

# **Chapter 10**

## **Fluids**

# 10-1 Phases of Matter

The three common phases of matter are solid, liquid, and gas.

A solid has a definite shape and size.

A liquid has a fixed volume but can be any shape.

A gas can be any shape and also can be easily compressed.

Liquids and gases both flow, and are called fluids.

## 10-2 Density and Specific Gravity

The density  $\rho$  of an object is its mass per unit volume:

$$\rho = \frac{m}{V}, \quad (10-1)$$

The SI unit for density is  $\text{kg/m}^3$ . Density is also sometimes given in  $\text{g/cm}^3$ ; to convert  $\text{g/cm}^3$  to  $\text{kg/m}^3$ , multiply by 1000.

Water at  $4^\circ\text{C}$  has a density of  $1 \text{ g/cm}^3 = 1000 \text{ kg/m}^3$ .

The specific gravity of a substance is the ratio of its density to that of water.

**Mass, given volume and density.** What is the mass of a solid iron wrecking ball of radius 18 cm?

**TABLE 10–1**  
**Densities of Substances<sup>†</sup>**

Substance	Density, $\rho$ (kg/m <sup>3</sup> )
<i>Solids</i>	
Aluminum	$2.70 \times 10^3$
Iron and steel	$7.8 \times 10^3$
Copper	$8.9 \times 10^3$
Lead	$11.3 \times 10^3$
Gold	$19.3 \times 10^3$
Concrete	$2.3 \times 10^3$
Granite	$2.7 \times 10^3$
Wood (typical)	$0.3 - 0.9 \times 10^3$
Glass, common	$2.4 - 2.8 \times 10^3$
Ice (H <sub>2</sub> O)	$0.917 \times 10^3$
Bone	$1.7 - 2.0 \times 10^3$
<i>Liquids</i>	
Water (4°C)	$1.000 \times 10^3$
Sea water	$1.025 \times 10^3$
Blood, plasma	$1.03 \times 10^3$
Blood, whole	$1.05 \times 10^3$
Mercury	$13.6 \times 10^3$
Alcohol, ethyl	$0.79 \times 10^3$
Gasoline	$0.7 - 0.8 \times 10^3$
<i>Gases</i>	
Air	1.29
Helium	0.179
Carbon dioxide	1.98
Water (steam) (100°C)	0.598

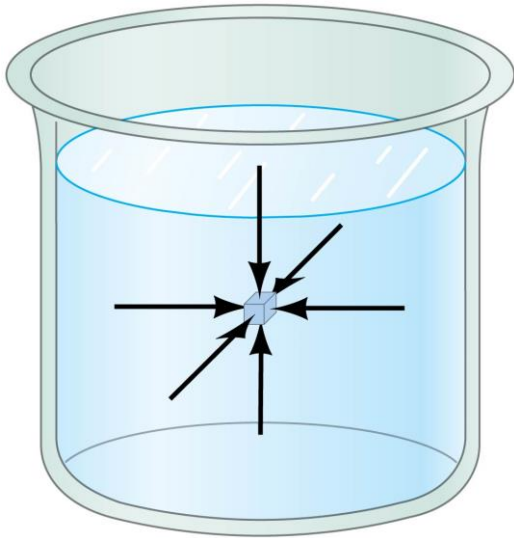
A bottle has a mass of 35.00 g when empty and 98.44 g when filled with water. When filled with another fluid, the mass is 89.22 g. What is the specific gravity of this other fluid?

# 10-3 Pressure in Fluids

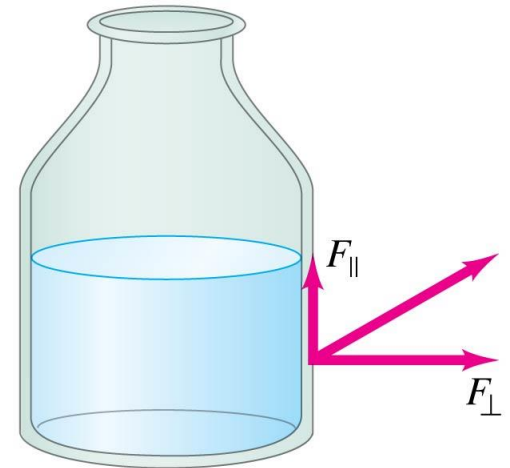
Pressure is defined as the force per unit area.

Pressure is a scalar; the units of pressure in the SI system are pascals:

$$1 \text{ Pa} = 1 \text{ N/m}^2$$



Pressure is the same in every direction in a fluid at a given depth; if it were not, the fluid would flow.



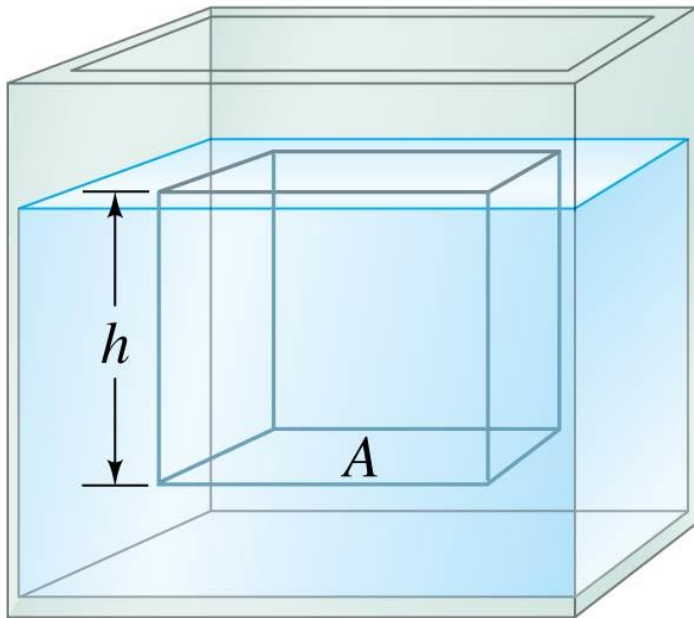
Also for a fluid at rest, there is no component of force parallel to any solid surface once again, if there were the fluid would flow.

## 10-3 Pressure in Fluids

The pressure at a depth  $h$  below the surface of the liquid is due to the weight of the liquid above it. We can quickly calculate:

$$P = \frac{F}{A} = \frac{\rho Ahg}{A} \quad (10-3a)$$

$$P = \rho gh.$$



This relation is valid for any liquid whose density does not change with depth.

A 60-kg person's two feet cover an area of (a) Determine the pressure exerted by the two feet on the ground. (b) If the person stands on one foot, what will be the pressure under that foot?

The surface of the water in a storage tank is 30 m above a water faucet in the kitchen of a house. Calculate the difference in water pressure between the faucet and the surface of the water in the tank.

# 10-4 Atmospheric Pressure and Gauge Pressure

At sea level the atmospheric pressure is about  $1.013 \times 10^5 \text{ N/m}^2$ ; this is called one atmosphere (atm).

Another unit of pressure is the bar:

$$1 \text{ bar} = 1.00 \times 10^5 \text{ N/m}^2$$

Standard atmospheric pressure is just over 1 bar.

This pressure does not crush us, as our cells maintain an internal pressure that balances it.



# 10-4 Atmospheric Pressure and Gauge Pressure

Most pressure gauges measure the pressure above the atmospheric pressure—this is called the gauge pressure.

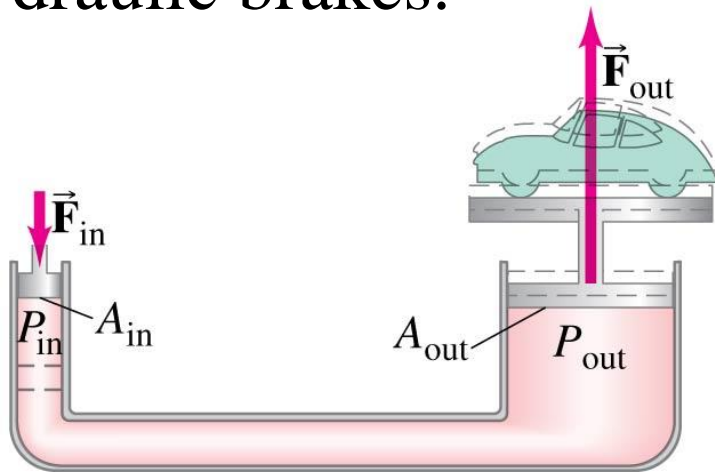
The absolute pressure is the sum of the atmospheric pressure and the gauge pressure.

$$P = P_A + P_G$$

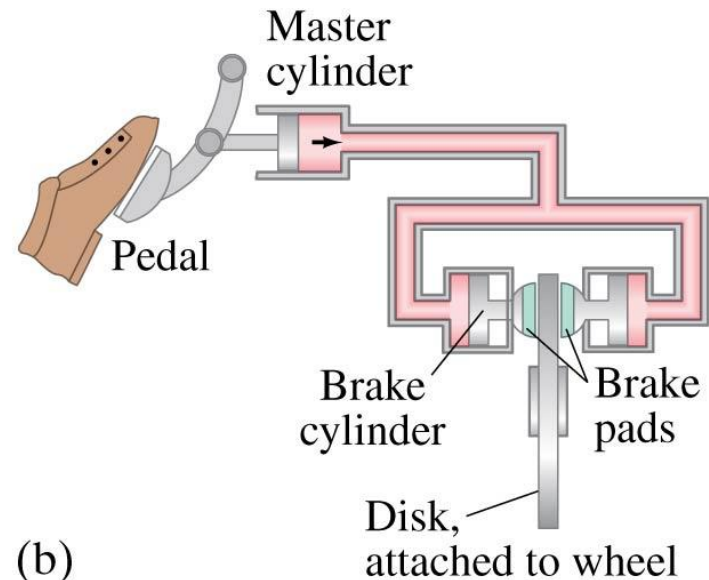
# 10-5 Pascal's Principle

If an external pressure is applied to a confined fluid, the pressure at every point within the fluid increases by that amount.

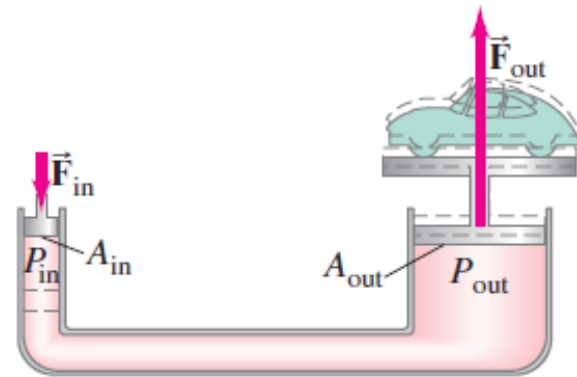
This principle is used, for example, in hydraulic lifts and hydraulic brakes.



(a)



(b)

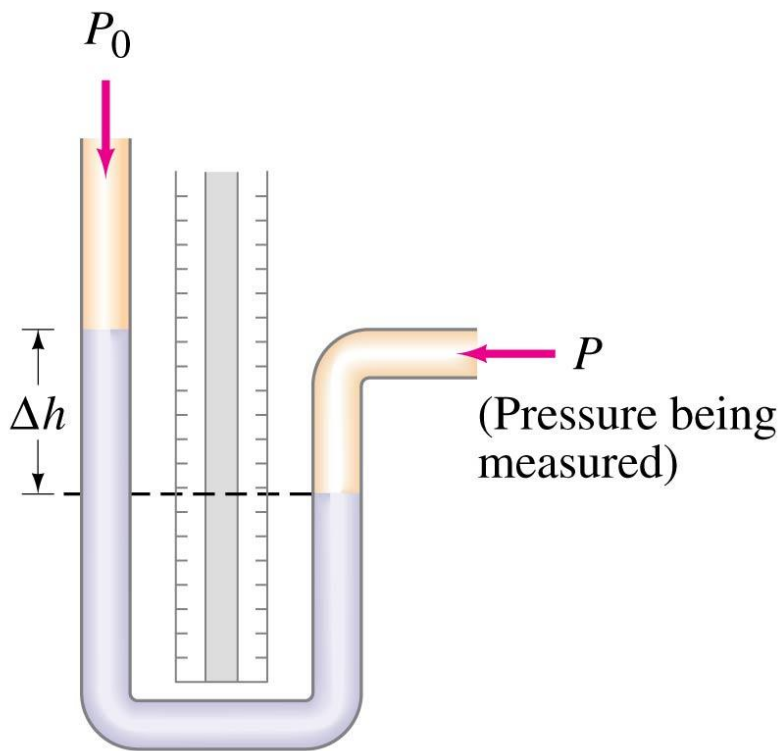


(a)

14. (II) The maximum gauge pressure in a hydraulic lift is 17.0 atm. What is the largest-size vehicle (kg) it can lift if the diameter of the output line is 25.5 cm?

# 10-6 Measurement of Pressure; Gauges and the Barometer

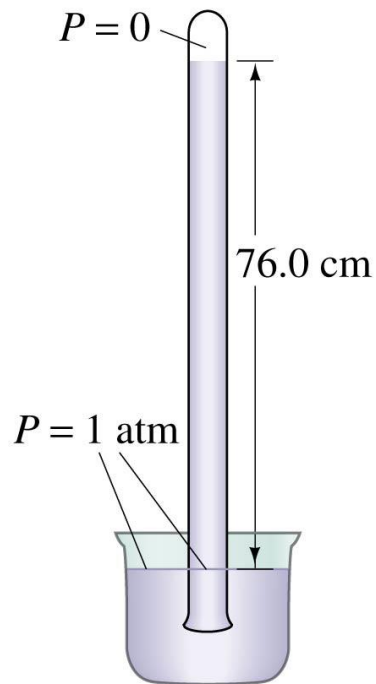
There are a number of different types of pressure gauges. This one is an open-tube manometer. The pressure in the open end is atmospheric pressure; the pressure being measured will cause the fluid to rise until the pressures on both sides at the same height are equal.



(a) Open-tube manometer

This is a mercury barometer, developed by Torricelli to measure atmospheric pressure. The height of the column of mercury is such that the pressure in the tube at the surface level is 1 atm.

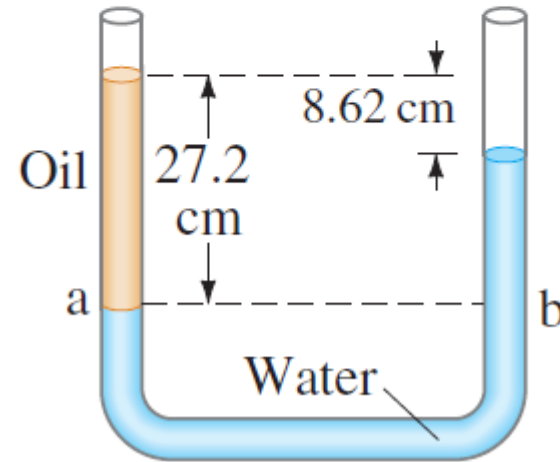
Therefore, pressure is often quoted in millimeters (or inches) of mercury.



**TABLE 10-2 Conversion Factors Between Different Units of Pressure**

In Terms of $1 \text{ Pa} = 1 \text{ N/m}^2$	1 atm in Different Units
$1 \text{ atm} = 1.013 \times 10^5 \text{ N/m}^2$ $= 1.013 \times 10^5 \text{ Pa} = 101.3 \text{ kPa}$	$1 \text{ atm} = 1.013 \times 10^5 \text{ N/m}^2$
$1 \text{ bar} = 1.000 \times 10^5 \text{ N/m}^2$	$1 \text{ atm} = 1.013 \text{ bar}$
$1 \text{ dyne/cm}^2 = 0.1 \text{ N/m}^2$	$1 \text{ atm} = 1.013 \times 10^6 \text{ dyne/cm}^2$
$1 \text{ lb/in.}^2 = 6.90 \times 10^3 \text{ N/m}^2$	$1 \text{ atm} = 14.7 \text{ lb/in.}^2$
$1 \text{ lb/ft}^2 = 47.9 \text{ N/m}^2$	$1 \text{ atm} = 2.12 \times 10^3 \text{ lb/ft}^2$
$1 \text{ cm-Hg} = 1.33 \times 10^3 \text{ N/m}^2$	$1 \text{ atm} = 76.0 \text{ cm-Hg}$
$1 \text{ mm-Hg} = 133 \text{ N/m}^2$	$1 \text{ atm} = 760 \text{ mm-Hg}$
$1 \text{ torr} = 133 \text{ N/m}^2$	$1 \text{ atm} = 760 \text{ torr}$
$1 \text{ mm-H}_2\text{O} (4^\circ\text{C}) = 9.80 \text{ N/m}^2$	$1 \text{ atm} = 1.03 \times 10^4 \text{ mm-H}_2\text{O} (4^\circ\text{C})$ $\approx 10 \text{ m of water}$

18. (II) Water and then oil (which don't mix) are poured into a U-shaped tube, open at both ends. They come to equilibrium as shown in Fig. 10–50. What is the density of the oil? [*Hint*: Pressures at points a and b are equal. Why?]

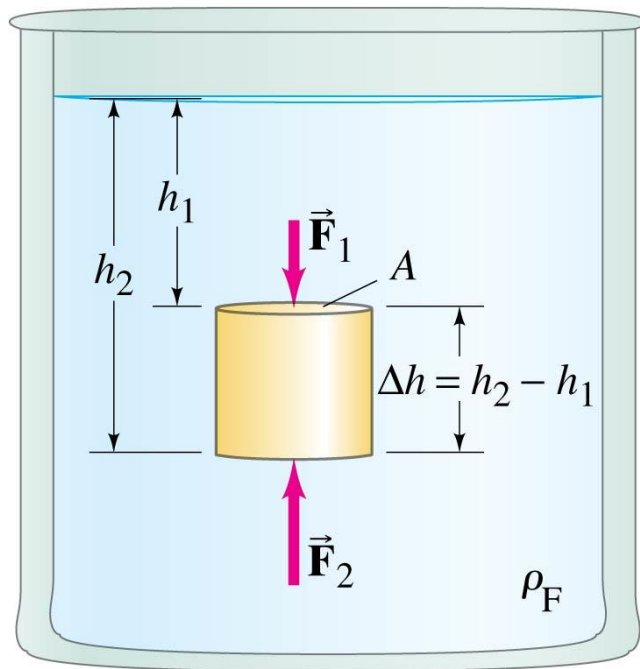


**FIGURE 10–50**  
Problem 18.

- 20.** (II) Determine the minimum gauge pressure needed in the water pipe leading into a building if water is to come out of a faucet on the fourteenth floor, 44 m above that pipe.

# 10-7 Buoyancy and Archimedes' Principle

This is an object submerged in a fluid. There is a net force on the object because the pressures at the top and bottom of it are different.



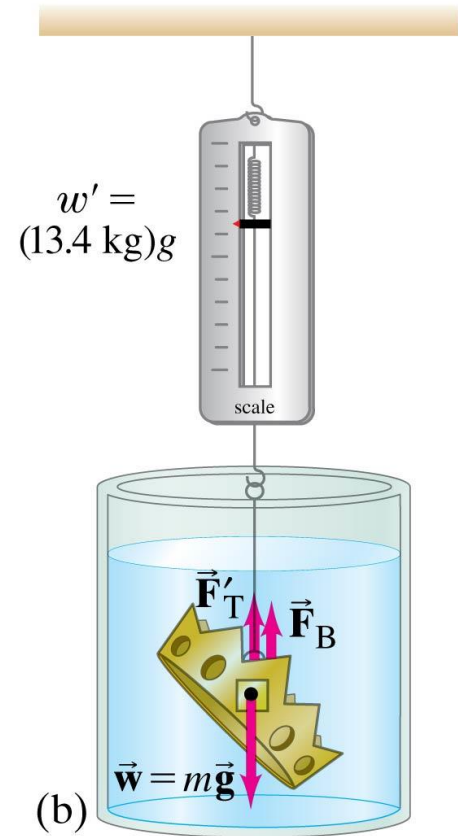
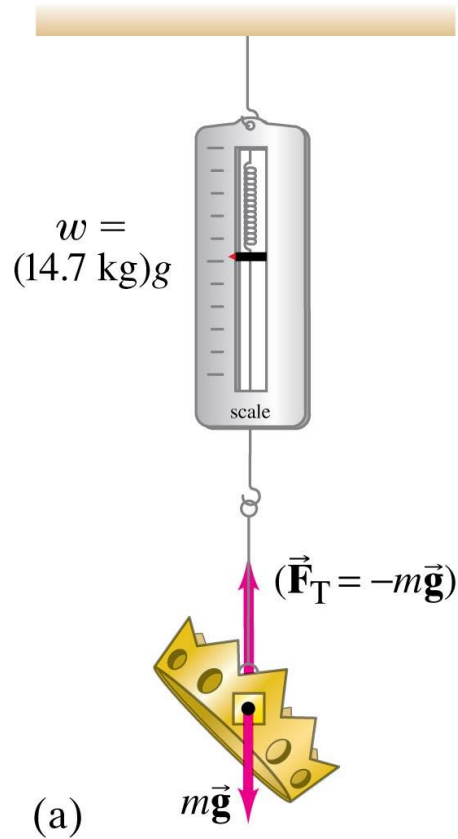
The buoyant force is found to be the upward force on the same volume of water:

$$\begin{aligned} F_B &= F_2 - F_1 = \rho_F g A (h_2 - h_1) \\ &= \rho_F g A \Delta h \\ &= \rho_F V g \\ &= m_F g, \end{aligned}$$



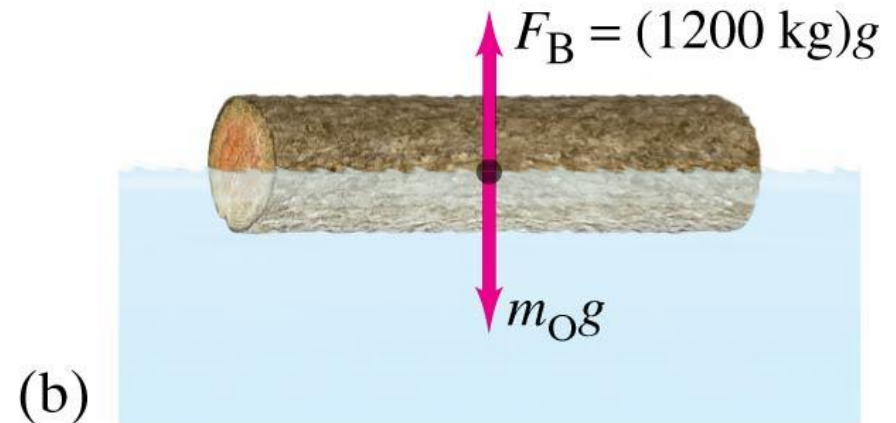
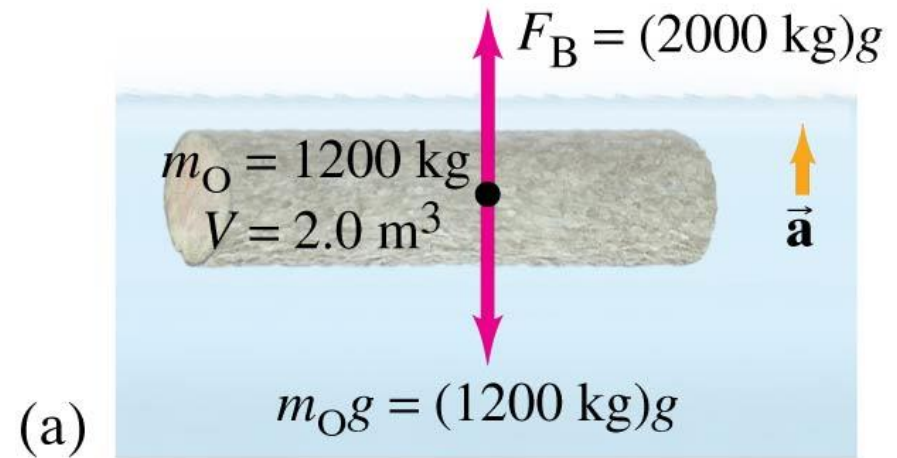
# 10-7 Buoyancy and Archimedes' Principle

The net force on the object is then the difference between the buoyant force and the gravitational force.



# 10-7 Buoyancy and Archimedes' Principle

If the object's density is less than that of water, there will be an upward net force on it, and it will rise until it is partially out of the water.

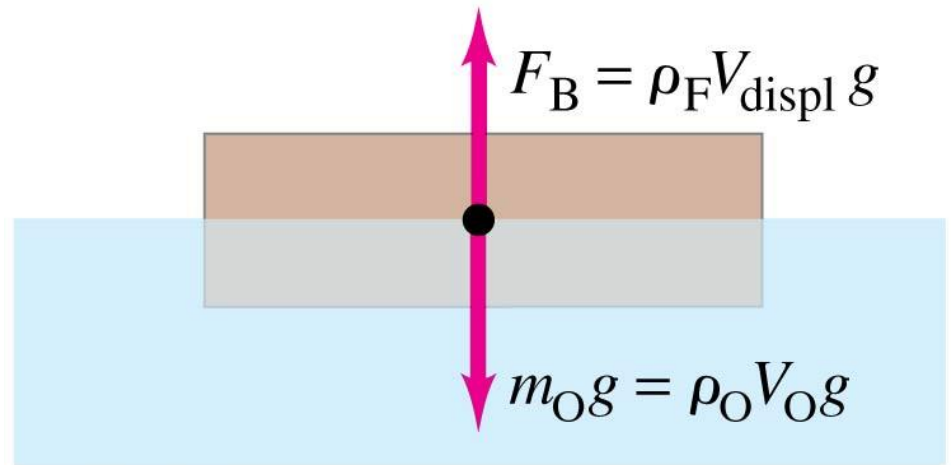


A 70-kg ancient statue lies at the bottom of the sea. Its volume is  $30000 \text{ cm}^3$ . How much force is needed to lift it (without acceleration)?

When a crown of mass 14.7 kg is submerged in water, an accurate scale reads only 13.4 kg. Is the crown made of gold?

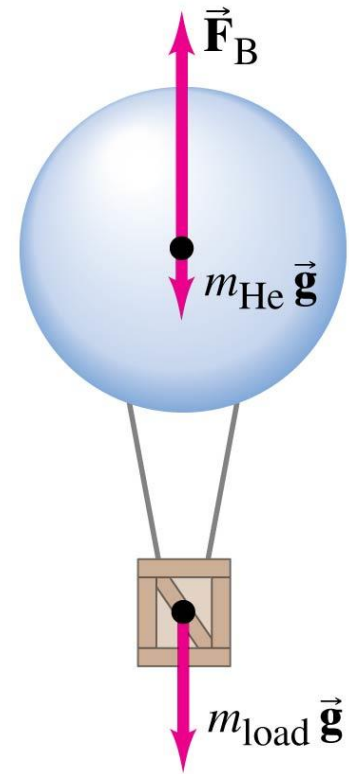
# 10-7 Buoyancy and Archimedes' Principle

For a floating object, the fraction that is submerged is given by the ratio of the object's density to that of the fluid.



**31.** (II) The specific gravity of ice is 0.917, whereas that of seawater is 1.025. What percent of an iceberg is above the surface of the water?

What volume  $V$  of helium is needed if a balloon is to lift a load of 180 kg (including the weight of the empty balloon)?

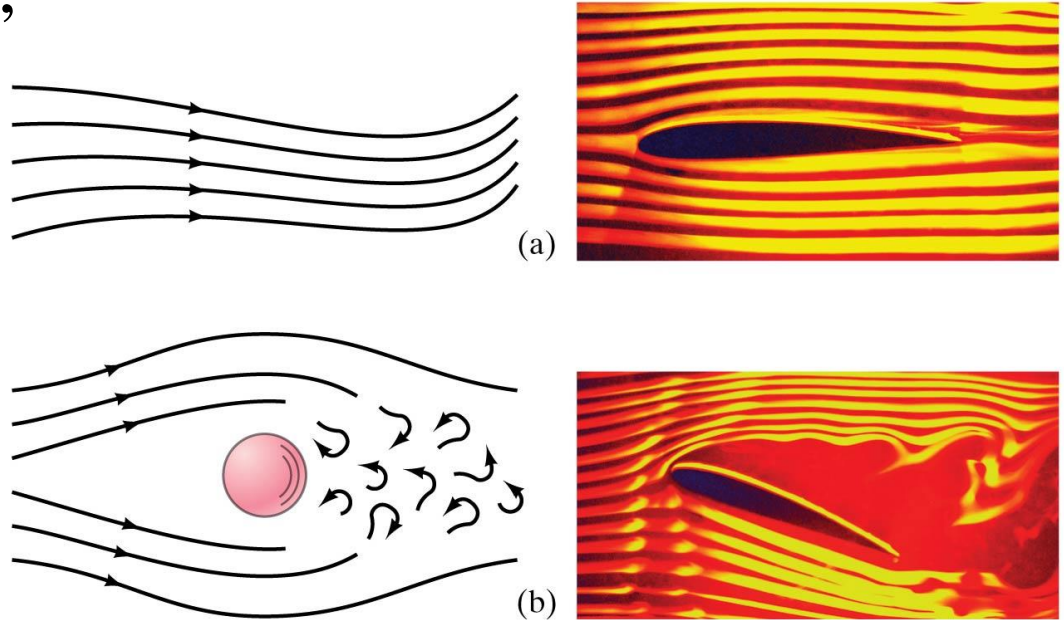


# 10-8 Fluids in Motion; Flow Rate and the Equation of Continuity

If the flow of a fluid is smooth, it is called streamline or laminar flow (a).

Above a certain speed, the flow becomes turbulent (b).

Turbulent flow has eddies; the viscosity of the fluid is much greater when eddies are present.





# 10-8 Fluids in Motion; Flow Rate and the Equation of Continuity

We will deal with laminar flow.

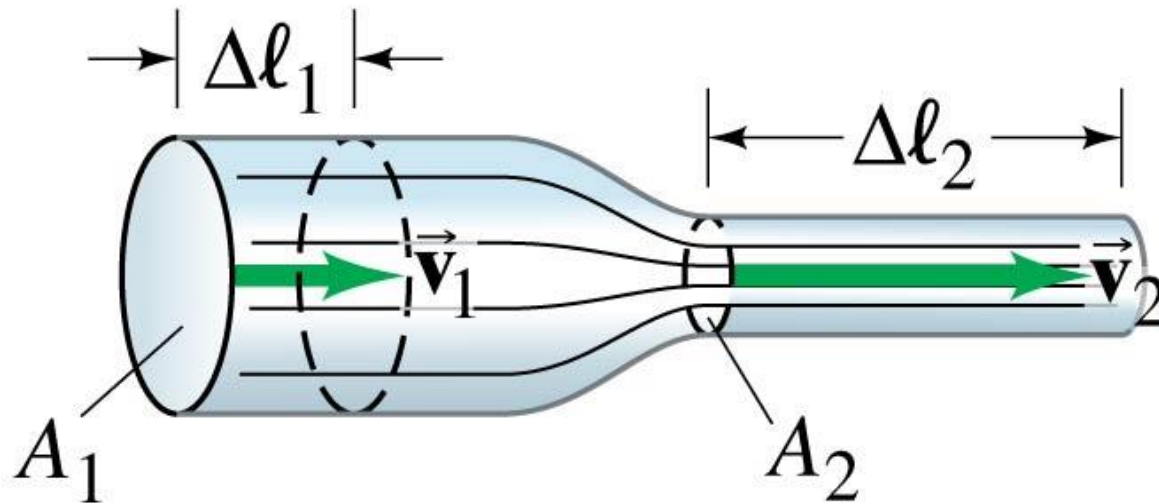
The mass flow rate is the mass that passes a given point per unit time. The flow rates at any two points must be equal, as long as no fluid is being added or taken away.

This gives us the equation of continuity:

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2. \quad (10-4a)$$

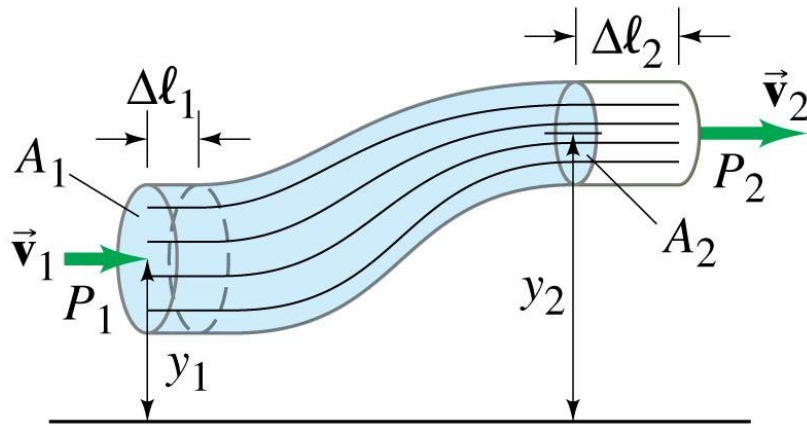
# 10-8 Fluids in Motion; Flow Rate and the Equation of Continuity

If the density doesn't change—typical for liquids—this simplifies to  $A_1v_1 = A_2v_2$ . Where the pipe is wider, the flow is slower.

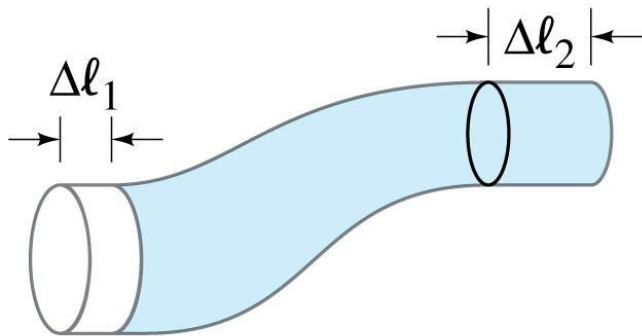


**EXAMPLE 10–12** **ESTIMATE** **Blood flow.** In humans, blood flows from the heart into the aorta, from which it passes into the major arteries, Fig. 10–20. These branch into the small arteries (arterioles), which in turn branch into myriads of tiny capillaries. The blood returns to the heart via the veins. The radius of the aorta is about 1.2 cm, and the blood passing through it has a speed of about 40 cm/s. A typical capillary has a radius of about  $4 \times 10^{-4}$  cm, and blood flows through it at a speed of about  $5 \times 10^{-4}$  m/s. Estimate the number of capillaries that are in the body.

# 10-9 Bernoulli's Equation



(a)



(b)

A fluid can also change its height. By looking at the work done as it moves, we find:

$$P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2 = P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1. \quad (10-5)$$

This is Bernoulli's equation. One thing it tells us is that as the speed goes up, the pressure goes down.

**EXAMPLE 10–14** Flow and pressure in a hot-water heating system.

Water circulates throughout a house in a hot-water heating system. If the water is pumped at a speed of  $0.50 \text{ m/s}$  through a  $4.0\text{-cm}$ -diameter pipe in the basement under a pressure of  $3.0 \text{ atm}$ , what will be the flow speed and pressure in a  $2.6\text{-cm}$ -diameter pipe on the second floor  $5.0 \text{ m}$  above? Assume the pipes do not divide into branches.

# 10-10 Applications of Bernoulli's Principle: Torricelli, Airplanes, Baseballs, Blood Flow

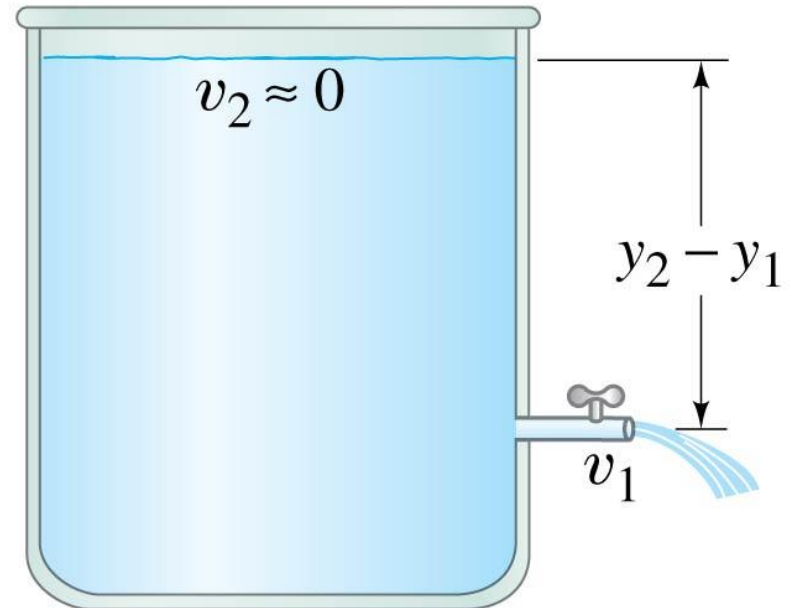
Using Bernoulli's principle, we find that the speed of fluid coming from a spigot on an open tank is:

$$\frac{1}{2}\rho v_1^2 + \rho g y_1 = \rho g y_2 \quad (10-6)$$

or

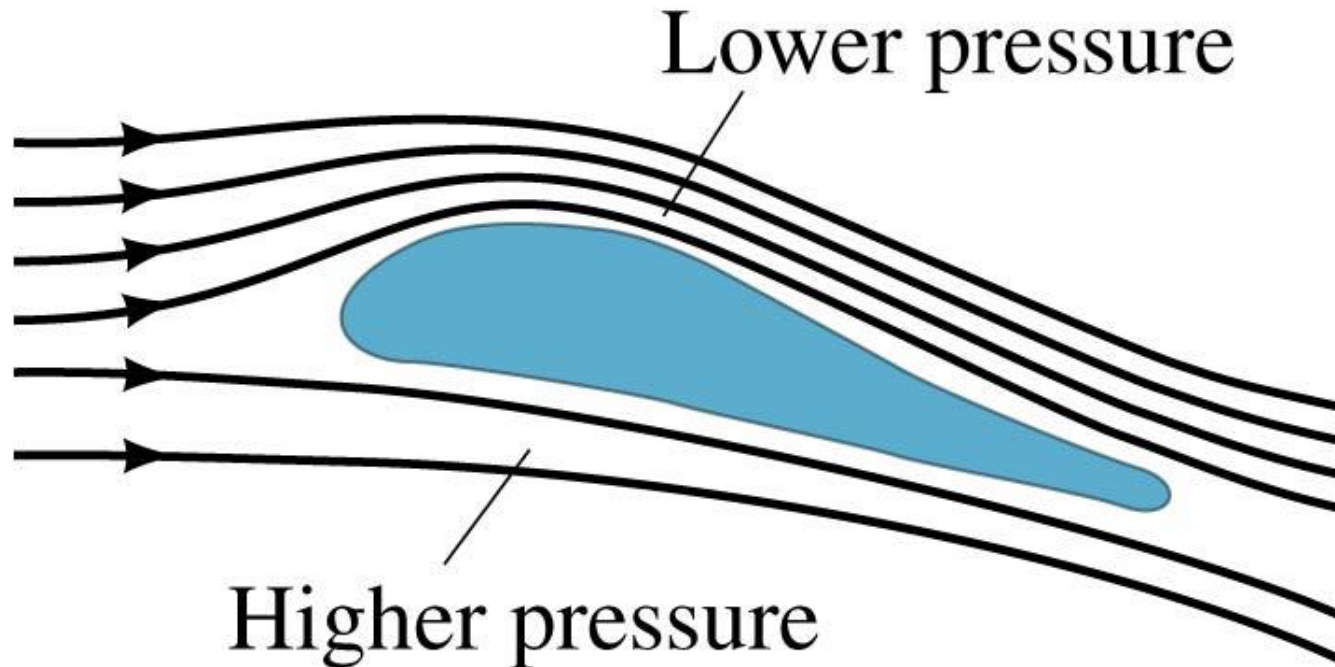
$$v_1 = \sqrt{2g(y_2 - y_1)}.$$

This is called Torricelli's theorem.



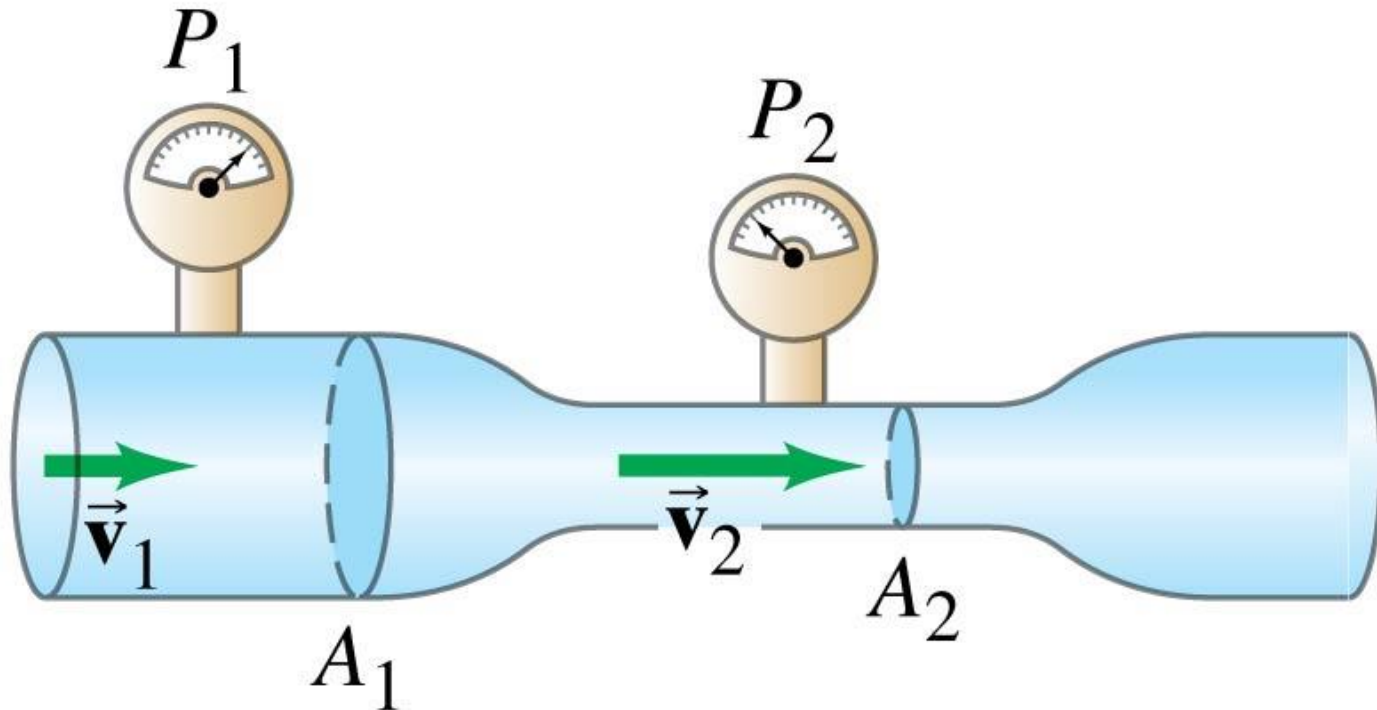
# 10-10 Applications of Bernoulli's Principle: Torricelli, Airplanes, Baseballs, Blood Flow

Lift on an airplane wing is due to the different air speeds and pressures on the two surfaces of the wing.



# 10-10 Applications of Bernoulli's Principle: Torricelli, Airplanes, Baseballs, Blood Flow

A venturi meter can be used to measure fluid flow by measuring pressure differences.





# 10-12 Flow in Tubes; Poiseuille's Equation, Blood Flow

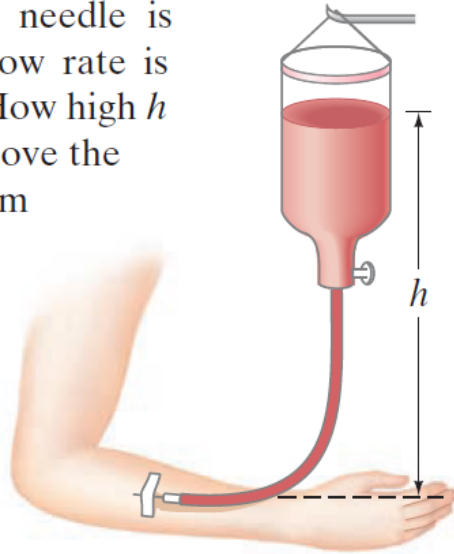
The rate of flow in a fluid in a round tube depends on the viscosity of the fluid, the pressure difference, and the dimensions of the tube.

The volume flow rate is proportional to the pressure difference, inversely proportional to the length of the tube and to the pressure difference, and proportional to the fourth power of the radius of the tube.

$$Q = \frac{\pi R^4 (P_1 - P_2)}{8\eta \ell},$$

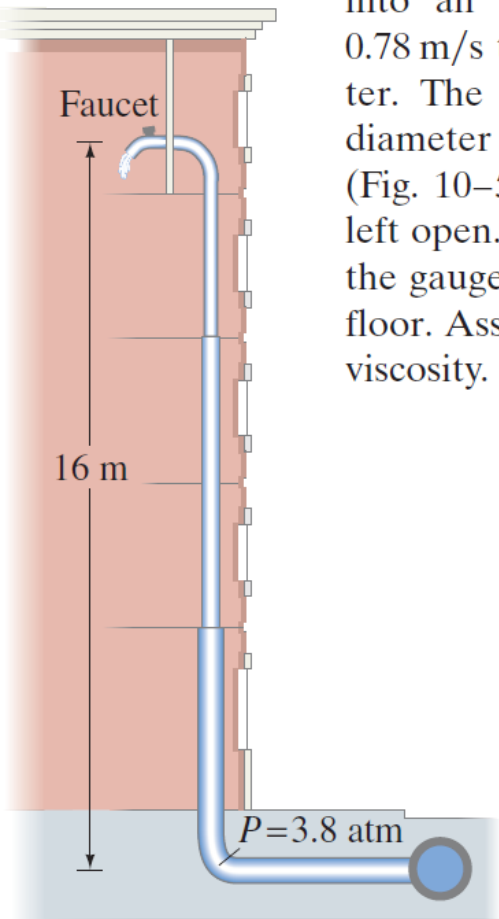
- \*54.** (I) A gardener feels it is taking too long to water a garden with a  $\frac{3}{8}$ -in.-diameter hose. By what factor will the time be cut using a  $\frac{5}{8}$ -in.-diameter hose instead? Assume nothing else is changed.

\*60. (III) A patient is to be given a blood transfusion. The blood is to flow through a tube from a raised bottle to a needle inserted in the vein (Fig. 10–54). The inside diameter of the 25-mm-long needle is 0.80 mm, and the required flow rate is  $2.0 \text{ cm}^3$  of blood per minute. How high  $h$  should the bottle be placed above the needle? Obtain  $\rho$  and  $\eta$  from the Tables. Assume the blood pressure is 78 torr above atmospheric pressure.



**FIGURE 10–54**  
Problem 60.

48. (II) Water at a gauge pressure of 3.8 atm at street level flows into an office building at a speed of 0.78 m/s through a pipe 5.0 cm in diameter. The pipe tapers down to 2.8 cm in diameter by the top floor, 16 m above (Fig. 10–53), where the faucet has been left open. Calculate the flow velocity and the gauge pressure in the pipe on the top floor. Assume no branch pipes and ignore viscosity.



**FIGURE 10–53**  
Problem 48.

- 26.** (II) A spherical balloon has a radius of 7.15 m and is filled with helium. How large a cargo can it lift, assuming that the skin and structure of the balloon have a mass of 930 kg? Neglect the buoyant force on the cargo volume itself.

17. (II) A house at the bottom of a hill is fed by a full tank of water 6.0 m deep and connected to the house by a pipe that is 75 m long at an angle of  $61^\circ$  from the horizontal (Fig. 10–49). (a) Determine the water gauge pressure at the house. (b) How high could the water shoot if it came vertically out of a broken pipe in front of the house?

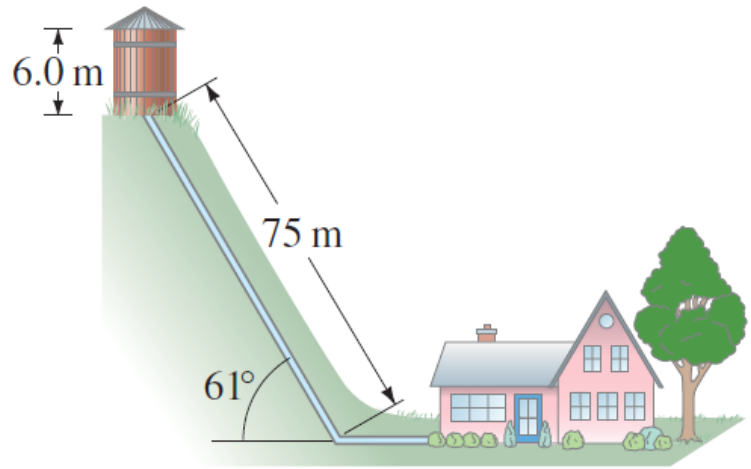


FIGURE 10–49 Problem 17.