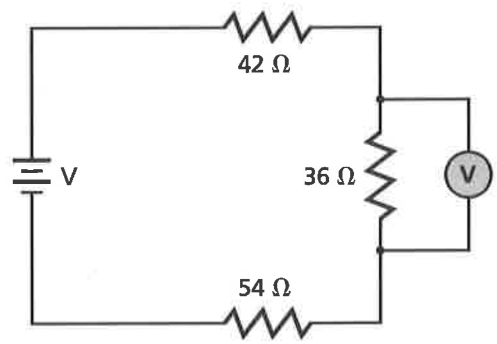
$$R = R_1 + R_2 + R_3$$

$$V = IR$$

$$= I(R_1 + R_2 + R_3)$$

$$= (1.8\ \text{A})(42\ \Omega + 36\ \Omega + 54\ \Omega)$$

$$= 240\ \text{V}$$




9. Three identical resistors are connected in parallel across a power source. Their equivalent resistance is 8.00 Ω. What is the resistance of each resistor?

**Let** $R_1 = R_2 = R_3 = R$

**Then,** $\frac{1}{8} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R}$

$$= \frac{3}{R}$$

$$R = 24.0\ \Omega$$

10. A 10.0-Ω resistor and a 20.0-Ω resistor are connected in series with a potentiometer and a 9.0-V battery.

a. What should the potentiometer be set at for a total equivalent resistance of 50.0 Ω in this circuit?

$$R_T = R_1 + R_2 + R_P$$

$$R_P = R_T - R_1 - R_2 = 50.0\ \Omega - 10.0\ \Omega - 20.0\ \Omega = 20.0\ \Omega$$

b. If the potentiometer is set at 32.0 Ω, what would be the current in this circuit?

$$R_T = R_1 + R_2 + R_P = 10.0\ \Omega + 20.0\ \Omega + 32.0\ \Omega = 62.0\ \Omega$$

$$I = \frac{V_{\text{source}}}{R_T} = \frac{9.0\ \text{V}}{62.0\ \Omega} = 0.14\ \text{A}$$

c. If the potentiometer were turned so that the resistance increases, what would happen to the current?

**Since the resistors are connected in series, as $R_P$ increases, $R_T$ will increase by the same amount. From Ohm's law, we see that as resistance and current are inversely proportional so as $R_T$ increases, the current in the circuit will decrease.**

11. A piece of lab equipment must be connected to a standard 6.0-V dry cell. The manual for the equipment says that this device has an internal resistance of 0.10 Ω and cannot handle more than 2.5 A of current.

a. What value of resistor can you connect in series with this device that would allow it to be connected to the power source?

**From Ohm's law,**

$$R_T = \frac{V_{\text{source}}}{I} = \frac{6.0\ \text{V}}{2.5\ \text{A}} = 2.4\ \Omega$$

$$R_T = R + R_{\text{internal}}$$

$$R = R_T - R_{\text{internal}} = 2.4\ \Omega - 0.10\ \Omega$$

$$= 2.3\ \Omega$$

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**b.** What three resistors of equal value could you use in series instead of the single resistor determined in part a?

**From part a, $R_T = 2.4\ \Omega$**

$$R_T = 3R + R_{internal}$$

$$R = \frac{R_T - R_{internal}}{3}$$

$$= \frac{2.4\ \Omega - 0.10\ \Omega}{3}$$

$$= 0.77\ \Omega$$

**12.** Two resistors are connected in parallel to a 3.0-V power source. The first resistor is marked as 150 Ω but the second resistor is unmarked and unknown. Using an ammeter, you measure the current passing through the unknown resistor as 45.0 mA.

**a.** What is the value of the second resistor?

$$R_2 = \frac{V}{I_2} = \frac{3.0\ \text{V}}{45.0\times10^{-3}\ \text{A}} = 67\ \Omega$$

**b.** What is the current passing through the 150-Ω resistor?

$$I_1 = \frac{V}{R_2} = \frac{3.0\ \text{V}}{150\ \Omega} = 0.020\ \text{A} = 20\ \text{mA}$$

**c.** What is the total current passing through this power source?

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R_T = \frac{R_1R_2}{R_1 + R_2} = \frac{(150\ \Omega)(67\ \Omega)}{150\ \Omega + 67\ \Omega}$$

$$= 46\ \Omega$$

$$I_T = \frac{V}{R_T} = \frac{3.0\ \text{V}}{46\ \Omega} = 0.065\ \text{A}$$

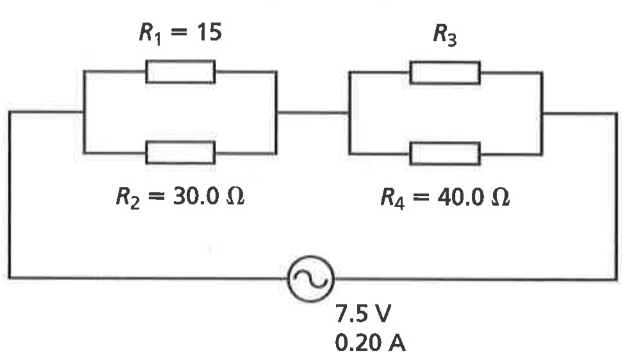
$$= 65\ \text{mA}$$

**or**

$$I_T = I_1 + I_2$$

$$= 45\ \text{mA} + 20\ \text{mA} = 65\ \text{mA}$$

**13.** A circuit is constructed, as shown in the figure below: What is the value of $R_3$?

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**Chapter 23 continued**

$$R_T = \frac{V}{I} = \frac{7.5\text{ V}}{0.20\text{ A}} = 37\ \Omega$$

$$\frac{1}{R_{12}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R_{12} = \frac{R_1R_2}{R_1 + R_2} = \frac{(15\ \Omega)(30.0\ \Omega)}{15\ \Omega + 30.0\ \Omega} = 1.0\times10^1\ \Omega$$

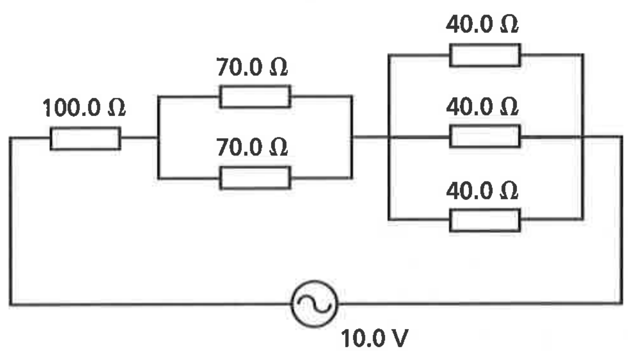
$$R_T = R_{12} + R_{34}$$

$$R_{34} = R_T - R_{12} = 37\ \Omega - 10.0\ \Omega = 27\ \Omega$$

$$\frac{1}{R_{34}} = \frac{1}{R_3} + \frac{1}{R_4}$$

$$R_3 = \frac{R_{34}R_4}{R_4 - R_{34}} = \frac{(27\ \Omega)(40.0\ \Omega)}{40.0\ \Omega - 27\ \Omega} = 9.0\times10^1\ \Omega$$

**14.** What is the equivalent resistance of the resistors in the circuit as shown in the figure below?




$$R_A = 100\ \Omega$$

$$\frac{1}{R_B} = \frac{1}{R_{70}} + \frac{1}{R_{70}} = \frac{2}{R_{70}}$$

$$R_B = \frac{R_{70}}{2} = \frac{70.0\ \Omega}{2} = 35.0\ \Omega$$

$$\frac{1}{R_C} = \frac{1}{R_{40}} + \frac{1}{R_{40}} + \frac{1}{R_{40}} = \frac{3}{R_{40}}$$

$$R_C = \frac{R_{40}}{3} = \frac{40.0\ \Omega}{3} = 13.0\ \Omega$$

$$R_T = R_A + R_B + R_C$$
$$= 100.0\ \Omega + 35.0\ \Omega + 13.0\ \Omega$$
$$= 148\ \Omega$$

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# Chapter 24

1. A 1.20-cm wire carrying a current of 0.80 A is perpendicular to a 2.40-T magnetic field. What is the magnitude of the force on the wire?

   $F = ILB$

   $= (0.80\ \text{A})(0.0120\ \text{m})(2.40\ \text{T})$

   $= 0.023\ \text{N}$

2. A 24.0-cm length of wire carries a current and is perpendicular to a 0.75-T magnetic field. If the force on the wire is 1.80 N, what is the current in the wire?

   $F = ILB$

   $I = \frac{F}{LB}$

   $= \frac{1.80\ \text{N}}{(0.240\ \text{m})(0.75\ \text{T})}$

   $= 1.0\times10^{1}\ \text{A}$

3. A 0.50-cm length of wire carries a current and is perpendicular to a magnetic field, as shown below.

   **a.** What is the direction of the force on the wire?

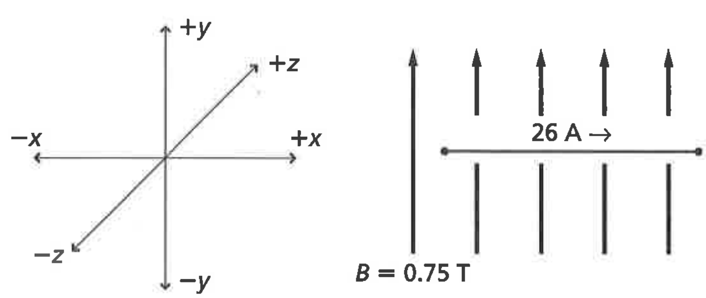
   **According to the third right-hand rule, in which the fingers of the right hand point in the direction of the magnetic field and the thumb points in the direction of the conventional current, the direction of the force on the wire is out of the page or in the negative *z* direction.**

   **b.** What is the magnitude of the force on the wire?

   $F = ILB$

   $= (2.6\ \text{A})(0.0050\ \text{m})(0.75\ \text{T})$

   $= 0.0098\ \text{N}$

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**Chapter 24 continued**

**4.** A 4.50-cm length of wire carries a 2.1-A current and is perpendicular to a magnetic field. If the wire experiences a force of 3.8 N from the magnetic field, what is the magnitude of the magnetic field?

$F = ILB$

$B = \frac{F}{IL}$

$= \frac{3.8\ \text{N}}{(2.1\ \text{A})(0.0450\ \text{m})}$

$= 40\ \text{T}$

**5.** A length of wire carrying a current of 2.0 A is perpendicular to a 6.5-T magnetic field. What is the length of the wire if it experiences a force of 2.99 N?

$F = ILB$

$L = \frac{F}{IB}$

$= \frac{2.99\ \text{N}}{(2.0\ \text{A})(6.5\ \text{T})}$

$= 0.23\ \text{m}$

**6.** An electron beam is perpendicular to a 0.020-T magnetic field. What is the force experienced by one electron if the beam has a velocity of $9.8\times10^3$ m/s?

$F = qvB$

$= (1.60\times10^{-19}\ \text{C})(9.8\times10^3\ \text{m/s})(0.020\ \text{T})$

$= 3.1\times10^{-17}\ \text{N}$

**7.** A proton experiences a force of $6.9\times10^{-15}$ N when it travels at a right angle to a 1.35-T magnetic field. What is the velocity of the proton?

$F = qvB$

$v = \frac{F}{qB}$

$= \frac{6.9\times10^{-15}\ \text{N}}{(1.60\times10^{-19}\ \text{C})(1.35\ \text{T})}$

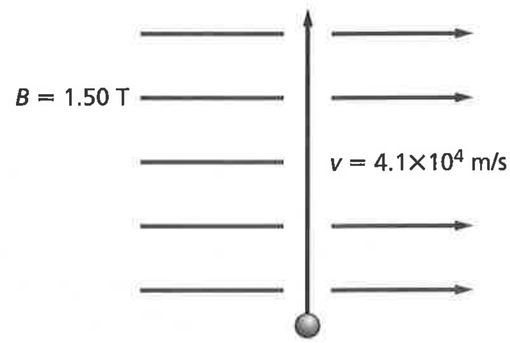
$= 3.2\times10^4\ \text{m/s}$

**8.** A doubly ionized particle travels through a magnetic field, as shown in the figure below. What is the force experienced by the particle?

$F = qvB$

$= (3.2\times10^{-19}\ \text{C})(4.1\times10^4\ \text{m/s})(1.50\ \text{T})$

$= 2.0\times10^{-14}\ \text{N}$




**9.** A positively charged particle travels at a right angle through a 3.00-T magnetic field with a velocity of $4.50\times10^5$ m/s. If the particle experiences a force of $4.32\times10^{-13}$ N as it travels through the magnetic field, what is the charge on the particle?

$F = qvB$

$q = \frac{F}{vB}$

$= \frac{4.32\times10^{-13}\ \text{N}}{(4.50\times10^5\ \text{m/s})(3.00\ \text{T})}$

$= 3.20\times10^{-19}\ \text{C}$

**10.** An electron traveling $8.6\times10^7$ m/s at a right angle to a magnetic field experiences a force of $2.9\times10^{-11}$ N. What is the strength of the magnetic field?

$F = qvB$

$B = \frac{F}{qv}$

$= \frac{2.9\times10^{-11}\ \text{N}}{(1.6\times10^{-19}\ \text{C})(8.6\times10^7\ \text{m/s})}$

$= 2.1\ \text{T}$

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**Chapter 24 continued**

**11.** A screen of ten straight wires is laid horizontally in a magnetic field of 24.0 T oriented at right angles to the wires. Each wire carries a current of 12 mA and is 50 cm long.

**a.** What is the total force experienced by this screen?

$$F_T = 10F$$
$$= 10ILB$$
$$= 10(12\times10^{-3}\text{ A})(0.50\text{ m})(24.0\text{ T})$$
$$= 1.4\text{ N}$$

**b.** As the current in the wires increases, what happens to the force experienced by the screen?

**Since the current is directly proportional to the force through the relationship $F = ILB$, as the current increases, so does the force.**

**12.** A 15-cm length of wire is suspended horizontally in a magnetic field of 8.0 T oriented at a right angle to the wire in such a way that the force experienced by this wire acts in the upward direction.

**a.** If the wire has a mass of 3.0 g and is able to move freely, what current running through this wire is necessary to lift the wire off the ground?

$$F = mg = ILB$$
$$I = \frac{mg}{LB}$$
$$= \frac{(0.0030\text{ kg})(9.80\text{ m/s}^2)}{(0.15\text{ m})(8.0\text{ T})}$$
$$= 0.025\text{ A}$$
$$= 25\text{ mA}$$

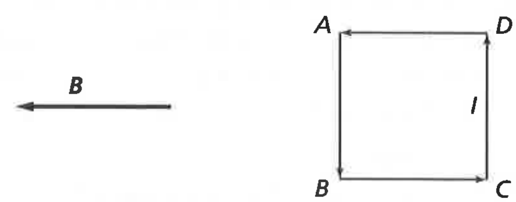
**b.** If this wire is turned 90° so that the direction of the current lines up with the magnetic field, what happens to the force?

**When the wire is rotated, the force falls to zero. The force exists only when the current is perpendicular to the direction of the magnetic field.**

**13.** A square loop of current-carrying wire is placed horizontally in a magnetic field that also is oriented horizontally, as shown in the figure below. Describe the forces on each segment of wire and the resulting force or motion if the wire is able to move freely.

**Since segments *BC* and *DA* are parallel with the direction of the magnetic field, these segments experience no resultant force. The segments *AB* and *CD*, however, are oriented perpendicular to the magnetic field and will experience a force according to the relationship $F = ILB$.**

**Using the third right-hand rule, we find the direction of the force on segment *AB* is down (into the page) and the force on segment *CD* is up (out of the page). These forces combine to produce a rotation of the loop about an axis running perpendicular to the magnetic field and in the plane of the page.**




**14.** A negatively charged particle passes through a magnetic field of strength 0.40 T perpendicular to the direction of travel. By measuring its deflection, you calculate that the particle experiences a force of $-9.2\times10^{-12}$ N.

**a.** How fast is this particle moving?

$$F = qvB$$
$$v = \frac{F}{qB} = \frac{-9.2\times10^{-12}\text{ N}}{(-1.60\times10^{-19}\text{ C})(0.40\text{ T})}$$
$$= 1.4\times10^{8}\text{ m/s}$$

**b.** What force would a neutral particle experience under these same conditions?

**None; with no net charge, neutral particles experience no force due to the magnetic field when traveling at any velocity.**

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**Chapter 24 continued**

**15.** The speed of charged subatomic particles may be calculated by measuring their curved orbits due to centripetal forces when passing through a strong magnetic field. If a proton circles in an orbit of 3.10 cm within a magnetic field of 8.0 T, how fast is this proton moving?

$$F = qvB = \frac{mv^2}{r}$$

$$v = \frac{qrB}{m}$$

$$= \frac{(1.60\times10^{-19}\ \text{C})(0.0310\ \text{m})(8.0\ \text{T})}{1.67\times10^{-27}\ \text{kg}}$$

$$= 2.4\times10^{7}\ \text{m/s}$$

**16.** How strong would a magnetic field have to be to offset the force of gravity acting on an electron traveling at a speed of $9.5\times10^{7}$ m/s?

$$F = mg = qvB$$

$$B = \frac{mg}{qv}$$

$$= \frac{(9.11\times10^{-31}\ \text{kg})(9.80\ \text{m/s}^2)}{(-1.60\times10^{-19}\ \text{C})(9.5\times10^{7}\ \text{m/s})}$$

$$= -5.9\times10^{-19}\ \text{T}$$

# Chapter 25

**1.** A 21.0-cm length of wire moves perpendicular to a 2.45-T magnetic field at 3.5 m/s.

**a.** What is the magnitude of the *EMF* induced in the wire?

$$EMF = BLv$$

$$= (2.45\ \text{T})(0.210\ \text{m})(3.5\ \text{m/s})$$

$$= 1.8\ \text{V}$$

**b.** The wire is part of a circuit with a total resistance of 3.0 Ω. What is the current through the wire?

$$R = \frac{V}{I}$$

$$I = \frac{V}{R}$$

$$= \frac{1.8\ \text{V}}{3.0\ \Omega}$$

$$= 0.60\ \text{A}$$

**2.** An induced *EMF* of 0.089 V is induced in a 5.0-cm wire when it is moved perpendicular to a magnetic field at 2.1 m/s. What is the magnitude of the magnetic field?

$$EMF = BLv\sin\theta$$

$$B = \frac{EMF}{Lv}$$

$$= \frac{0.089\ \text{V}}{(0.050\ \text{m})(2.1\ \text{m/s})}$$

$$= 0.85\ \text{T}$$

**3.** An unknown length of wire moves perpendicular to a 3.40-T magnetic field with a velocity of 12.0 m/s. If the induced *EMF* is 49 V, what is the length of the wire?

$$EMF = BLv$$

$$L = \frac{EMF}{Bv}$$

$$= \frac{49\ \text{V}}{(3.40\ \text{T})(12.0\ \text{m/s})}$$

$$= 1.2\ \text{m}$$

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**Chapter 25 continued**

**4.** A 0.9-T magnetic field points 40.0° north of west. A 34-cm wire perpendicular to the surface of Earth moves directly westward at a speed of 8.9 m/s.

**a.** What is the component of the velocity that is perpendicular to the magnetic field?

$$v_{\text{perpendicular}} = v \sin \theta$$
$$= (8.9 \text{ m/s})(\sin 40.0°)$$
$$= 5.7 \text{ m/s}$$

**b.** What *EMF* is induced in the wire?

$$EMF = BLv \sin \theta$$
$$= (0.90 \text{ T})(0.34 \text{ m})(8.9 \text{ m/s})(\sin 40.0°)$$
$$= 1.8 \text{ V}$$

**5.** An AC generator produces a maximum voltage of $3.00 \times 10^2$ V.

**a.** What is the effective voltage in a circuit connected to the generator?

$$V_{\text{eff}} = 0.707 V_{\text{max}}$$
$$= 0.707(3.00 \times 10^2 \text{ V})$$
$$= 212 \text{ V}$$

**b.** If the resistance of the circuit is 53 Ω, what is the effective current in the circuit?

$$R = \frac{V_{\text{eff}}}{I_{\text{eff}}}$$
$$I_{\text{eff}} = \frac{V_{\text{eff}}}{R}$$
$$= \frac{212 \text{ V}}{53 \text{ Ω}}$$
$$= 4.0 \text{ A}$$

**6.** A straight wire that is 28.0 cm long moves through a magnetic field of 2.0 T at a constant speed of 3.25 m/s in a direction that is 45° from the direction of the magnetic field. If the wire is 0.30 Ω, what is the induced current in the wire?

$$EMF = BLv(\sin \theta) = IR$$
$$I = \frac{BLv \sin \theta}{R}$$
$$= \frac{(2.0 \text{ T})(0.280 \text{ m})(3.25 \text{ m/s})(\sin 45°)}{0.30 \text{ Ω}}$$
$$= 4.3 \text{ A}$$

**7.** A lightbulb is connected to an AC generator, as shown below.

**a.** What is the resistance of the bulb?

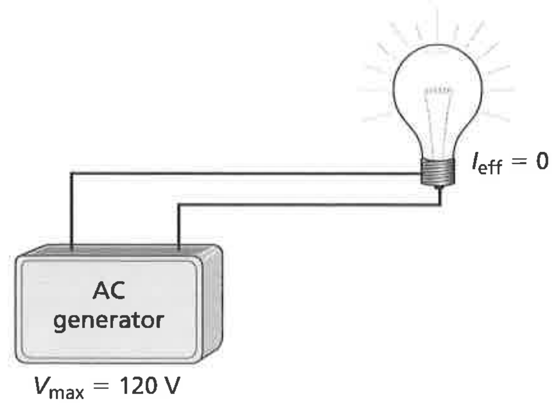
$$R = \frac{V_{\text{eff}}}{I_{\text{eff}}}$$
$$V_{\text{eff}} = 0.70 V_{\text{max}}$$
$$R = \frac{0.707 V_{\text{max}}}{I_{\text{eff}}}$$
$$= \frac{(0.707)(120 \text{ V})}{(0.35 \text{ A})}$$
$$= 240 \text{ Ω}$$

**b.** What is the maximum current through the bulb?

$$R = \frac{V_{\text{max}}}{I_{\text{max}}}$$
$$I_{\text{max}} = \frac{V_{\text{max}}}{R}$$
$$= \frac{120 \text{ V}}{240 \text{ Ω}}$$
$$= 0.50 \text{ A}$$

**c.** What is the peak power dissipated by the bulb?

$$P = VI$$
$$P_{\text{max}} = V_{\text{max}} I_{\text{max}}$$
$$= (120 \text{ V})(0.50 \text{ A})$$
$$= 6.0 \times 10^1 \text{ W}$$

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**Chapter 25 continued**

**8.** A step-up transformer has 50 turns on its primary coil and 2000 turns on its secondary coil. The primary circuit is supplied with an effective AC voltage of 150 V.

**a.** What is the voltage in the secondary circuit?

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_s = \frac{V_p N_s}{N_p}$$

$$= \frac{(150\ \text{V})(2000\ \text{turns})}{50\ \text{turns}}$$

$$= 6.0\times10^3\ \text{V}$$

**b.** If the current in the secondary circuit is 0.24 A, what is the current in the primary circuit?

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

$$I_p = \frac{N_s I_s}{N_p}$$

$$= \frac{(2000\ \text{turns})(0.24\ \text{A})}{50\ \text{turns}}$$

$$= 9.6\ \text{A}$$

**9.** A step-down transformer has 3000 turns on its primary coil and 20 turns on its secondary coil. The primary circuit is supplied with an effective AC voltage of 325 V.

**a.** What is the voltage in the secondary circuit?

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_s = \frac{N_s V_p}{N_p}$$

$$= \frac{(20\ \text{turns})(325\ \text{V})}{3000\ \text{turns}}$$

$$= 2.17\ \text{V}$$

**b.** If the current in the primary circuit is 1.25 A, what power is drawn by the primary circuit?

$$P = IV$$

$$= (1.25\ \text{A})(325\ \text{V})$$

$$= 406\ \text{W}$$

**c.** Assuming the transformer is perfectly efficient, what power is supplied to the secondary circuit?

**If the transformer is perfectly efficient, the power supplied to the secondary circuit will equal the power drawn by the primary circuit. Thus, the power supplied to the secondary circuit would be 406 W.**

**10.** The primary coil of a transformer has 60 turns. It is connected to an AC power supply with an effective voltage of 120 V. Calculate the number of turns on the secondary coil needed to produce 45 V in the secondary circuit.

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$N_s = \frac{N_p V_s}{V_p}$$

$$= \frac{(60\ \text{turns})(45\ \text{V})}{120\ \text{V}}$$

$$= 22\ \text{turns}$$

**11.** A 2.0-kW transformer has an input voltage of $8.00\times10^2$ V and an output current of 24 A. What is the ratio of turns on the secondary coil to turns on the primary coil?

$$P = V_p I_p$$

$$I_p = \frac{P}{V_p}$$

$$= \frac{2.0\times10^3\ \text{W}}{8.00\times10^2\ \text{V}} = 2.5\ \text{A}$$

$$\frac{N_s}{N_p} = \frac{I_p}{I_s}$$

$$= \frac{2.5\ \text{A}}{25\ \text{A}}$$

$$= 0.10$$

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**Chapter 25 continued**

**12.** A generator produces an average power output of 80.0 W and includes an internal resistance of 0.50 Ω.

**a.** What is the effective current from this generator?

$$P_{AC} = I_{eff}^2 R$$

$$I_{eff} = \sqrt{\frac{P_{AC}}{R}} = \sqrt{\frac{80.0\ \text{W}}{0.50\ \Omega}}$$

$$= 6.3\times10^{-3}\ \text{A}$$

$$= 6.3\ \text{mA}$$

**b.** What is the maximum current from this generator?

$$I_{eff} = \frac{\sqrt{2}}{2} I_{max}$$

$$I_{max} = \frac{2}{\sqrt{2}} I_{eff} = \frac{2(6.3\times10^{-3}\ \text{A})}{\sqrt{2}}$$

$$= 8.9\times10^{-3}\ \text{A} = 8.9\ \text{mA}$$

**13.** A transformer is needed to bring a power source of 10.0 V up to a usable value of 12.0 V.

**a.** What is the ratio of the number of turns on the primary and secondary coils necessary to achieve the desired output of 12.0 V? Give your answer in a number of whole turns of the included coils.

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} = \frac{12.0\ \text{V}}{10.0\ \text{V}} = \frac{1.2}{1} = \frac{6}{5}$$

**That is, five turns on the primary coil and six turns on the secondary coil.**

**b.** With a transformer such as this stepping up the voltage of the power source, what happens to the current from that same source?

**From the relationship,**

$$\frac{I_P}{I_S} = \frac{V_S}{V_P} = \frac{N_S}{N_P}$$

**we can see the voltage and current are inversely proportional. If the voltage from the power source is stepped up with our transformer, the current will be reduced by the same inverse ratio.**

**14.** A transformer is constructed with 20 turns on the primary coil and 100 turns on the secondary coil.

**a.** With a primary voltage of 6.0 V, what is the resulting secondary voltage?

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

$$V_S = \frac{V_P N_S}{N_P} = \frac{(6.0\ \text{V})(100)}{20} = 30\ \text{V}$$

**b.** Twenty turns each are added to the primary and secondary coils. What is the new secondary voltage?

$$V_S = \frac{V_P N_S}{N_P} = \frac{(6.0\ \text{V})(100 + 20)}{20 + 20} = 18\ \text{V}$$

**c.** Explain why adding the same number of turns to both primary and secondary coils changes the secondary voltage produced.

**The effect of stepping up the voltage is due to the ratio of turns in the secondary coil to the primary coil. It is the ratio that is important, not the total number of turns. Adding the same number of turns to both coils reduces the overall ratio of the coils and so reduces the stepping effect on the voltage.**

**15.** Two different transformers both step up a 2.5-V source to a usable voltage of 10.0 V. You can see that the first transformer has eight turns on its primary coil and the second transformer has 50 turns on its primary coil but both secondary coils are hidden from view.

**a.** Calculate the number of turns on each secondary coil.

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

$$N_{S1} = \frac{N_{P1} V_S}{V_P} = \frac{(8)(10.0\ \text{V})}{2.5\ \text{V}}$$

$$= 32\ \text{turns}$$

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**Chapter 25 continued**

$$N_{S2} = \frac{N_{P2}V_S}{V_P} = \frac{(50)(10.0\text{ V})}{2.5\text{ V}}$$

$$= 200\text{ turns}$$

**b.** How can two very different transformers produce the same results?

**The total number of turns on each primary and secondary coil is not important. Only the ratio of the secondary to primary turns is important and works equally as well for any number of turns as long as the ratio is constant.**

**16.** A power source produces 8.4 A of current with an internal resistance of 0.60 Ω. This power source is connected to a transformer with 35 turns on its primary coil and 1000 turns on its secondary coil. What is the average power output of this system when connected?

$$\frac{I_P}{I_S} = \frac{V_S}{V_P} = \frac{N_S}{N_P}$$

$$I_S = \frac{I_P N_P}{N_S} = \frac{(8.4\text{ A})(35)}{1000} = 0.30\text{ A}$$

$$I_{eff} = \frac{\sqrt{2}}{2}I_{max} = \frac{\sqrt{2}}{2}(0.30\text{ A}) = 0.21\text{ A}$$

$$P_{AC} = I_{eff}{}^2R = (0.21\text{ A})^2(0.60\ \Omega)$$

$$= 0.026\text{ W} = 26\text{ mW}$$

# Chapter 26

**1.** Electrons moving at a speed of $1.8\times10^6$ m/s travel undeflected through crossed electric and magnetic fields. If the strength of the electric field is $4.2\times10^3$ N/C, what is the strength of the magnetic field?

$$v = \frac{E}{B}$$

$$B = \frac{E}{v}$$

$$= \frac{4.2\times10^3\text{ N/C}}{1.8\times10^6\text{ m/s}}$$

$$= 0.0023\text{ T}$$

**2.** A beam of doubly ionized particles is accelerated by a 95-V potential difference and through a magnetic field of 0.090 T.

**a.** If the particles are nitrogen ions ($m = 2.3260\times10^{-26}$ kg), what is the radius of the beam's path?

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

$$r = \sqrt{\frac{2Vm}{B^2q}}$$

$$= \sqrt{\frac{2(95\text{ V})(2.3260\times10^{-26}\text{ kg})}{(0.090\text{ T})^2(3.20\times10^{-19}\text{ C})}}$$

$$= 41\text{ mm}$$

**b.** If the beam's path has a radius of 6.28 mm, what is the mass of the ion?

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

$$m = \frac{qB^2r^2}{2V}$$

$$= \frac{(3.20\times10^{-19}\text{ C})(0.090\text{ T})^2(0.00628\text{ m})^2}{2(95\text{ V})}$$

$$= 5.4\times10^{-28}\text{ kg}$$

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3. The charge-to-mass ratio of a particle is $4.81\times10^7$ C/kg. The particle moves at a velocity of $4.5\times10^4$ m/s through a field of 0.013 T.

   a. What is the radius of the particle's path?

$$\frac{q}{m}=\frac{v}{Br}$$

$$r=\left(\frac{m}{q}\right)\left(\frac{v}{B}\right)$$

$$=\left(\frac{1}{4.81\times10^7\ \text{C/kg}}\right)\left(\frac{4.5\times10^4\ \text{m/s}}{0.013\ \text{T}}\right)$$

$$=72\ \text{mm}$$

   b. How strong would the magnetic field have to be to give the particle's path a radius of 30.0 mm?

$$\frac{q}{m}=\frac{v}{Br}$$

$$B=\left(\frac{m}{q}\right)\left(\frac{v}{r}\right)$$

$$=\left(\frac{1}{4.81\times10^7\ \text{C/kg}}\right)\left(\frac{4.5\times10^4\ \text{m/s}}{0.030\ \text{m}}\right)$$

$$=0.031\ \text{T}$$

4. A proton ($m = 1.67\times10^{-27}$ kg) enters a magnetic field of strength 0.021 T moving at $4.33\times10^3$ m/s. What is the radius of the proton's path?

$$\frac{q}{m}=\frac{v}{Br}$$

$$r=\frac{mv}{qB}$$

$$=\frac{(1.67\times10^{-27}\ \text{kg})(4.33\times10^3\ \text{m/s})}{(1.6\times10^{-19}\ \text{C})(0.021\ \text{T})}$$

$$=2.2\ \text{mm}$$

5. A beam of electrons follows a circular path with a radius of 18.01 mm in a magnetic field of strength 0.00900 T. What is the speed of the electrons?

$$\frac{q}{m}=\frac{v}{Br}$$

$$v=\frac{qBr}{m}$$

$$=\frac{(1.60\times10^{-19}\ \text{C})(0.00900\ \text{T})(0.01801\ \text{m})}{9.11\times10^{-31}\ \text{kg}}$$

$$=2.85\times10^7\ \text{m/s}$$

6. A certain FM radio station broadcasts its signal at 102.7 MHz. What is the best length for an antenna designed specifically to receive signals from this radio station?

$$c=lf$$

$$l=\frac{c}{f}$$

$$L=\frac{l}{2}$$

$$=\frac{c}{2f}$$

$$=\frac{3.00\times10^8\ \text{m/s}}{2(1.027\times10^8\ \text{Hz})}$$

$$=1.46\ \text{m}$$

7. An ion in a mass spectrometer is accelerated through a voltage of 45 V. The ion has a mass of $6.634\times10^{-26}$ kg. It passes through a magnetic field of strength 0.080 T and its path has a radius of 53.99 mm.

   a. What is the charge on the ion?

$$\frac{q}{m}=\frac{2V}{B^2r^2}$$

$$q=\frac{2Vm}{B^2r^2}$$

$$=\frac{2(45\ \text{V})(6.634\times10^{-26}\ \text{kg})}{(0.080\ \text{T})^2(0.05399\ \text{m})^2}$$

$$=3.2\times10^{-19}\ \text{C}$$

   b. How many electrons were removed to create this charge on the ion?

$q_{electron} = 1.60\times10^{-19}$ C

**if n is the number of electrons,**

$$n=\frac{q_{total}}{q_{electron}}$$

$$=\frac{3.2\times10^{-19}\ \text{C}}{1.60\times10^{-19}\ \text{C}}$$

$$=2\ \text{electrons}$$

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**Chapter 26 continued**

**8.** An electromagnetic wave has a frequency of $5.00\times10^{14}$ Hz as it travels through a vacuum. When the same wave travels through glass, it has a wavelength of $2.24\times10^{-7}$ m.

**a.** What is the speed of the wave in glass?

$$v = \lambda f$$
$$= (2.24\times10^{-7}\ \text{m})(5.00\times10^{14}\ \text{Hz})$$
$$= 1.12\times10^{8}\ \text{m/s}$$

**b.** What is the dielectric constant of the glass?

$$v = \frac{c}{\sqrt{K}}$$
$$K = \left(\frac{c}{v}\right)^2$$
$$= \left(\frac{3.00\times10^{8}\ \text{m/s}}{1.12\times10^{8}\ \text{m/s}}\right)^2$$
$$= 7.17$$

**c.** What would the speed of the wave be in a material with a dielectric constant of 42.5?

$$v = \frac{c}{\sqrt{K}}$$
$$= \frac{3.00\times10^{8}\ \text{m/s}}{\sqrt{42.5}}$$
$$= 4.60\times10^{7}\ \text{m/s}$$

**9.** A sample containing singly ionized oxygen ($m = 2.6569\times10^{-26}$ kg/atom) and fluorine ($m = 3.1549\times10^{-26}$ kg/atom) are run through a mass spectrometer. The ions are accelerated with a potential difference of 27 V and pass through a magnetic field of 0.091 T.

**a.** What is the radius of the oxygen ion's path?

$$\frac{q}{m} = \frac{2V}{B^2{r_o}^2}$$
$$r_o = \sqrt{\frac{2Vm_o}{B^2q}}$$
$$= \sqrt{\frac{2(27\ \text{V})(2.6569\times10^{-26}\ \text{kg})}{(0.091\ \text{T})^2(1.60\times10^{-19}\ \text{C})}}$$
$$= 33\ \text{mm}$$

**b.** How much larger or smaller is the radius of the fluorine ion's path?

$$\frac{q}{m} = \frac{2V}{B^2{r_F}^2}$$
$$r_F = \sqrt{\frac{2Vm}{B^2q}}$$
$$\frac{r_F}{r_o} = \frac{\sqrt{\frac{2VM_F}{B^2q}}}{\sqrt{\frac{2VM_o}{B^2q}}} = \sqrt{\frac{M_F}{M_o}}$$
$$= \frac{3.1549\times10^{-26}\ \text{kg}}{2.6569\times10^{-26}\ \text{kg}}$$
$$= 1.0897$$

**The fluorine ion's path radius is 8.97 percent larger than that of oxygen or about 36 mm.**

**10.** A spectral analysis of a substance yields electromagnetic waves of frequencies in the $6.52\times10^{14}$ Hz range. What color do these spectral lines appear?

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\ \text{m/s}}{6.52\times10^{14}\ \text{Hz}}$$
$$= 4.60\times10^{-7}\ \text{m} = 460\ \text{nm}$$

**Electromagnetic waves of this wavelength appear as visible blue lines (460 nm).**

**11.** An ion beam passes through crossed electric and magnetic fields without deflection. The electric field is 2340 N/C and the magnetic field is 0.026 T. When the electric field is turned off, the beam's path takes on a curvature with a radius of 36.1298 mm.

**a.** What is the mass-to-charge ratio of the particle in question?

$$v = \frac{E}{B}$$
$$\frac{q}{m} = \frac{v}{Br}$$
$$= \frac{E}{B^2r}$$
$$= \frac{2340\ \text{N/C}}{(0.026\ \text{T})^2(0.0361298\ \text{m})}$$
$$= 9.6\times10^{7}\ \text{C/kg}$$

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**b.** Assuming the particle is singly ionized, what is the mass of the particle?

$$\frac{q}{m} = \frac{E}{B^2r}$$

$$m = \frac{qB^2r}{E}$$

$$= \frac{(1.60\times10^{-19}\ \text{C})(0.026\ \text{T})^2(0.0361298\ \text{m})}{2340\ \text{N/C}}$$

$$= 1.7\times10^{-27}\ \text{kg}$$

**12.** Positively charged sodium ions are tracked as they travel through a magnetic field of strength 0.85 T with a velocity of $4.0\times10^6$ m/s. The observed radius of their circular path through this magnetic field is 1.12 m. What is the mass of a single sodium ion?

$$Bqv = \frac{mv^2}{r}$$

$$m = \frac{Bqr}{v}$$

$$= \frac{(0.85\ \text{T})(1.60\times10^{-19}\ \text{C})(1.12\ \text{m})}{4.0\times10^6\ \text{m/s}}$$

$$= 3.8\times10^{-26}\ \text{kg}$$

**13.** A mass spectrometer is capable of observing the curved track of a particle up to a radius of 5.0 cm using a magnetic field strength of 4.5 T. What voltage is necessary to measure the charge-to-mass ratio of a proton?

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

$$V = \frac{qB^2r^2}{2m}$$

$$= \frac{(1.60\times10^{-19}\ \text{C})(4.5\ \text{T})^2(0.050\ \text{m})^2}{2(1.67\times10^{-27}\ \text{kg})}$$

$$= 2.4\times10^6\ \text{V}$$

**14. a.** What is the speed of a light wave with a wavelength of 640 nm in water? The dielectric constant for water is $K_{\text{water}} = 78$.

$$v = \frac{c}{\sqrt{K}} = \frac{3.00\times10^8\ \text{m/s}}{\sqrt{78}}$$

$$= 3.4\times10^7\ \text{m/s, or } 0.11c$$

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**b.** What is the frequency of this light wave in water compared to its frequency in a vacuum?

$$f_{\text{vacuum}} = \frac{c}{\lambda} = \frac{3.00\times10^{8}\ \text{m/s}}{640\times10^{-9}\ \text{m}}$$

$$= 4.7\times10^{14}\ \text{Hz}$$

$$f_{\text{water}} = \frac{v}{\lambda} = \frac{3.4\times10^{7}\ \text{m/s}}{640\times10^{-9}\ \text{m}}$$

$$= 5.3\times10^{13}\ \text{Hz}$$

$$= 0.11\ f_{\text{vacuum}}$$

**15.** A dish radio antenna with a diameter of 55 m is used to receive electromagnetic signals from deep space. What frequency is this antenna best suited to detect?

$$f = \frac{c}{\lambda} = \frac{3.00\times10^{8}\ \text{m/s}}{55\ \text{m}} = 5.4\times10^{6}\ \text{Hz}$$

$$= 5.4\ \text{MHz}$$

**16. a.** With a frequency of $10^{18}$ Hz, are X rays visible to the unaided human eye?

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\ \text{m/s}}{10^{18}\ \text{Hz}}$$

$$= 3.00\times10^{-10}\ \text{m}$$

$$= 300{,}000\ \text{nm}$$

**No; the wavelength of X rays falls far outside the range of visible light, approximately 400 nm to 700 nm and, as such, is not detectable by the human eye.**

**b.** In terms of the dielectric constant, explain why X rays will pass through your body but will not pass through bone and metal, allowing internal details to show up on photographic plates.

**The dielectric constant is related to the density of a substance; that is, the higher the density, the larger the dielectric constant, *K*. From the relationship**

$$v = \frac{c}{\sqrt{K}}$$

**we see that the dielectric constant and the velocity of the wave are inversely proportional.**

**Materials with high dielectric constants such as bone or metal will reduce the velocity of an X ray to such a point that it is significantly slower than its surrounding waves or stopped altogether. Materials with a low dielectric constant, like your body tissues or cloth, will not slow the velocity of an X ray to any significant degree. When a photosensitive film is exposed to these X rays, the differences in velocity reveal internal details of the denser materials.**

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# Chapter 27

1. What is the potential difference needed to stop electrons with a kinetic energy of $5.6\times10^{-18}$ J?

   $KE = -qV_0$

   $$V_0 = -\frac{KE}{q} = \frac{-5.6\times10^{-18}\ \text{J}}{-1.60\times10^{-19}\ \text{C}} = 3.5\times10^{1}\ \text{V}$$

2. The threshold frequency of cesium is $5.2\times10^{14}$ Hz.
   a. How much work, expressed in joules, must be done to free an electron from the surface of cesium?

   $W = hf_0 = (6.63\times10^{-34}\ \text{J/Hz})(5.2\times10^{14}\ \text{Hz}) = 3.4\times10^{-19}\ \text{J}$

   b. What is the maximum kinetic energy (in eV) of electrons emitted when cesium is exposed to light with a frequency of $7.4\times10^{14}$ Hz?

   $$KE = hf - hf_0 = h(f - f_0)$$
   $$= (6.63\times10^{-34}\ \text{J/Hz})$$
   $$(7.4\times10^{14}\ \text{Hz} - 5.2\times10^{14}\ \text{Hz})$$
   $$\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right) = 0.91\ \text{eV}$$

3. A proton is held in a trap with a kinetic energy of 0.65 eV.
   a. What is the velocity of the proton?

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

   $$\text{Thus, } v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2(0.65\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}{1.67\times10^{-27}\ \text{kg}}} = 1.1\times10^{4}\ \text{m/s}$$

   b. What is the de Broglie wavelength of the proton?

   $$\lambda = \frac{h}{mv} = \frac{(6.63\times10^{-34}\ \text{J}\cdot\text{s})}{(1.67\times10^{-27}\ \text{kg})(1.1\times10^{4}\ \text{m/s})} = 3.6\times10^{-11}\ \text{m}$$

4. The work function of a metal is 7.3 eV.
   a. Calculate the threshold frequency of the metal.

   $W = hf_0$

   $$f_0 = \frac{W}{h} = \frac{(7.3\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}{6.63\times10^{-34}\ \text{J/Hz}} = 1.8\times10^{15}\ \text{Hz}$$

   b. What is the maximum kinetic energy of an electron ejected from the metal when it is exposed to ultraviolet light with a wavelength of $1.1\times10^{16}$ Hz?

   $$E = hf - hf_0$$
   $$= (6.63\times10^{-34}\ \text{J/Hz})(1.1\times10^{16}\ \text{Hz} - 1.8\times10^{15}\ \text{Hz})$$
   $$\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right) = 38\ \text{eV}$$

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**Chapter 27 continued**

5. An electron is moving at $4.50\times10^5$ m/s.
   a. What is the de Broglie wavelength of the electron?

$$\lambda = \frac{h}{mv} = \frac{(6.63\times10^{-34}\text{ J·s})}{(9.11\times10^{-31}\text{ kg})(4.50\times10^{5}\text{ m/s})} = 1.62\times10^{-9}\text{ m}$$

   b. If the electron was accelerated from rest, what was the potential difference?

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

$$\text{Thus, } V = \frac{-mv^2}{2q} = \frac{-(9.11\times10^{-31}\text{ kg})(4.50\times10^{5}\text{ m/s})^2}{2(-1.60\times10^{-19}\text{ C})} = 5.76\times10^{-1}\text{ V}$$

6. A bowling ball with a mass of 5.5 kg is moving with a speed of 5.0 m/s. Calculate the de Broglie wavelength of the bowling ball.

$$\lambda = \frac{h}{mv} = \frac{6.63\times10^{-34}\text{ J·s}}{(5.5\text{ kg})(5.0\text{ m/s})} = 2.4\times10^{-35}\text{ m}$$

7. A photon of ultraviolet light has a frequency of $9.00\times10^{14}$ Hz.
   a. What is the momentum of the photon?

$$p = \frac{hf}{c} = \frac{(6.63\times10^{-34}\text{ J·s})(9.00\times10^{14}\text{ Hz})}{3.00\times10^{8}\text{ m/s}} = 1.99\times10^{-27}\text{ kg·m/s}$$

   b. What is the wavelength of the photon?

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{9.00\times10^{14}\text{ Hz}} = 3.33\times10^{-7}\text{ m}$$

8. Electrons are accelerated through a potential difference of $7.20\times10^4$ V in an electron microscope.
   a. What is the wavelength of the electrons?

**The wavelength is** $\lambda = \frac{h}{mv}$

**Find the velocity from the kinetic energy equations:**

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

$$v = \sqrt{\frac{2qV}{m}}$$

**Combining the wavelength and velocity equations gives:**

$$\lambda = \frac{h}{(-2q\,Vm)^{\frac{1}{2}}}$$

$$= \frac{6.63\times10^{-34}\text{ J·s}}{(-2(-1.60\times10^{-19}\text{ C})(7.20\times10^{4}\text{ V})(9.11\times10^{-31}\text{ kg}))}$$

$$= 4.58\times10^{-12}\text{ m}$$

   b. How does this wavelength compare with the wavelengths of visible light?

**It is much shorter than visible light.**

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**Chapter 27 continued**

**9.** A particle is accelerated through a potential, resulting in a de Broglie wavelength of $8.54\times10^{-12}$ m.

**a.** What is the voltage if the particle is a proton?

**Find the voltage from the kinetic energy equations:**

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

$$V = \frac{-mv^2}{2q}$$

**Where the velocity is found from the de Broglie wavelength equations:**

$$\lambda = \frac{h}{mv}$$

$$v = \frac{h}{m\lambda}$$

**Combining these gives:**

$$V = \frac{-h^2}{2qm\lambda^2}$$

$$= \frac{-(6.63\times10^{-34}\ \text{J}\cdot\text{s})^2}{2(1.60\times10^{-19}\ \text{C})(1.67\times10^{-27}\ \text{kg})(8.54\times10^{-12}\ \text{m})^2}$$

$$= 11.3\ \text{V}$$

**b.** What is the voltage if the particle is an electron?

**Using the derivation from (a), the voltage is:**

$$V = \frac{-h^2}{2qm\lambda^2}$$

$$= \frac{-(6.63\times10^{-34}\ \text{J}\cdot\text{s})^2}{2(-1.60\times10^{-19}\ \text{C})(9.11\times10^{-31}\ \text{kg})(8.54\times10^{-12}\ \text{m})^2}$$

$$= 2.07\times10^{4}\ \text{V}$$

**10.** An electron in a computer monitor crosses a potential difference of $3.5\times10^4$ V.

**a.** What is the velocity of the electron?

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

$$v = \sqrt{\frac{-2qV}{m}}$$

$$= \sqrt{\frac{-2(-1.60\times10^{-19}\ \text{C})(3.5\times10^{4}\ \text{V})}{9.11\times10^{-31}\ \text{kg}}}$$

$$= 1.1\times10^{8}\ \text{m/s}$$

**b.** What is the de Broglie wavelength of the electron?

$$\lambda = \frac{h}{mv}$$

$$= \frac{6.63\times10^{-34}\ \text{J}\cdot\text{s}}{(9.11\times10^{-31}\ \text{kg})(1.1\times10^{8}\ \text{m/s})}$$

$$= 6.6\times10^{-12}\ \text{m}$$

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**11.** Calculate the de Broglie wavelength of a 75,000-kg jet airplane with a velocity of 200 m/s.

$$\lambda = \frac{h}{mv}$$

$$= \frac{6.63\times10^{-34}\ \text{J·s}}{(7.5\times10^{4}\ \text{kg})(200\ \text{m/s})}$$

$$= 4\times10^{-41}\ \text{m}$$

**12.** Molybdenum has a work function of 4.20 eV.

**a.** What is the threshold wavelength of the incident light?

$$W = \frac{hc}{\lambda_0}$$

$$\lambda_0 = \frac{hc}{W}$$

$$= \frac{1240\ \text{eV}\cdot\text{nm}}{4.20\ \text{eV}}$$

$$= 295\ \text{nm}$$

**b.** What is the stopping potential of the photoelectrons emitted from molybdenum if the incident light has a wavelength of $2.00\times10^{2}$ nm?

$$KE + W = \frac{hc}{\lambda} - W$$

$$= \frac{1240\ \text{eV}\cdot\text{nm}}{2.00\times10^{2}\ \text{nm}} - 4.2\ \text{eV}$$

$$= 2.0\ \text{eV}$$

**c.** What is the change in the stopping potential if the wavelength of the incident light is reduced to $1.00\times10^{2}$ nm?

$$KE + W = \frac{hc}{\lambda} - W$$

$$= \frac{1240\ \text{eV}\cdot\text{nm}}{1.00\times10^{2}\ \text{nm}} - 4.2\ \text{eV}$$

$$= 8.2\ \text{eV}$$

$$8.2\ \text{eV} - 2.0\ \text{eV} = 6.2\ \text{eV}$$

**The stopping potential is more than tripled to 6.2 eV when the wavelength is halved.**

**13.** What energy is radiated by an atom vibrating at a frequency of $4.0\times10^{14}$ Hz as its energy falls from the $n = 3$ state to $n = 1$ state?

$$E_n = nhf$$

$$\Delta E = E_3 - E_1 = 3hf - hf = 2hf$$

$$= 2(6.63\times10^{-34}\ \text{J/Hz})(4.0\times10^{14}\ \text{Hz})$$

$$= 5.3\times10^{-19}\ \text{J}$$

**14.** A radium nucleus undergoes nuclear decay by emitting a beta particle with a kinetic energy of $3.49\times10^{-13}$ J. Express the particle's energy in MeV.

$$KE = (3.49\times10^{-13}\ \text{J})\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right)\left(\frac{1\ \text{MeV}}{1\times10^{6}\ \text{eV}}\right)$$

$$= 2.18\ \text{MeV}$$

**15.** What minimum potential difference will stop electrons moving at a speed of $1.54\times10^{6}$ m/s?

$$KE = \frac{1}{2}mv^2 = -qV_0$$

$$V_0 = \frac{-mv^2}{2q}$$

$$= \frac{-(9.11\times10^{-31}\ \text{kg})(1.54\times10^{6}\ \text{m/s})^2}{2(-1.60\times10^{-19}\ \text{C})}$$

$$= 6.75\ \text{V}$$

**16.** A photocell with a cadmium electrode fails to emit photoelectrons if illuminated by light with wavelengths longer than 328 nm. What is the work function of cadmium in eV?

$$KE = E - W = 0$$

$$W = E = \frac{hc}{\lambda_0} = \left(\frac{1240\ \text{eV}\cdot\text{nm}}{332\ \text{nm}}\right) = 3.73\ \text{eV}$$

**17.** When illuminated with ultraviolet light of wavelength 231 nm, the maximum kinetic energy of the photoelectrons emitted from a zinc electrode is 1.25 eV. What is the threshold frequency of the light that will cause the emission of photoelectrons from zinc?

$$KE = E - W$$

$$W = E - KE = \frac{hc}{\lambda_0} - KE$$

$$= \frac{1240\ \text{eV}\cdot\text{nm}}{231\ \text{nm}} - 1.25\ \text{eV}$$

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$= 4.12\ \text{eV}$

$W = hf_0$

$f_0 = \frac{W}{h}$

$= \frac{(4.12\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}{6.63\times10^{-34}\ \text{J/Hz}}$

$= 9.94\times10^{14}\ \text{Hz}$

**18.** The wavelength of an X ray scattered by an electron is 0.0195 nm.

**a.** What is the momentum of the scattered X ray?

$p = \frac{h}{\lambda}$

$= \frac{6.63\times10^{-34}\ \text{J·s}}{(0.0195\ \text{nm})\left(\frac{1\times10^{-9}\ \text{m}}{1\ \text{nm}}\right)}$

$= 3.40\times10^{-23}\ \text{kg m/s}$

**b.** If the wavelength of the incident X ray was 0.0185 nm, what is the change in momentum of the electron?

$\Delta p = p_2 - p_1$

$= \frac{h}{\lambda_2} - \frac{h}{\lambda_1} = \frac{h(\lambda_1 - \lambda_2)}{\lambda_1\lambda_2}$

$= \frac{(6.63\times10^{-34}\ \text{J·s})(0.0185\ \text{nm} - 0.0195\ \text{nm})}{(0.0185\ \text{nm})(0.0195\ \text{nm})}\left(\frac{1\times10^{-9}\ \text{m}}{1\ \text{nm}}\right)$

$= -1.84\times10^{-24}\ \text{J·s/m}$

$= -1.84\times10^{-24}\ \text{kg·m/s}$

$\Delta p_{\text{electron}} = -\Delta p_{\text{Xray}}$

$= -(-1.84\times10^{-24}\ \text{kg·m/s})$

$= 1.84\times10^{-24}\ \text{kg·m/s}$

**19.** At what speed would an electron have a wavelength similar to that of a photon of ultraviolet light ($1.00\times10^{-8}$ m)?

$p = mv = \frac{h}{\lambda}$

$v = \frac{h}{m\lambda}$

$= \frac{6.63\times10^{-34}\ \text{J·s}}{(9.11\times10^{-31}\ \text{kg})(1.00\times10^{-8}\ \text{m})}$

$= 7.28\times10^{4}\ \text{m/s}$

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**Chapter 27 continued**

**20.** Light of wavelength 345 nm causes electrons to be ejected from a potassium cathode. What is the de Broglie wavelength of the ejected electrons? The work function of potassium is 2.0 eV.

$$KE = E - W$$

$$\frac{1}{2}mv^2 = \frac{hc}{\lambda} - W$$

$$= \frac{1240\ \text{eV}\cdot\text{nm}}{345\ \text{nm}} - 2.0\ \text{eV}$$

$$= (1.6\ \text{eV})(1.6\ \text{eV})$$

$$(1.60\times10^{-19}\ \text{J/eV})$$

$$= 2.6\times10^{-19}\ \text{J}$$

$$v = \sqrt{\frac{2KE}{m}}$$

$$= \sqrt{\frac{2(2.6\times10^{-19}\ \text{J})}{9.11\times10^{-31}\ \text{kg}}}$$

$$= 7.5\times10^{5}\ \text{m/s}$$

$$p = mv$$

$$= (9.11\times10^{-31}\ \text{kg})(7.5\times10^{5}\ \text{m/s})$$

$$= 6.8\times10^{-25}\ \text{kg}\cdot\text{m/s}$$

$$\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}\ \text{J}\cdot\text{s}}{6.8\times10^{-25}\ \text{kg}\cdot\text{m/s}}$$

$$= 9.8\times10^{-10}\ \text{m}$$

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# Chapter 28

1. The energy of a calcium atom drops from 5.58 eV above the ground state to 4.13 eV above the ground state.

   a. What is the wavelength of the photon emitted by the transition?

$$\Delta E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{\Delta E}$$

$$= \frac{(6.63\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})}{(5.58\ \text{eV} - 4.13\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}$$

$$= 8.57\times10^{-7}\ \text{m}$$

   b. What is the frequency of the photon?

$$f = \frac{c}{\lambda}$$

$$= \frac{3.00\times10^{8}\ \text{m/s}}{8.57\times10^{-7}\ \text{m}}$$

$$= 3.50\times10^{14}\ \text{Hz}$$

2. For a hydrogen atom in the $n = 2$ Bohr orbital, calculate the radius of the orbital.

$$r_n = \frac{h^2n^2}{4\pi^2mq^2}$$

$$r_2 = \frac{(6.63\times10^{-34}\ \text{J·s})^2(2)^2}{4\pi^2(9.00\times10^{9}\ \text{N·m}^2/\text{C}^2)(9.11\times10^{-31}\ \text{kg})(1.60\times10^{-19}\ \text{C})^2}$$

$$= 2.11\times10^{-10}\ \text{m}$$

3. For a hydrogen atom,

   a. Determine the energy associated with the third and sixth energy levels.

$$E_n = -13.6\ \text{eV} \times \frac{1}{n^2}$$

$$E_3 = -13.6\ \text{eV} \times \frac{1}{3^2}$$

$$= -1.51\ \text{eV}$$

$$E_6 = -13.6\ \text{eV} \times \frac{1}{6^2}$$

$$= -0.378\ \text{eV}$$

   b. What is the energy of a photon emitted as the electron drops from the sixth level to the third level?

$$\Delta E = E_6 - E_3$$

$$= -0.378\ \text{eV} - (-1.51\ \text{eV})$$

$$= 1.13\ \text{eV}$$

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**c.** What is the wavelength of the photon emitted by the transition?

$$\Delta E = hf$$
$$= \frac{hc}{\lambda}$$
$$\lambda = \frac{hc}{\Delta E}$$
$$= \frac{(6.63\times10^{-34}\ \text{J}\cdot\text{s})(3.00\times10^{8}\ \text{m/s})}{(1.13\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}$$
$$= 1.10\times10^{-6}\ \text{m}$$

**4. a.** How much energy must be supplied to a hydrogen atom to excite its electron from energy level 2 to energy level 6?

$$E_n = -13.6\ \text{eV} \times \frac{1}{n^2}$$
$$\Delta E = E_6 - E_2$$
$$= -13.6\ \text{eV}\left(\frac{1}{6^2} - \frac{1}{2^2}\right)$$
$$= 3.02\ \text{eV}$$

**b.** What is the wavelength of the photon that supplies the energy for this transition?

$$\lambda = \frac{hc}{\Delta E}$$
$$= \frac{(6.63\times10^{-34}\ \text{J}\cdot\text{s})(3.00\times10^{8}\ \text{m/s})}{(3.02\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}$$
$$= 4.12\times10^{-7}\ \text{m}$$

*Use the values in* **Table 28-1** *to answer questions 5–7.*

| Table 28-1 | |
|---|---|
| **Energy levels for a helium atom** | |
| **Level** | **Energy (eV)** |
| $E_5$ | −2.2 |
| $E_4$ | −3.4 |
| $E_3$ | −6.0 |
| $E_2$ | −13.6 |
| $E_1$ (ground state) | −54.4 |

**5. a.** How much energy in eV must be absorbed by an electron in the ground state of a helium atom in order for it to jump to the fifth energy level?

$$\Delta E = E_5 - E_1$$
$$= -2.2\ \text{eV} - (-54.4\ \text{eV})$$
$$= 52.2\ \text{eV}$$

**b.** An electron energy transition in a helium atom emits a photon with a wavelength of $1.64\times10^{-7}$ m. What change of energy levels did the electron experience?

$$\Delta E = \frac{hc}{\lambda}$$
$$= \frac{(6.63\times10^{-34}\ \text{J}\cdot\text{s})(3.00\times10^{8}\ \text{m/s})}{(1.64\times10^{-7}\ \text{m})(1.60\times10^{-19}\ \text{J/eV})}$$
$$= 7.58\ \text{eV}$$

**A difference of 7.6 eV occurs between $E_2$ and $E_3$.**

**Because energy is released, the transition is downward from $E_3$ to $E_2$.**

**c.** A photon with a wavelength of $2.43\times10^{-8}$ m strikes a helium atom and is absorbed. What corresponding electron energy transition occurs?

$$\Delta E = \frac{hc}{\lambda}$$
$$= \frac{(6.63\times10^{-34}\ \text{J}\cdot\text{s})(3.00\times10^{8}\ \text{m/s})}{(2.43\times10^{-8}\ \text{m})(1.60\times10^{-19}\ \text{J/eV})}$$
$$= 51.2\ \text{eV}$$

**A difference of 51 eV occurs between $E_1$ and $E_4$**

**Because energy is absorbed, the transition is upward from $E_1$ to $E_4$.**

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**Chapter 28 continued**

6. The atomic emission spectrum of helium has a prominent line at an infrared wavelength of $1.08\times10^{-7}$ m.

   a. What causes this light emission?

   $$\Delta E = \frac{hc}{\lambda}$$

   $$= \frac{(6.63\times10^{-34}\ \text{J}\cdot\text{s})(3.00\times10^{8}\ \text{m/s})}{(1.08\times10^{-7}\ \text{m})(1.60\times10^{-19}\ \text{J/eV})}$$

   $$= 11.5\ \text{eV}$$

   **The downward transition from $E_5$ to $E_2$ corresponds to an energy change of 11.4 eV, the closest combination to 11.5 eV.**

   b. Why does the calculated value not match an energy transition on the table exactly?

   **The third significant digit differs by 1, due to rounding on the table and/or during calculations.**

7. A photon with a wavelength of 20.8 nm strikes a helium atom, ionizing it by ejecting an electron from the ground state. What is the kinetic energy of the electron, in joules, assuming that the electron receives all the excess energy?

   $$E_{\text{electron}} = E_{\text{photon}} - E_{\text{ground}}$$

   $$= \frac{hc}{\lambda} - E_{\text{ground}}$$

   $$= \frac{(6.63\times10^{-34}\ \text{J}\cdot\text{s})(3.00\times10^{8}\ \text{m/s})}{(20.8\times10^{-9}\ \text{m})} - (54.4\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})$$

   $$= 8.58\times10^{-19}\ \text{J}$$

8. What is the maximum possible wavelength of light emitted by an electron with an orbital radius of $8.3\times10^{-11}$ m? (Assume $n = 1$.)

   $$n\lambda = 2\pi r$$

   $$\lambda = \frac{2\pi r}{n}$$

   $$= \frac{2\pi(8.3\times10^{-11}\ \text{m})}{1}$$

   $$= 5.2\times10^{-10}\ \text{m}$$

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**Chapter 28 continued**

**9.** What is the power of an InGaAs laser that produces 980-nm light with a rate of $2.5\times10^{15}$ photons per second?

**If $N$ is the number of photons per second, the power is:**

$$P_{\text{laser}} = NE_{\text{photon}}$$

$$= \frac{Nhc}{\lambda}$$

$$= \frac{(2.5\times10^{15}\ \text{s}^{-1})(6.63\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})}{(980\times10^{-9}\ \text{m})} \times \left(\frac{1\ \text{W}}{1\ \text{J/s}}\right)$$

$$= 49\ \text{mW}$$

**10.** An electron in a mercury atom drops from 8.82 eV to 6.67 eV.

**a.** What is the energy of the photon emitted?

$$\Delta E = E_f - E_i = 8.82\ \text{eV} - 6.67\ \text{eV} = 2.15\ \text{eV}$$

**b.** What is the wavelength of this photon?

$$\lambda = \frac{hc}{\Delta E} = \frac{1240\ \text{eV}\cdot\text{nm}}{2.15\ \text{eV}} = 577\ \text{nm}$$

**c.** What is the frequency of this photon?

$$f = \frac{c}{h} = \frac{3.00\times10^{8}\ \text{m/s}}{577\times10^{-9}\ \text{m}} = 5.20\times10^{14}\ \text{Hz}$$

**11.** What is the energy of a hydrogen atom in the $n = 10$ Bohr orbital? How much energy must a hydrogen atom absorb to move its electron from a state where $n = 5$ to one where $n = 10$?

$$E_n = -13.6\ \text{eV} \times \frac{1}{n^2}$$

$$E_{10} = -13.6\ \text{eV} \times \frac{1}{10^2} = -0.136\ \text{eV}$$

$$E_5 = -13.6\ \text{eV} \times \frac{1}{5^2} = -0.544\ \text{eV}$$

$$\Delta E = E_f - E_i = E_{10} - E_5$$

$$= -0.136\ \text{eV} - (-0.544\ \text{eV})$$

$$= 0.408\ \text{eV}$$

**12.** What energy is emitted when an excited hydrogen atom drops from a state where $n = 8$ to a state where $n = 5$?

$$E_8 = -13.6\ \text{eV} \times \frac{1}{8^2} = -0.212\ \text{eV}$$

$$E_5 = -13.6\ \text{eV} \times \frac{1}{5^2} = -0.544\ \text{eV}$$

$$\Delta E = E_8 - E_5$$

$$= -0.212 - (-0.544\ \text{eV})$$

$$= 0.332\ \text{eV}$$

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**13.** Consider a hydrogen atom in the following situations.

**a.** What is the orbital radius of the hydrogen atom when $n = 8$?

$$r_n = \frac{h^2n^2}{4\pi^2Kmq^2}$$

$$= \frac{(6.63\times10^{-34}\ \text{J·s})^2(8)^2}{4\pi^2(9.00\times10^{9}\ \text{N·m}^2/\text{C}^2)(9.11\times10^{-31}\ \text{kg})(1.60\times10^{-19}\ \text{C})^2}$$

$$= 3.39\times10^{-9}\ \text{m}$$

$$= 3.39\ \text{nm}$$

**b.** What is the orbital radius of the hydrogen atom when $n = 5$?

$$r_5 = \frac{(6.63\times10^{-34}\ \text{J·s})^2(5)^2}{4\pi^2(9.00\times10^{9}\ \text{N·m}^2/\text{C}^2)(9.11\times10^{-31}\ \text{kg})(1.60\times10^{-19}\ \text{C})^2}$$

$$= 1.32\times10^{-9}\ \text{m} = 1.32\ \text{nm}$$

**c.** If the radius of an hydrogen atom is $4.77\times10^{-10}$ m, in what energy state is the atom?

$$4.77\times10^{-10}\ \text{m} = \frac{(6.63\times10^{-34}\ \text{J·s})^2(n)^2}{4\pi^2(9.00\times10^{9}\ \text{N·m}^2/\text{C}^2)(9.11\times10^{-31}\ \text{kg})(1.60\times10^{-19}\ \text{C})^2}$$

$$n = \sqrt{\frac{(4.77\times10^{-10}\ \text{m})4\pi^2(9.00\times10^{9}\ \text{N·m}^2/\text{C}^2)(9.11\times10^{-31}\ \text{kg})(1.60\times10^{-19}\ \text{C})^2}{}}$$

$$= 3.00$$

**The atom is in the $n = 3.00$ energy state.**

**14.** What is the energy, in joules, of the photon produced when a hydrogen electron jumps from $n = 5$ to $n = 2$?

$$E_n = (-2.17\times10^{-18}\ \text{J}) \times \frac{1}{n_2}$$

$$E_2 = (-2.17\times10^{-18}\ \text{J}) \times \frac{1}{2^2} = -5.42\times10^{-19}\ \text{J}$$

$$E_5 = (-2.17\times10^{-18}\ \text{J}) \times \frac{1}{5^2} = -8.68\times10^{-20}\ \text{J}$$

$$\Delta E = E_5 - E_2 = (-8.68\times10^{-20}\ \text{J}) - (-5.42\times10^{-19}\ \text{J})$$

$$= 4.55\times10^{-19}\ \text{J}$$

**15.** A hydrogen atom is in the second excited state.

**a.** What is the energy, in joules, of the photon that was emitted?

**The second excited state is when $n = 3$.**

$$E_3 = (-2.17\times10^{-18}\ \text{J}) \times \frac{1}{3^2} = -2.41\times10^{-19}\ \text{J}$$

**b.** What is the wavelength of the photon emitted when the atom drops from the second excited state to the first excited state?

**The first excited state is when $n = 2$.**

$$E_2 = (-2.17\times10^{-18}\ \text{J}) \times \frac{1}{2^2}$$

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$$= -5.43\times10^{-19}\text{ J}$$

$$\Delta E = E_3 - E_2$$

$$= (-2.41\times10^{-19}\text{ J}) - (-5.43\times10^{-19}\text{ J}) = 3.02\times10^{-19}\text{ J}$$

$$\Delta E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{\Delta E} = \frac{(6.63\times10^{-34}\text{ J·s})(3.00\times10^{8}\text{ m/s})}{(3.02\times10^{-19}\text{ J})}$$

$$= 6.59\times10^{-7}\text{ m} = 659\text{ nm}$$

**16.** What is the frequency of light emitted when an electron transitions between two levels, if the energy emitted during the transition is $2.96\times10^{-23}$ kJ?

$$2.96\times10^{-23}\text{ kJ} = 2.96\times10^{-20}\text{ J}$$

$$f = \frac{\Delta E}{h} = \frac{(2.96\times10^{-20}\text{ J})}{(6.63\times10^{-34}\text{ J})} = 4.46\times10^{13}\text{ Hz}$$

**17.** What is the minimum amount of energy needed to remove an electron from a hydrogen atom? What wavelength must a photon have to remove the electron from a hydrogen atom?

**The minimum energy required to remove an electron from a hydrogen atom, or to ionize it, is to remove the electron from the ground state, or $n = 1$:**

$$E_1 = -13.6\text{ eV} \times \frac{1}{1^2} = -13.6\text{ eV}$$

**Because the electron has been removed from the zero-energy atom, the energy of the atom has a negative value. However, the minimum energy needed to remove the electron is a positive value, 13.6 eV.**

$$\lambda = \frac{hc}{\Delta E} = \frac{(1240\text{ eV·nm})}{(13.6\text{ eV})} = 91.2\text{ nm}$$

**18.** If 1.1 eV are needed to break apart a silicon electron from its atom, what is the frequency of the photon?

$$\lambda = \frac{(1240\text{ eV·nm})}{(1.1\text{ eV})}$$

$$f = \frac{c}{\lambda} = \frac{(3.00\times10^{8}\text{ m/s})}{(1100\times10^{-9}\text{ m})} = 2.7\times10^{14}\text{ Hz}$$

**19.** A hydrogen atom absorbs a photon with a wavelength of 102.8 nm. What is the state of the excited atom?

$$\lambda = \frac{hc}{\Delta E}$$

$$\Delta E = \frac{hc}{\lambda} = \frac{(1240\text{ eV·nm})}{(102.8\text{ nm})} = 12.1\text{ eV}$$

$$\Delta E = E_n - E_1$$

$$E_1 = -13.6\text{ eV}$$

$$E_n = \Delta E + E_1 = (12.1\text{ eV}) + (-13.6\text{ eV})$$

$$= -1.5\text{ eV}$$

$$E_n = (-13.6\text{ eV}) \times \frac{1}{n^2}$$

$$n = \sqrt{\frac{-13.6\text{ eV}}{E_n}}$$

$$= \sqrt{\frac{-13.6\text{ eV}}{-1.5\text{ eV}}}$$

$$= 3.0$$

**$n = 3$, which is the second excited state**

**20.** An atom has five energy levels, with $E_5$ being the highest and $E_1$ being the lowest.

**a.** If the atom can make transitions between any two levels, how many spectral lines can the atom emit?

**Ten spectral lines are possible, as follows: $E_5-E_4$; $E_5-E_3$; $E_5-E_2$; $E_5-E_1$; $E_4-E_3$; $E_4-E_2$; $E_4-E_1$; $E_3-E_2$; $E_3-E_1$; $E_2-E_1$.**

**b.** Which transition produces the highest energy photon?

**The transition, $E_5-E_1$, produces the highest energy photon because this transition involves the greatest change in energy for the atom.**

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**21.** The energy produced by the light emitted by a neon gas laser is 1.96 eV. What is the wavelength of the light produced assuming the laser is 100 percent efficient?

$$\lambda = \frac{hc}{\Delta E} = \frac{1240\ \text{eV·nm}}{1.96\ \text{eV}} = 633\ \text{nm}$$

**22.** Consider a 5.0-mW, 500.0-nm laser.

**a.** How many photons per second are emitted?

$$P_{laser} = NE_{ph}$$

$$N = \frac{P_{laser}}{E_{ph}} = \frac{\lambda P_{laser}}{hc}$$

$$= \frac{(500.0\times10^{-9}\ \text{m})(5.0\times10^{-3}\ \text{W})}{(6.63\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})} \times \frac{(1\ \text{J/s})}{(1\ \text{W})}$$

$$= 1.3\times10^{16}\ \text{photons per second}$$

**b.** How many times more photons are needed per second if you want a laser at 500.0 nm to have the same power as one at 250.0 nm? The power in a laser beam equals the energy of each photon multiplied by the number of photons emitted per second.

$$N = \frac{(250.0\times10^{-9}\ \text{m})(5.0\times10^{-3}\ \text{W})}{(6.63\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})} \times \frac{(1\ \text{J/s})}{(1\ \text{W})}$$

$$= 6.3\times10^{15}\ \text{photons/s}$$

$$\frac{(1.26\times10^{16}\ \text{photons/s})}{(6.3\times10^{15}\ \text{photons/s})} = 2$$

**Twice as many photons are needed.**

**23.** What is the lowest photon energy associated with the infrared light spectrum, which begins at 700.0 nm?

$$E_{ph} = \frac{hc}{\lambda} = \frac{(1240\ \text{eV·nm})}{(700.0\ \text{nm})} = 1.77\ \text{eV}$$

**24.** A fiber-optics laser light produces a wavelength of $1.40\times10^{3}$ nm. What is the energy of the light it produces, assuming 100 percent of the electric energy delivered to the laser is converted to light energy?

$$E_{ph} = \frac{hc}{\lambda}$$

$$= \frac{(6.63\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})}{(1.40\times10^{-6}\ \text{m})}$$

$$= 1.42\times10^{-19}\ \text{J}$$

**25.** A photon of radiation has an energy of $4.65\times10^{-15}$ J. What is the wavelength of this light?

$$\Delta E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{\Delta E} = \frac{(6.63\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})}{(4.65\times10^{-15}\ \text{J})}$$

$$= 4.28\times10^{-11}\ \text{m} = 0.0428\ \text{nm}$$

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# Chapter 29

**1.** The atomic mass of barium is 137.3 g/mol and its density is 3.594 g/cm$^3$.

**a.** Calculate how many free electrons exist in a cubic centimeter of barium, which has two free electrons per atom.

$$\frac{\text{free e}^-}{\text{cm}^3} = \left(\frac{2 \text{ free e}^-}{1 \text{ atom}}\right)\left(\frac{6.02\times10^{23} \text{ atoms}}{1 \text{ mol}}\right)\left(\frac{1 \text{ mol}}{137.3 \text{ g}}\right)\left(\frac{3.594 \text{ g}}{\text{cm}^3}\right)$$

$$= 3.15\times10^{22} \text{ free e}^-/\text{cm}^3$$

**b.** Is barium a conductor, a semiconductor, or an insulator?

**Barium is a conductor because it has a large number of electrons in a cubic centimeter.**

**2.** Silicon is doped with one atom of phosphorus per one million atoms of silicon. Each phosphorus atom adds one electron to the conduction band. The intrinsic ratio of pure silicon is $1.45\times10^{10}$ free electrons per cubic centimeter.

**a.** There are $4.99\times10^{22}$ silicon atoms per cubic centimeter. What is the density of free electrons in the doped silicon available from phosphorus?

$$\frac{\text{P}_{\text{atoms}}}{\text{cm}^3} = \left(\frac{4.99\times10^{22} \text{ Si atoms}}{\text{cm}^3}\right)\left(\frac{1 \text{ P atom}}{1\times10^6 \text{ Si atoms}}\right)$$

$$= 4.99\times10^{16} \text{ P atoms/cm}^3$$

$$\frac{\text{free e}^-}{\text{cm}^3} = \left(\frac{1 \text{ free e}^-}{\text{P atom}}\right)\left(\frac{4.99\times10^{16} \text{ P atoms}}{\text{cm}^3}\right)$$

$$= 4.99\times10^{16} \text{ free e}^-/\text{cm}^3 \text{ from P}$$

**b.** What is the ratio of phosphorus-donated electrons to silicon-donated electrons?

$$\text{Ratio} = \left(\frac{\text{free e}^-/\text{cm}^3 \text{ from P}}{\text{free e}^-/\text{cm}^3 \text{ from Si}}\right)$$

$$= \left(\frac{4.99\times10^{16} \text{ free e}^-/\text{cm}^3 \text{ from P}}{1.45\times10^{10} \text{ free e}^-/\text{cm}^3 \text{ from Si}}\right)$$

$$= 3.44\times10^6 \text{ P e}^- \text{ per Si e}^-$$

**c.** Which element is primarily responsible for the conduction in the doped silicon?

**Because there are more than 3 million free electrons from phosphorus for each free electron from silicon, phosphorus is the primary source of electrons for conduction.**

**3.** A light emitting diode (LED) produces red light at a wavelength of 635 nm. What is the width of the forbidden gap in the diode?

$$E = \frac{1240 \text{ eV·nm}}{\lambda}$$

$$= \frac{1240 \text{ eV·nm}}{635 \text{ nm}}$$

$$= 1.95 \text{ eV}$$

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4. A diode in an infrared laser used in a remote-control device for a television has a forbidden gap of 1.02 eV. What is the wavelength of the light that it emits?

$$E = \frac{1240\ \text{eV·nm}}{\lambda}$$

$$\lambda = \frac{1240\ \text{eV·nm}}{E}$$

$$= \frac{1240\ \text{eV·nm}}{1.02\ \text{eV}}$$

$$= 1.22\times10^{-6}\ \text{m}$$

5. The voltage drop across a diode is 1.2 V when it is connected in series to a 300.0-Ω resistor and a battery. If the current is 16 mA, what is the battery voltage?

$$V_b = IR + V_d$$

$$= (1.6\times10^{-2}\ \text{A})(300.0\ \Omega) + 1.2\ \text{V}$$

$$= 6.0\ \text{V}$$

6. What is the voltage drop across a diode connected to a 9.0-V battery and a 150-Ω resistor if the current is 42 mA?

$$V_b = IR + V_d$$

$$V_d = V_b - IR$$

$$= 9.0\ \text{V} - (4.2\times10^{-2}\ \text{A})(150\ \Omega)$$

$$= 2.7\ \text{V}$$

7. In a diode connected to a 9.0-V battery in series with a 625-Ω resistor, the voltage drop is 3.2 V. What is the current in the diode?

$$V_b = IR + V_d$$

$$I = \frac{V_b - V_d}{R}$$

$$= \frac{9.0\ \text{V} - 3.2\ \text{V}}{625\ \Omega}$$

$$= 0.0093\ \text{A or } 9.3\ \text{mA}$$

8. The voltage across a glowing LED is 2.3 V when it is placed in a circuit with a 6.0-V battery and a 150-Ω resistor.

**a.** What is the voltage drop across the resistor?

$$IR = V_b - V_d$$

$$= 6.0\ \text{V} - 2.3\ \text{V}$$

$$= 3.7\ \text{V}$$

**b.** What is the current through the resistor?

$$I = \frac{V_d}{R}$$

$$= \frac{3.7\ \text{V}}{150\ \Omega}$$

$$= 25\ \text{mA}$$

**c.** What is the current through the diode?

**25 mA. The current is uniform throughout the circuit.**

**d.** If you want to make the LED glow brighter by increasing the current to 35 mA, what size resistor should replace the 150-Ω resistor?

$$R = \frac{V}{I}$$

$$= \frac{3.7\ \text{V}}{35\ \text{mA}}$$

$$= 1.1\times10^{2}\ \Omega$$

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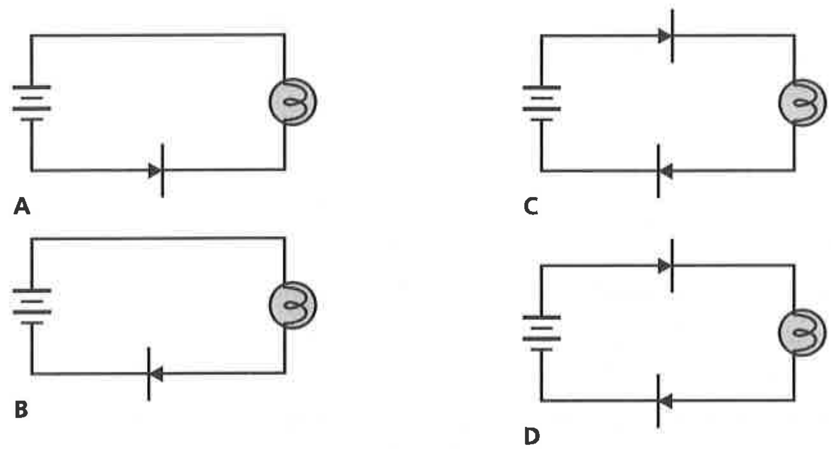
**Chapter 29 continued**

**9.**




For each of these circuits consisting of a battery and lightbulb, will the lightbulb come on when the circuit is closed? Explain.

**A. Yes, current flows through the forward-biased diode.**

**B. No, current does not flow through the reverse-biased diode.**

**C. No, current does not flow through the reverse-biased diode.**

**D. Yes, current flows through the forward-biased diode, because the diodes are in a parallel circuit.**

**10.** For each of the following elements, indicate whether it could be used as dopant to make an $n$-type semiconductor, a $p$-type semiconductor, or neither. Use the periodic table in Appendix D.

**a.** aluminum

***p*-type (three valence electrons)**

**b.** nitrogen

***n*-type (five valence electrons)**

**c.** antimony

***n*-type (five valence electrons)**

**d.** carbon

**neither (four valence electrons)**

**e.** gallium

***p*-type (three valence electrons)**

**11.** Iron has $1.69\times10^{23}$ free electrons per $cm^3$. How many free $e^-$ per iron atom exist at room temperature? The atomic mass of iron is 55.85 g/mol; the density of iron is 7.86 $g/cm^3$.

$$\left(\frac{\text{free } e^-}{\text{atom}}\right) = \left(\frac{1}{N_A}\right)(M)\left(\frac{1}{\rho}\right)\left(\frac{1.69\times10^{23}\text{ free } e^-}{cm^3}\right)$$

$$= \left(\frac{1\text{ mol}}{6.02\times10^{23}\text{ atoms}}\right)\left(\frac{55.85\text{ g}}{1\text{ mol}}\right)\left(\frac{1\text{ cm}^3}{7.86\text{ g}}\right)\left(\frac{1.69\times10^{23}\text{ free } e^-}{cm^3}\right)$$

$$= \frac{1.99\text{ free } e^-}{\text{atom of Fe}}$$

**= 2 free electrons per atom of iron**

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**Chapter 29 continued**

**12.** The atomic mass of mercury is 200.59 g/mol; its density is 13.53 g/cm$^3$.

**a.** How many free electrons exist in a cubic centimeter of mercury, if each atom contributes two electrons?

$$\frac{\text{free e}^-}{\text{cm}^3} = \left(\frac{\text{free e}^-}{1\text{ atom}}\right)(N_A)\left(\frac{1}{M}\right)(\rho)$$

$$= \left(\frac{2\text{ free e}^-}{1\text{ atom}}\right)\left(\frac{6.02\times10^{23}\text{ atoms}}{1\text{ mol}}\right)\left(\frac{1\text{ mol}}{200.59\text{ g}}\right)\left(\frac{13.53\text{ g}}{1\text{ cm}^3}\right)$$

$$= 8.12\times10^{22}\text{ free e}^-/\text{cm}^3$$

**b.** Using the answer to part a, how many atoms of mercury are there in 1.0 cm$^3$, assuming all mercury atoms free their valence electrons?

**Each atom of mercury has 2 free electrons. Thus, if there are $8.12\times10^{22}$ free e$^-$/cm$^3$ of mercury, there are $4.06\times10^{22}$ mercury atoms:**

$$\left(\frac{8.12\times10^{22}\text{ free e}^-/\text{cm}^3}{2\text{ free e}^-/\text{atom}}\right) = 4.06\times10^{22}\text{ atoms/cm}^3$$

**13.** A 24-karat gold ring is made of 2.00 g of pure gold.

**a.** How many free electrons are in this ring at room temperature? The density of gold is 19.32 g/cm$^3$ and its atomic weight is 196.97. Gold has one valence electron.

$$\frac{\text{free e}^-}{\text{cm}^3} = \left(\frac{\text{free e}^-}{1\text{ atom}}\right)(N_A)\left(\frac{1}{M}\right)(\rho)$$

$$= \left(\frac{1\text{ free e}^-}{1\text{ atom}}\right)\left(\frac{6.02\times10^{23}\text{ atoms}}{1\text{ mol}}\right)\left(\frac{1\text{ mol}}{196.97\text{ g}}\right)\left(\frac{19.32\text{ g}}{1\text{ cm}^3}\right)$$

$$= \frac{5.90\times10^{22}\text{ free e}^-}{\text{cm}^3}$$

$$\left(\frac{5.90\times10^{22}\text{ free e}^-}{\text{cm}^3}\right)\left(\frac{1\text{ cm}^3}{19.32\text{ g}}\right)(2\text{ g})$$

$$= 6.11\times10^{21}\text{ free e}^-\text{ in 2 g of pure gold}$$

**b.** How many atoms of gold are in 1 g of pure gold, assuming all gold atoms have freed their electrons?

**If each gold atom frees one electron, then there are $6.11\times10^{21}$ atoms of gold in 2 g of pure gold and $3.06\times10^{21}$ atoms in 1 g of pure gold:**

$$\left(\frac{6.11\times10^{21}\text{ atoms/2 g}}{2\text{ free e}^-/\text{atom}}\right) = 3.06\times10^{21}\text{ atoms/g}$$

**14.** At 200 K, silicon has $3.79\times10^{-18}$ free e$^-$/atom.

**a.** How many free electrons are there per cm$^3$ at this temperature? The density of silicon is 2.33 g/cm$^3$, and its atomic weight is 28.09 g/mol.

$$\frac{\text{free e}^-}{\text{cm}^3} = \left(\frac{\text{free e}^-}{1\text{ atom}}\right)(N_A)\left(\frac{1}{M}\right)(\rho) =$$

$$= \left(\frac{3.79\times10^{-18}\text{ free e}^-}{1\text{ atom}}\right)\left(\frac{6.02\times10^{23}\text{ atoms}}{1\text{ mol}}\right)\left(\frac{1\text{ mol}}{28.09\text{ g}}\right)\left(\frac{2.33\text{ g}}{1\text{ cm}^3}\right)$$

$$= \frac{1.89\times10^{5}\text{ free e}^-}{\text{cm}^3}$$

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**Chapter 29 continued**

**b.** If all silicon atoms free their electrons at 200 K, how many silicon atoms are contained in 1 $cm^3$ at this temperature?

**If each silicon atom frees $3.79\times10^{-18}$ $e^-$ at 200 K and there are $1.89\times10^5$ free $e^-/cm^3$, then there are $4.99\times10^{22}$ silicon atoms/$cm^3$:**

$$\frac{1.89\times10^5 \text{ free e}^-/\text{cm}^3}{3.79\times10^{-8} \text{ free e}^-/\text{atom}} = 4.99\times10^{22} \text{ atoms/cm}^3$$

**c.** How many silicon atoms are contained in 1 $cm^3$ at 100 K, if silicon has $1.85\times10^{-32}$ free $e^-$/atom and $9.23\times10^{-10}$ free $e^-/cm^3$ at this temperature?

$$\frac{9.23\times10^{-10} \text{ free e}^-/\text{cm}^3}{1.85\times10^{-32} \text{ free e}^-/\text{atom}} = 4.99\times10^{22} \text{ atoms/cm}^3$$

**15.** Each silver atom (atomic mass: 107.87) contributes one electron. Each cubic centimeter of silver contains $5.82\times10^{22}$ free $e^-$. Calculate the density of silver at 20°C.

$$\frac{\text{free e}^-}{\text{cm}^3} = \left(\frac{\text{free e}^-}{1 \text{ atom}}\right)(N_A)\left(\frac{1}{M}\right)(\rho)$$

$$\rho = \left(\frac{\text{free e}^-}{\text{cm}^3}\right)\left(\frac{1 \text{ atom}}{\text{free e}^-}\right)\left(\frac{1}{N_A}\right)(M)$$

$$= \left(\frac{5.82\times10^{22} \text{ free e}^-}{\text{cm}^3}\right)\left(\frac{1 \text{ atom}}{\text{free e}^-}\right)\left(\frac{1 \text{ mol}}{6.02\times10^{23} \text{ atoms}}\right)\left(\frac{107.87 \text{ g}}{\text{mol}}\right)$$

$$= \frac{10.43 \text{ g}}{\text{cm}^3}$$

**16.** Germanium (Ge) has $2.25\times10^{13}$ free electrons/$cm^3$.

**a.** How many atoms of germanium are there in 1 $cm^3$ at room temperature?

$$\left(\frac{\text{atoms}}{\text{cm}^3}\right) = \left(\frac{\text{free e}^-/\text{cm}^3}{\text{free e}^-/\text{atom}}\right)$$

$$= \left(\frac{2.25\times10^{13} \text{ free e}^-/\text{cm}^3}{5.19\times10^{-10} \text{ free e}^-/\text{atom}}\right)$$

$$= 4.34\times10^{22} \text{ atoms/cm}^3$$

**b.** Germanium is doped with two atoms of antimony (Sb) for every million atoms of germanium. Each antimony atom donates one electron. What is the density of the free electrons?

$$\left(\frac{\text{free e}^-}{\text{cm}^3} \text{ from Sb}\right) = \left(\frac{\text{free e}^-}{\text{Sb atom}}\right)\left(\frac{\text{Sb atoms}}{\text{Ge atoms}}\right)\left(\frac{\text{Ge atoms}}{\text{cm}^3}\right)\left(\frac{\text{free e}^-}{\text{cm}^3}\right)$$

$$= \left(\frac{1 \text{ free e}^-}{1 \text{ Sb atom}}\right)\left(\frac{2 \text{ Sb atoms}}{1\times10^6 \text{ Ge atoms}}\right)\left(\frac{4.34\times10^{22} \text{ atoms}}{\text{cm}^3}\right)$$

$$= \frac{8.68\times10^{16} \text{ free e}^-}{\text{cm}^3}$$

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**Chapter 29 continued**

**c.** How does the density of this doped germanium compare to that of intrinsic germanium?

**Ratio of antimony-donated electrons in doped germanium to electrons in intrinsic germanium =**

$$\left(\frac{\text{free e}^-/\text{cm}^3 \text{ in doped Ge}}{\text{free e}^- /\text{cm}^3 \text{ in intrinsic Ge}}\right)$$

$$= \left(\frac{8.68 \times 10^{16} \text{ free e}^-/\text{cm}^3 \text{ in doped Ge}}{2.25 \times 10^{13} \text{ free e}^-/\text{cm}^3 \text{ in intrinsic Ge}}\right)$$

**= 3858 electrons**

**= $3.86 \times 10^3$ Sb-donated electrons/intrinsic Ge electrons**

**d.** Is conduction mainly by the germanium or antimony electrons?

**Since there are about 3900 Sb-donated electrons for every intrinsic germanium electron, conduction would more likely be by the antimony-donated electrons**

**e.** Is this semiconductor an *n*- or *p*-type semiconductor? Antimony has five valence electrons.

**It is a *n*-type semiconductor because the acceptor atom used as the dopant, antimony, has five valence electrons, which provides an unbound electron in the germanium crystal.**

**17.** The potential voltage drop across a glowing LED is 1.5 V.

**a.** What is the current through the LED when it is powered by a 12.0-V battery and a 50.0-Ω resistor?

$$V_b = IR + V_d$$

$$IR = V_b - V_d$$

$$I = \left(\frac{V_b - V_d}{R}\right) = \frac{(12.0 \text{ V} - 1.5 \text{ V})}{(50\ \Omega)}$$

$$= 0.2 \text{ A}$$

**b.** What is the current through the resistor if a 6.0-V battery is used?

$$I = \frac{(6.0 \text{ V} - 1.5 \text{ V})}{50\ \Omega} = 0.09 \text{ A}$$

**c.** What could you do to make the LED burn more brightly?

$$I = \frac{V}{R}$$

$$V = IR$$

$$R = \frac{V}{I}$$

**You could increase the current or decrease the resistance to make the LED burn more brightly.**

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**Chapter 29 continued**

**18.** A diode has a voltage drop of 0.5 V with 25 mA of current passing through it. If a 460-Ω resistor is used in series, what size battery is needed for the diode?

$IR = V_b - V_d$

$V_b = IR - V_d = (0.025\ \text{A})(460\ \Omega) + 0.5\ \text{V}$

$= 12\ \text{V}$

**A 12-V battery would be needed.**

# Chapter 30

**1.** The atomic number of tungsten is 74. It occurs predominantly as four isotopes with atomic masses of 182, 183, 184, and 186. How many neutrons are located in the nuclei of each of these isotopes?

**the number of neutrons = A − Z**

**182 − 74 = 108 neutrons**

**183 − 74 = 109 neutrons**

**184 − 74 = 110 neutrons**

**186 − 74 = 112 neutrons**

**2.** Determine the number of protons and neutrons in each of these isotopes:

$^{19}_{9}\text{F}$ $^{210}_{87}\text{Fr}$ $^{112}_{48}\text{Cd}$ $^{226}_{88}\text{Ra}$

**$^{19}_{9}$F has 9 protons and 10 neutrons**

**$^{210}_{87}$Fr has 87 protons and 123 neutrons**

**$^{112}_{48}$Cd has 48 protons and 64 neutrons**

**$^{226}_{88}$Ra has 88 protons and 138 neutrons**

**3.** Write the nuclear equation for the transformation of a radioactive isotope of plutonium, which has 94 protons and 144 neutrons, to uranium by emission of an alpha particle.

$^{238}_{94}\text{Pu} \rightarrow {}^{A}_{Z}\text{X} + {}^{4}_{2}\text{He}$

**where Z = 94 − 2 = 92,**
**A = 238 − 4 = 234**

**Thus, the equation is**
$^{238}_{94}\text{Pu} \rightarrow {}^{234}_{92}\text{U} + {}^{4}_{2}\text{He}$

**4.** Radon 212 decays by emission of an alpha particle to form polonium-208 with a half-life of 24 h. How much of a 95.0-g sample will have become polonium after three days?

**The original amount of the sample equals the amount that has decayed plus the amount that remains. Thus,**
**decayed = original − remaining**

$= \text{original} - \text{original}\left(\frac{1}{2}\right)^{t}$

**where *t* is the number of half-lives.**

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**Because three days equals three half-lives, the equation becomes:**

$$\text{decayed} = \text{original} - \text{original}\left(\frac{1}{2}\right)^3$$

$$= 95.0\text{ g} - (95.0\text{ g})\left(\frac{1}{2}\right)^3$$

$$= 83.1\text{ g}$$

**5.** Uranium-238 has a half-life of $4.46\times10^9$ years. If Earth is 4.5 billion years old, how much of the original U-238 has not yet decayed?

**4.5 billion years = $4.5\times10^9$ years, or approximately one half-life.**
**One half of the original uranium-238 still exists.**

**6.** The half-life of carbon-14 is 5730 years. If a wooden tool is measured to have one-eighth as much carbon-14 as a modern sample of wood, how old is the tool?

$\frac{1}{8}$ **represents** $\left(\frac{1}{2}\right)^3$ **or three half-lives.**

**The tool is 3 × 5730 years = about 17,000 years old.**

**7.** The mass of an electron is $9.11\times10^{-31}$ kg.

**a.** What is the energy equivalent of the electron's mass in joules?

$$E = mc^2$$
$$= (9.11\times10^{-31}\text{ kg})(3.00\times10^8\text{ m/s})^2$$
$$= 8.20\times10^{-14}\text{ J}$$

**b.** What is the energy equivalent of the electron's mass in eV?

$$E = (8.20\times10^{-14}\text{ J})\left(\frac{1\text{ eV}}{1.60\times10^{-19}\text{ J}}\right)$$
$$= 5.12\times10^5\text{ eV}$$

For questions 8 and 9, use the following values:
mass of hydrogen atom = 1.007825 u
mass of neutron = 1.008665 u
1 u = 931.49 MeV

**8.** The nuclear mass of deuterium, which has one proton and one neutron, is 2.014101 u.

**a.** Calculate the mass defect for deuterium.

$$\text{Mass defect} = (\text{isotope mass}) - (\text{mass of protons and electrons}) - (\text{mass of neutrons})$$
$$= 2.014101\text{ u} - 1.007825\text{ u} - 1.008665\text{ u}$$
$$= -0.002389\text{ u}$$

**b.** Calculate the binding energy.

$$\text{Binding energy} = (\text{mass defect})(\text{binding energy of 1 u})$$
$$= (-0.002389\text{ u})\left(\frac{931.49\text{ MeV}}{1\text{ u}}\right)$$
$$= -2.2253\text{ MeV}$$

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**c.** The nuclear mass of helium is 4.002602. How much energy, in joules, is released when two moles of deuterium nuclei fuse to form one mole of helium?

$$E = mc^2$$
$$= (4.028202 \text{ g/mol} - 4.002602 \text{ g/mol})(1 \text{ mol})(3.00\times10^8 \text{ m/s})^2\left(\frac{1 \text{ kg}}{1000 \text{ g}}\right)$$
$$= 2.30\times10^{12} \text{ J}$$

**d.** One ton of TNT is the equivalent of $5.0\times10^9$ J. How many tons of TNT correspond to the energy released during the formation of one mole of helium by fusion of deuterium?

$$(2.30\times10^{12} \text{ J})\left(\frac{1 \text{ ton of TNT}}{5.0\times10^9 \text{ J}}\right) = 4.6\times10^2 \text{ tons of TNT}$$

**9.** Thorium-230 has 90 protons, 140 neutrons, and a nuclear mass of 230.033127.

**a.** What is the mass defect of thorium-230?

**Mass defect = (isotope mass) − (mass of protons and electrons) − (mass of neutrons)**
$$= 230.033127 \text{ u} - 90(1.007825 \text{ u}) - 140(1.008665 \text{ u})$$
$$= -1.884223 \text{ u}$$

**b.** Calculate the binding energy of the thorium nucleus.

**Binding energy = (mass defect)(binding energy of 1 u)**
$$= (-1.884223 \text{ u})\left(\frac{931.49 \text{ MeV}}{\text{u}}\right)$$
$$= -1755.1 \text{ MeV}$$

**c.** What is the energy equivalent, expressed in tons of TNT, of the mass defect of a mole of thorium-230?

**From problem 8, you know that one ton of TNT equals $5.0\times10^9$ J. For thorium,**

$$E = mc^2$$
$$= \left(\frac{1.884223 \text{ g}}{\text{mol}}\right)\left(\frac{1 \text{ kg}}{1000 \text{ g}}\right)(3.00\times10^8 \text{ m/s})^2\left(\frac{1 \text{ ton of TNT}}{5.0\times10^9 \text{ J}}\right)$$
$$= 3.4\times10^4 \text{ tons of TNT/mole}$$

**10.** Complete these nuclear reaction equations:

**a.** ${}^{14}_{7}N + {}^{4}_{2}He \rightarrow ? + {}^{1}_{1}H$

$${}^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{A}_{Z}X + {}^{1}_{1}H$$

**where $Z = 7 + 2 - 1 = 8$, $A = 14 + 4 - 1 = 17$**

**For Z = 8, the element must be oxygen.**

**Thus, the equation is**

$${}^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$$

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**Chapter 30 continued**

**b.** $^{235}_{92}U + ? \rightarrow ^{94}_{36}Kr + ^{139}_{56}Ba + 3(^{1}_{0}n)$

$^{235}_{92}U + ^{A}_{Z}X \rightarrow ^{94}_{36}Kr + ^{139}_{56}Ba + 3(^{1}_{0}n)$

**where Z = 36 + 56 + 0 − 92 = 0**

**A = 94 + 139 + 3(1) − 235 = 1**

**For Z = 0, the particle must be a neutron.**

**Thus, the equation is**

$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{94}_{36}Kr + ^{139}_{56}Ba + 3(^{1}_{0}n)$

**c.** $? \rightarrow ^{62}_{28}Ni + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$

$^{A}_{Z}X \rightarrow ^{62}_{28}Ni + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$

**where Z = 28 + (−1) + 0 = 27**

**A = 62 + 0 + 0 = 62**

**For Z = 27, the element must be cobalt.**

**Thus, the equation is**

$^{62}_{27}Co \rightarrow ^{62}_{28}Ni + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$

**d.** $^{20}_{7}F \rightarrow ? + ^{?}_{?}e + ^{0}_{0}\bar{\nu}$

$^{20}_{7}F \rightarrow ^{A}_{Z}X + ^{?}_{?}e + ^{0}_{0}\bar{\nu}$

**Because this is beta decay, the equation is:**

$^{20}_{7}F \rightarrow ^{A}_{Z}X + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$

**where Z = 7 −(−1) − 0 = 8**

**A = 20 − 0 − 0 = 20**

**For Z = 8, the element must be oxygen.**

**Thus, the equation is**

$^{20}_{7}F \rightarrow ^{20}_{8}O + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$

**11.** How many protons and neutrons are in the following isotopes: $^{238}_{92}U$, $^{263}_{106}Sg$, $^{234}_{90}Th$, $^{7}_{4}Be$?

$^{238}_{92}U$ **has 92 protons and 146 neutrons.**

$^{263}_{106}Sg$ **has 106 protons and 157 neutrons.**

$^{234}_{90}Th$ **has 90 protons and 144 neutrons.**

$^{7}_{4}Be$ **has 4 protons and 3 neutrons.**

**12.** Zinc has four isotopes with mass numbers of 54, 63, 70, and 81. How many neutrons are there in the nuclei of each of isotope?

**Zinc's atomic number (Z) is 30.**

**The number of neutrons = mass number (A) − the atomic number (Z):**

**54 − 30 = 24**

**63 − 30 = 33**

**70 − 30 = 40**

**81 − 30 = 51**

**13.** What are the symbols for the five isotopes of nitrogen, each with the following number of neutrons in the nucleus: 6, 7, 8, 9, 10?

$^{13}_{7}N$, $^{14}_{7}N$, $^{15}_{7}N$, $^{16}_{7}N$, $^{17}_{7}N$

**14.** Write the nuclear equation for the decay of uranium-238 by emission of an α particle.

$^{238}_{92}U \rightarrow ^{A}_{Z}X + ^{4}_{2}He$

**where Z = 92 − 2 = 90, A = 238 − 4 = 234**

**The element with atomic number 90 is thorium (Th).**

**Thus, the equation is** $^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$

**15.** Write the equation for the β decay of $^{14}_{6}C$.

**Beta decay results in an increase in the atomic number by 1 and no change in the mass number.**

**The element with atomic number 7 is nitrogen (N).**

**Therefore,** $^{14}_{6}C \rightarrow ^{14}_{7}N + ^{1}_{-1}e$

**16.** Write the nuclear equation for the transmutation of a beryllium-7 atom by the emission of a β particle and an antineutrino.

$^{7}_{4}Be \rightarrow ^{A}_{Z}X + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$

**where Z = 4 − 1 = 3, A = 7 − 0 = 7**

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**The element with atomic number 3 is lithium (Li).**

**Thus, the equation is $^{7}_{4}Be \rightarrow ^{7}_{3}Li + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$**

**17.** How much of a 50.0-g sample of radium-226 will remain after 30.5 years? The half-life of radium-226 is 1662 years.

**Amount remaining = original amount $\left(\frac{1}{2}\right)^t$, where $t$ is the number of half-lives that have passed, therefore,**

$$\frac{30.5\ \text{y}}{1662\ \text{y}} = 0.0184$$

$$\text{Amount remaining} = 50.0\ \text{g}\left(\frac{1}{2}\right)^{0.0184}$$

$$= 49.4\ \text{g}$$

**18.** The isotope $^{131}_{53}I$ has a half-life of 8.07 days. If you have 50.0 g, what will be the mass of iodine-131 that remains two weeks from today?

**$t$ = the number of half-lives that have passed**

$$= \frac{14\ \text{days}}{8.07\ \text{days}}$$

$$= 1.73$$

$$\text{Amount remaining} = 50.0\ \text{g}\left(\frac{1}{2}\right)^{1.73}$$

$$= 15.1\ \text{g}$$

**19.** Suppose 50.0 kg of plutonium-242 waste were buried on January 1, 1982. How much of the waste will exist on January 1, 2982? The half-life of plutonium-242 is $3.79\times10^5$ years.

**$t$ = the number of half-lives that have passed**

$$= \frac{1000\ \text{years}}{3.79\times10^5\ \text{years/half-life}}$$

$$= 2.64\times10^{-3}$$

**Amount remaining**

$$= (50.0\ \text{kg})\left(\frac{1}{2}\right)^{2.64\times10^{-3}}$$

**= 49.9 kg remain after 1000 years.**

**20.** The atomic mass of $^{6}_{3}Li$ is 6.0151214 u, and the atomic mass of $^{7}_{3}Li$ is 7.0160030 u.

**a.** Calculate the mass defect of two isotopes of lithium, $^{6}_{3}Li$ and $^{7}_{3}Li$. The mass of one proton is 1.007825 u, and the mass of one neutron is 1.008665 u.

**The $^{6}_{3}Li$ atom has three protons and three neutrons.**

**Total mass of lithium nucleons**

**= 3(mass of 1 proton) + 3(mass of 1 neutron)**

$= 3(1.007825\ \text{u}) + 3(1.008665\ \text{u})$

$= 6.049470\ \text{u}$

**Mass defect $^{6}_{3}Li$**

**= (isotope mass) − (mass of protons and electrons)**

$= 6.0151214\ \text{u} - 6.049470\ \text{u}$

$= -0.034349\ \text{u}$

**The $^{7}_{3}Li$ atom has three protons and four neutrons.**

**Total mass of lithium nucleons**

**= Total mass of $^{6}_{3}Li$ + mass of 1 neutron**

$= 6.049470\ \text{u} + 1.008665\ \text{u}$

$= 7.058135\ \text{u}$

**Mass defect $^{7}_{3}Li$**

$= 7.016015\ \text{u} - 7.058135\ \text{u}$

$= -0.042120\ \text{u}$

**b.** Calculate the binding energies of the two lithium isotopes. The binding energy of 1 u = 931.49 MeV.

**E of $^{6}_{3}Li$**

**= (mass defect in u)(binding energy of 1 u)**

$= (-0.034349\ \text{u})(931.49\ \text{MeV/u})$

$= -31.995\ \text{MeV}$

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**E of $^{7}_{3}$Li**

**= (mass defect in u)(binding energy of 1 u)**

**= (−0.042120 u)(931.49 MeV/u)**

**= −39.234 MeV**

**21.** A zinc isotope, $^{64}_{30}$Zn, has an atomic mass of 63.929145 u. What is the mass defect of this isotope? The mass of one proton is 1.007825 u and the mass of one neutron is 1.008665 u.

**The $^{64}_{30}$Zn atom has 30 protons and 34 neutrons.**

**Total mass of zinc nucleons**

**= 30(mass of 1 proton) + 34(mass of 1 neutron)**

**= 30(1.007825 u) + 34(1.008665 u)**

**= 64.52936 u**

**Mass defect $^{63}_{30}$Zn**

**= (isotope mass) − (mass of nucleons)**

**= 63.929145 u − 64.52936 u**

**= −0.0600215 u**

**22.** An iron isotope has 26 protons and 28 neutrons and a mass of 53.939613 u. What is the mass defect of this isotope? The mass of one proton is 1.007825 u and the mass of one neutron is 1.008665 u.

**Total mass of iron nucleons**

**= 26(mass of 1 hydrogen atom) + 28(mass of 1 neutron)**

**= 26(1.007825 u) + 28(1.008665 u)**

**= 54.44607 u**

**Mass defect of the iron isotope**

**= (isotope mass) − (mass of nucleons)**

**= 53.939613 u − 54.44607 u**

**= 0.0506457 u**

**23.** Complete the following nuclear equations using a periodic table:

**a.** $^{1}_{1}\mathrm{H} + ^{9}_{4}\mathrm{Be} \rightarrow ^{6}_{3}\mathrm{Li} + ?$

**A = 1 + 9 = 10 − 6 = 4**

**Z = 1 + 4 = 5 − 3 = 2**

**The element with Z = 2 is helium. The isotope is $^{4}_{2}$He:**

$^{1}_{1}\mathrm{H} + ^{9}_{4}\mathrm{Be} \rightarrow ^{6}_{3}\mathrm{Li} + ^{4}_{2}\mathrm{He}$

**b.** $^{27}_{13}\mathrm{Al} + ^{4}_{2}\mathrm{He} \rightarrow ^{30}_{15}\mathrm{P} + ?$

**A = 27 + 4 = 31 − 30 = 1**

**Z = 13 + 2 = 15 − 15 = 0**

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**The particle would be $^{1}_{0}n$ (a neutron):**

$^{27}_{13}Al + ^{4}_{2}He \rightarrow ^{30}_{15}P + ^{1}_{0}n$

**c.** $^{4}_{2}He + ^{12}_{6}C \rightarrow ^{15}_{7}N + ?$

$A = 4 + 12 = 16 - 15 = 1$

$Z = 2 + 6 = 8 - 7 = 1$

**The element with Z = 1 is hydrogen. The isotope is $^{1}_{1}H$.**

$^{4}_{2}He + ^{12}_{6}C \rightarrow ^{15}_{7}N + ^{1}_{1}H$

**d.** $^{235}_{92}U + ^{1}_{0}n = ^{140}_{54}Xe + ? + 2^{1}_{0}n$

$A = 235 + 1 = 236 - 140$

$= 96 - 2 = 94$

$Z = 0 + 92 = 92 - 54$

$= 38 - 0 = 38$

**The element with Z = 38 is strontium. The isotope must be $^{94}_{38}Sr$.**

$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2^{1}_{0}n$

**24.** What is the charge of a particle that has two protons and one neutron? Each proton has two up quarks, u, with a charge of $+2/3$ e each, and one down quark, d, with a charge of $-1/3$ e. Each neutron is made up of one up quark and two down quarks.

**The charge = 2e(uud) + e(udd)**

$$= 2e\left(\frac{2}{3} + \frac{2}{3} + \left(-\frac{1}{3}\right)\right) + e\left(\frac{2}{3} + \left(-\frac{1}{3}\right) + \left(-\frac{1}{3}\right)\right)$$

$$= 2e\left(\frac{3}{3}\right) + 0$$

$$= 2e$$

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