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 ρ of an object is its mass per unit volume:

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

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

Water at 4°C has a density of 1 g/cm^3 = 1000 kg/m^3.

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

$$s = \frac{\rho_F}{\rho_W}$$

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

$$\frac{4}{3}\pi r^3$$

$$m = \rho V$$

$$= 7.8 \times 10^3 \times \frac{4}{3}\pi (0.18)^3$$

$$= 190.5 \text{ kg}$$

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?

$$S = \frac{\rho_F}{\rho_W} \times \frac{V}{V} = \frac{m_F}{m_W}$$

$$= \frac{(89.22 - 35)}{(98.44 - 35)}$$

$$= 0.85$$

TABLE 10–1
Densities of Substances‡

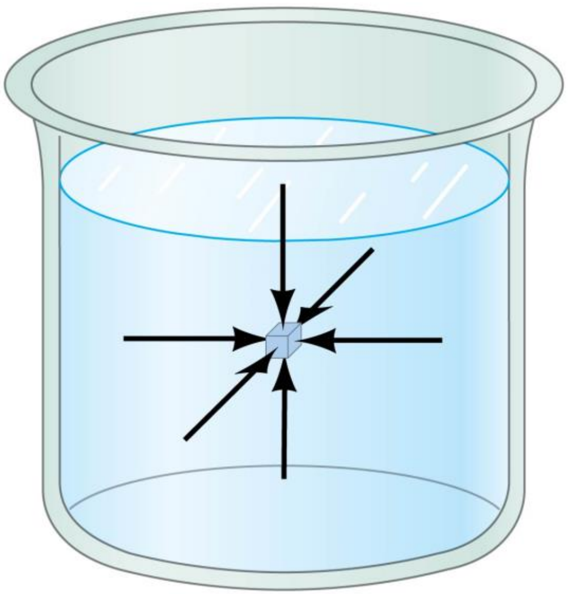
Substance	Density, ρ (kg/m^3)
Solids	
Aluminum	2.70×10^3
Iron and steel	7.8×10^3
Copper	8.9×10^3
Lead	11.3×10^3
Gold	19.3×10^3
Concrete	2.3×10^3
Granite	2.7×10^3
Wood (typical)	$0.3 - 0.9 \times 10^3$
Glass, common	$2.4 - 2.8 \times 10^3$
Ice (H_2O)	0.917×10^3
Bone	$1.7 - 2.0 \times 10^3$
Liquids	
Water (4°C)	1.000×10^3
Sea water	1.025×10^3
Blood, plasma	1.03×10^3
Blood, whole	1.05×10^3
Mercury	13.6×10^3
Alcohol, ethyl	0.79×10^3
Gasoline	$0.7–0.8 \times 10^3$
Gases	
Air	1.29
Helium	0.179
Carbon dioxide	1.98
Water (steam) (100°C)	0.598

10-3 Pressure in Fluids

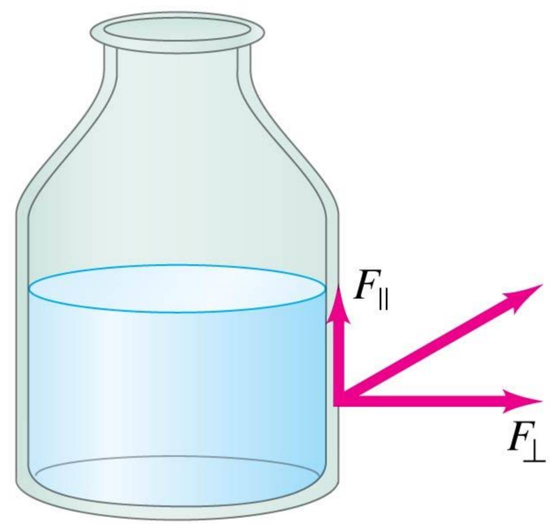
Pressure is defined as the force per unit area.

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.



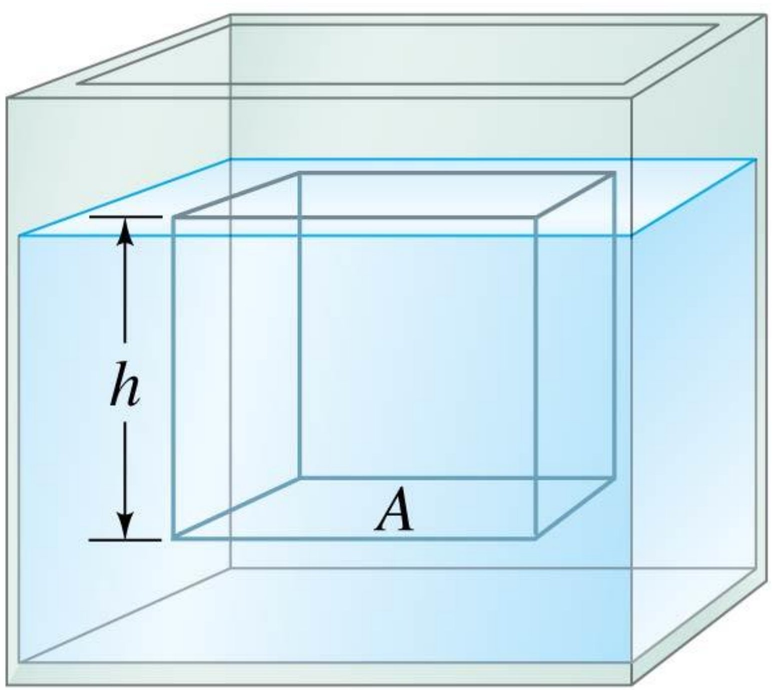
Also for a fluid at rest, there is no component of force parallel to any solid surface once again, if there were the fluid would flow.

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:

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

$$P = \rho g h.$$



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

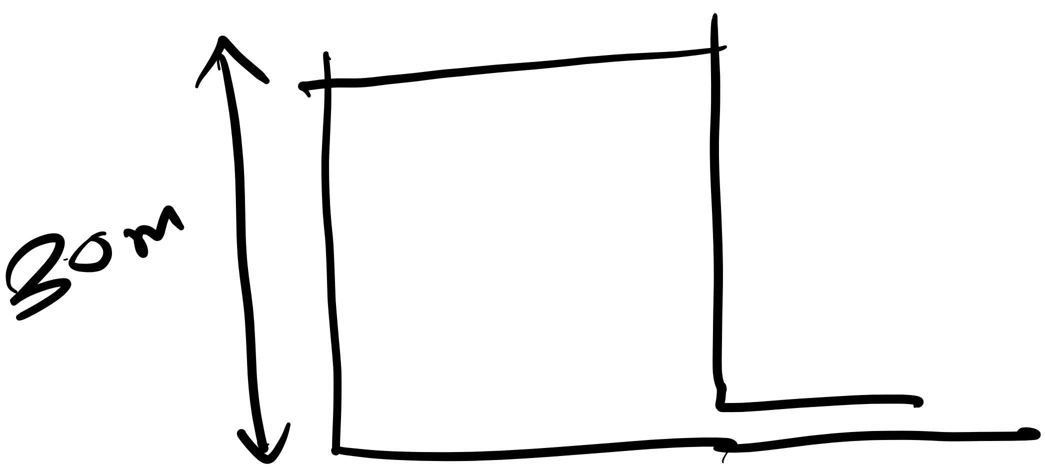
$400 cm^2$

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?

(a) $P = \frac{F}{A} = \frac{mg}{A} = \frac{60 \times 9.8}{400 \times 10^{-4}} = 14700 \text{ N}$

(b) $P = 14700 \times 2 = 29400 \text{ N}$

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.



$P = \rho g h$

$= 1000 \times 9.8 \times 30$

$= 29.4 \times 10^{4} \text{ Pa}$

10-4 Atmospheric Pressure and Gauge Pressure

At sea level the atmospheric pressure is about 1.013×10^5 N/m^2; this is called one atmosphere (atm).

1atm = 1.03×10^5 Pa

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.

$$P = P_A + P_G$$

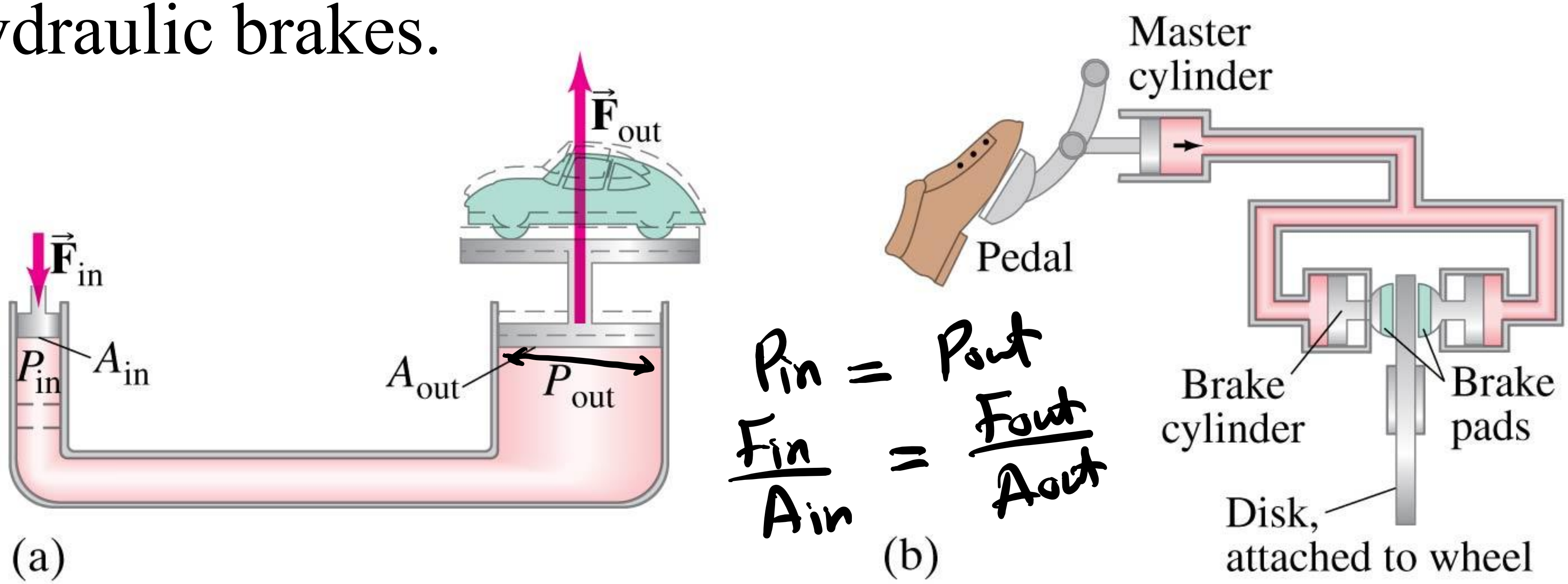
inside fluid at depth h

$$P = P_A + \rho g h$$

10-5 Pascal's Principle

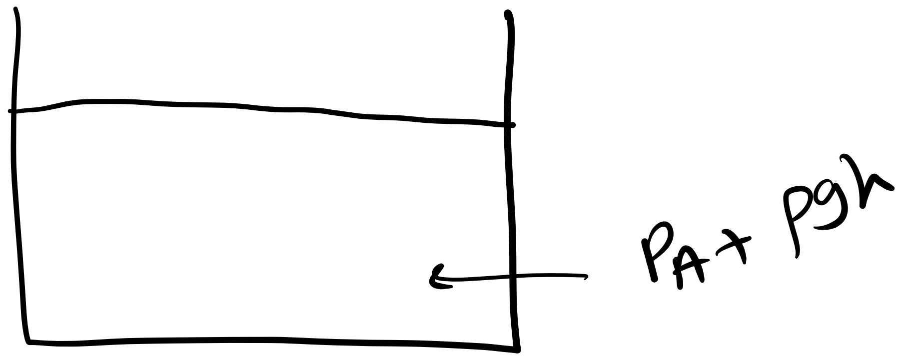
If an external pressure is applied to a confined fluid, the pressure at every point within the fluid increases by that amount.

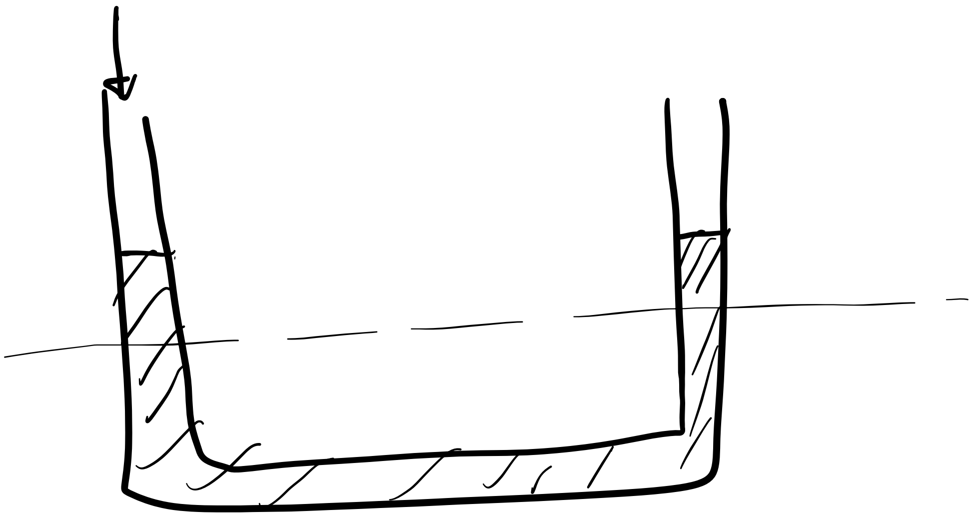
This principle is used, for example, in hydraulic lifts and hydraulic brakes.

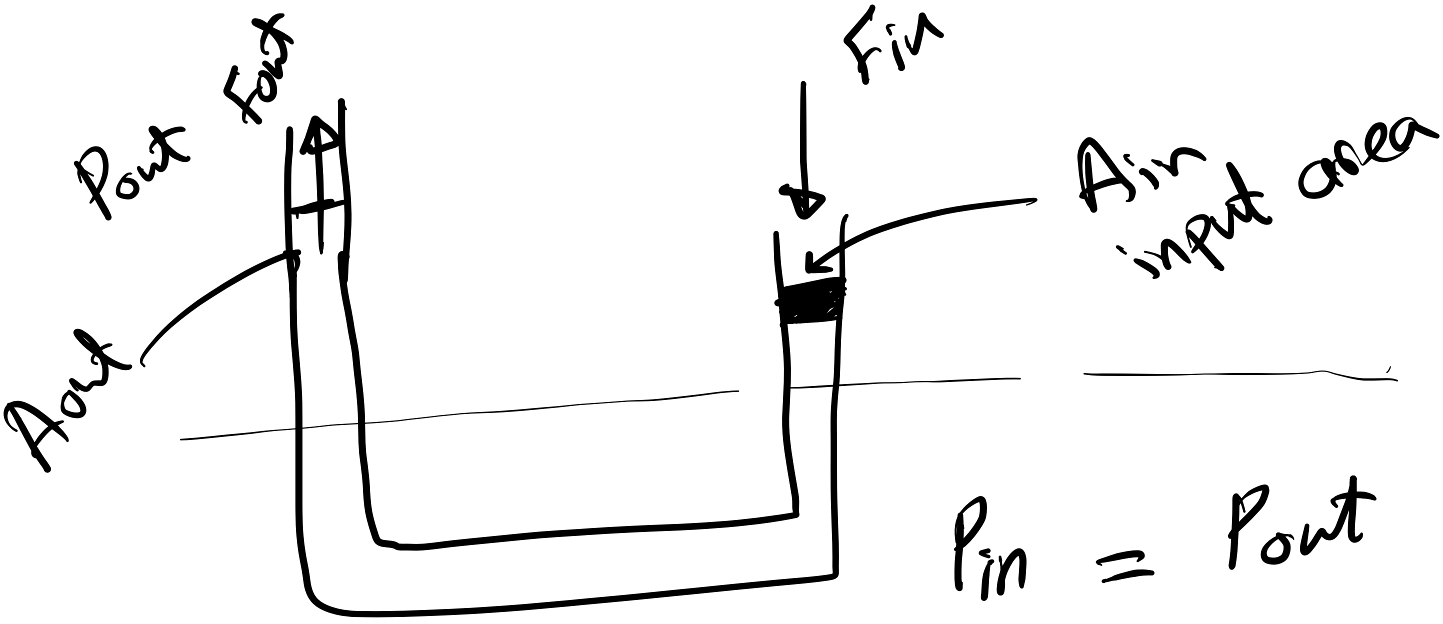


$P_{in} = P_{out}$

$\frac{F_{in}}{A_{in}} = \frac{F_{out}}{A_{out}}$

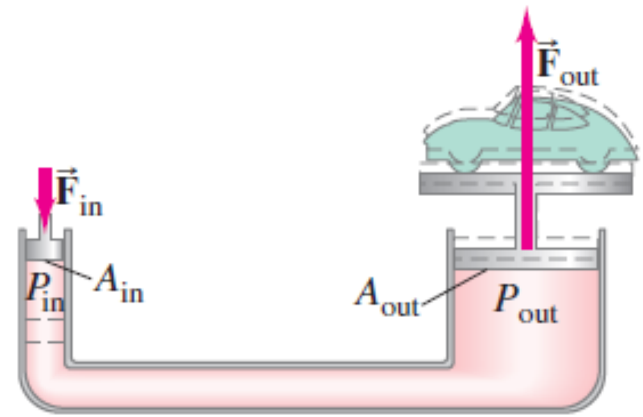






$$P_{in} = P_{out}$$

$$\frac{F_{in}}{A_{in}} = \frac{F_{out}}{A_{out}}$$



(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?

$$P_{in} = P_{out}$$

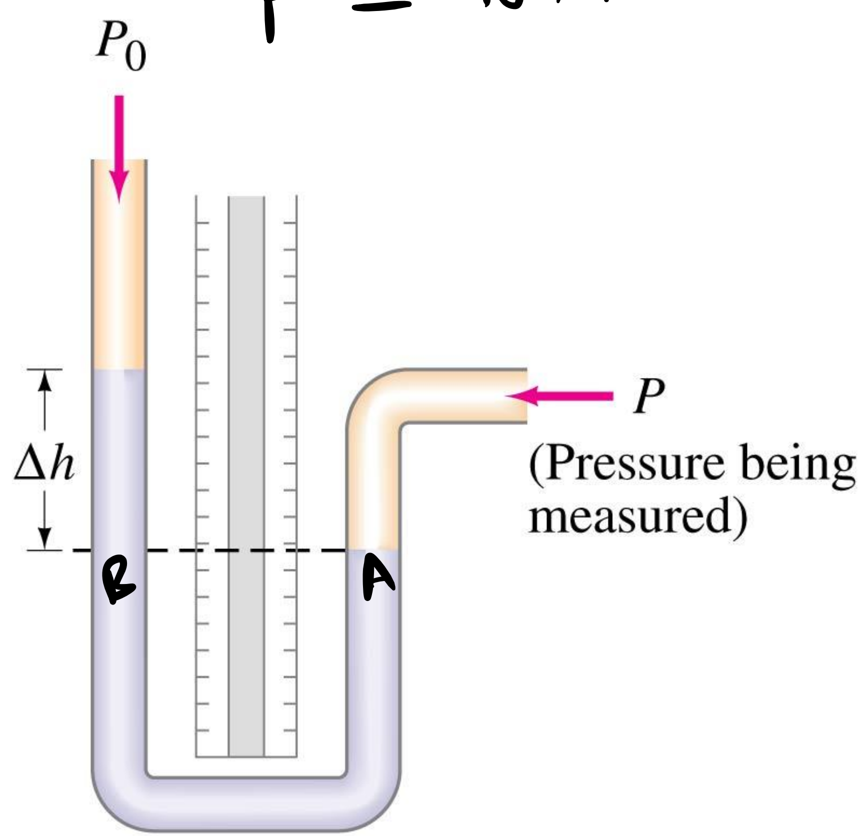
$$17 \times 1.03 \times 10^{5} = \frac{F_{out}}{\pi\left(\frac{25.5}{2} \times 10^{-2}\right)^2}$$

$$F_{out} \simeq 84000\ N \Rightarrow M = \frac{84000}{9.8} \simeq 8500\ kg$$

10-6 Measurement of Pressure; Gauges and the Barometer

$P_A = P_B$

$P = P_0 + \rho g \Delta h$



(a) Open-tube manometer

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.

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.

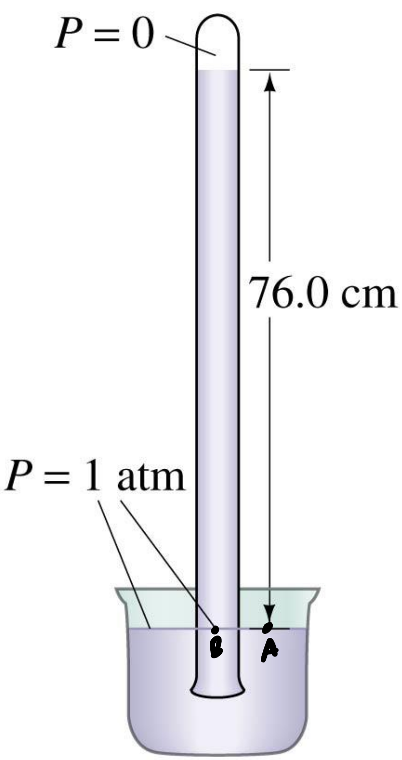
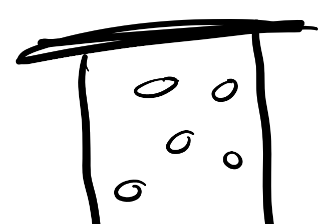


TABLE 10–2 Conversion Factors Between Different Units of Pressure

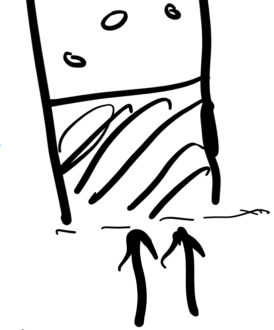
In Terms of $1\ \text{Pa} = 1\ \text{N/m}^2$	1 atm in Different Units
$1\ \text{atm} = 1.013 \times 10^5\ \text{N/m}^2$ $= 1.013 \times 10^5\ \text{Pa} = 101.3\ \text{kPa}$	$1\ \text{atm} = 1.013 \times 10^5\ \text{N/m}^2$
$1\ \text{bar} = 1.000 \times 10^5\ \text{N/m}^2$	$1\ \text{atm} = 1.013\ \text{bar}$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

$$P_A = P_B$$

$$P_{atm} = \rho g h$$



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?]



$$P_a = P_b$$

$$P_{atm} + \rho_{oil}\, g\, h_{oil} = P_{atm} + \rho_w\, g\, h_w$$

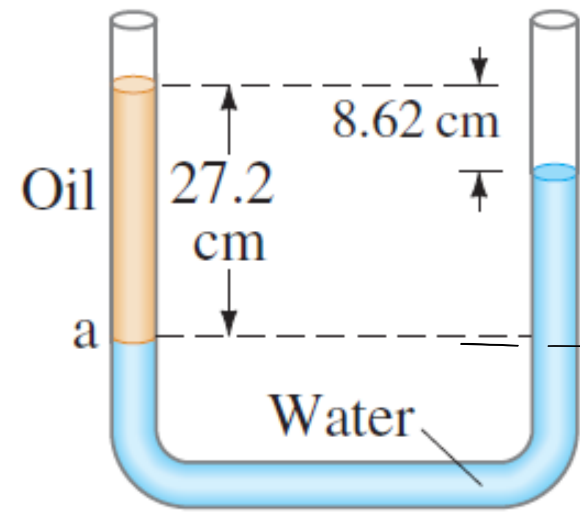


FIGURE 10–50
Problem 18.

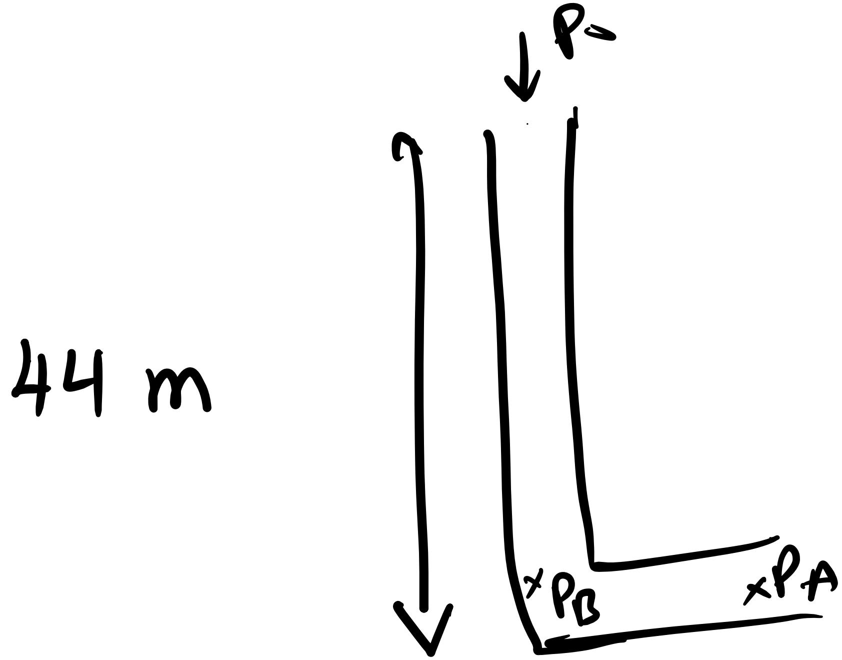
$$h_w = 27.2 - 8.62$$
$$= 18.58$$

$$\rho_{oil}\, h_{oil} = \rho_w\, h_w$$

$$\rho_{oil} = \frac{\rho_w h_w}{h_{oil}} = \frac{1000 \times 18.52}{27.2}$$

$$= 680 \text{ kg/m}^3$$

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.



$$P_A = P_0 + \rho g h$$

gauge pressure $= \rho g h$

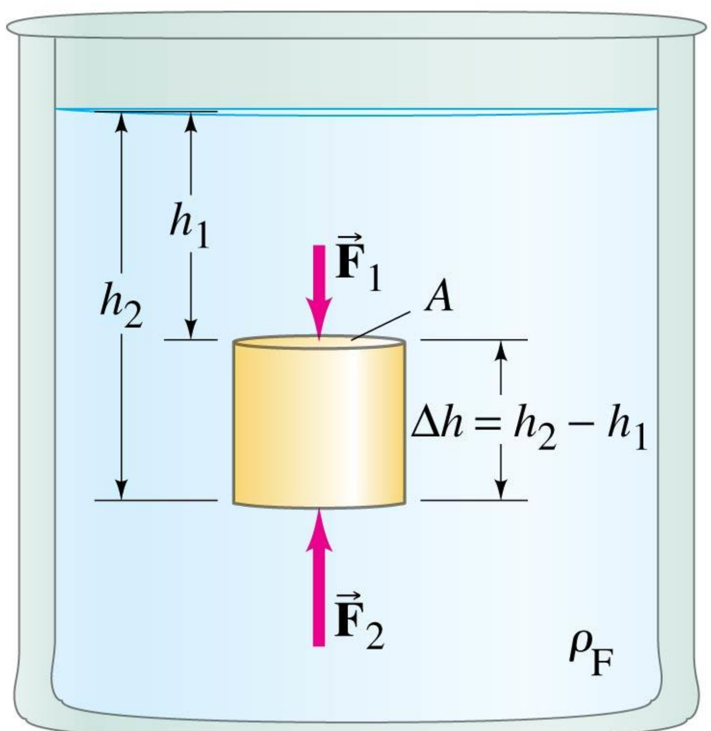
$$= 1000 \times 9.8 \times 44$$

$$\simeq 4.3 \text{ atm}$$

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.

$P_2 = \rho g h_2$



$F = PA$

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

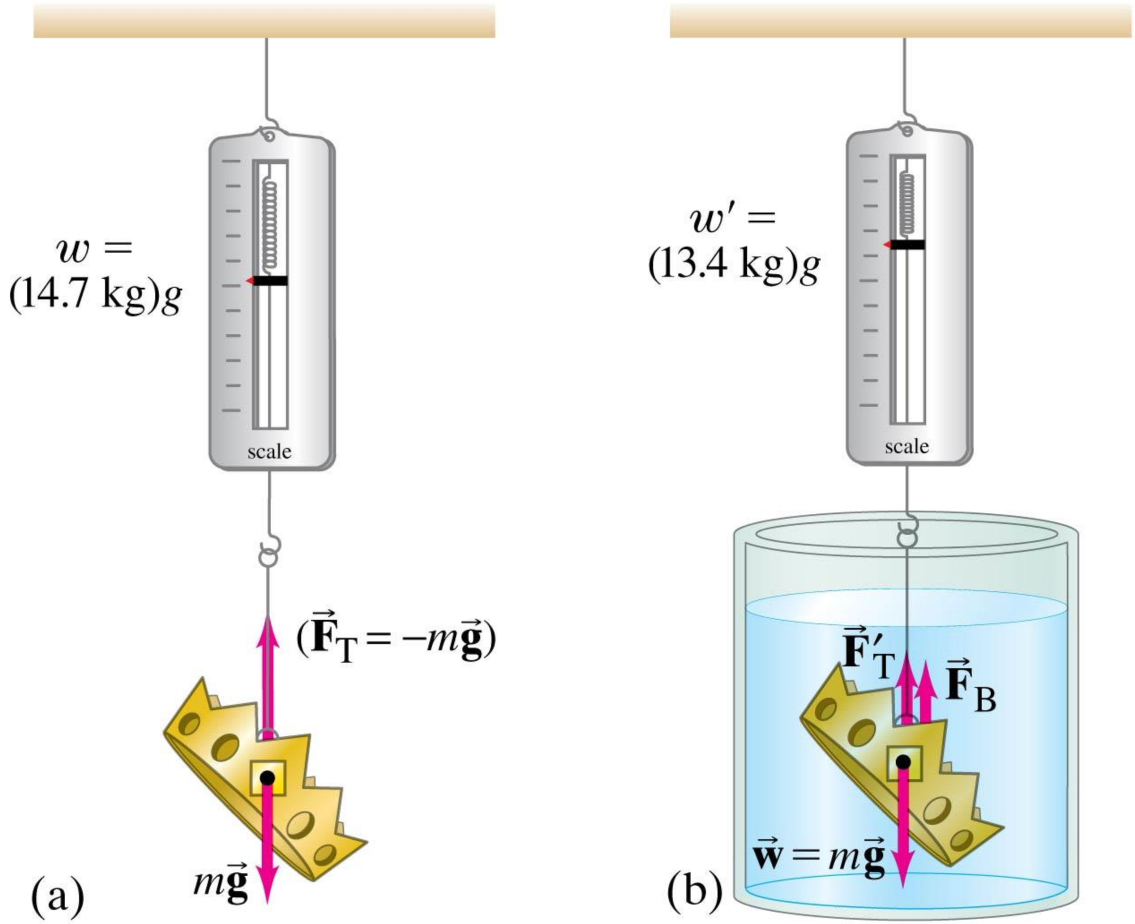
$= P_2 A - P_1 A = \rho_F g h_2 A - \rho_F g h_1 A$

$$F_B = F_2 - F_1 = \rho_F g A (h_2 - h_1)$$
$$= \rho_F g A \Delta h$$
$$= \rho_F V g$$
$$= m_F g,$$

$\rho_F V_{obj} g$

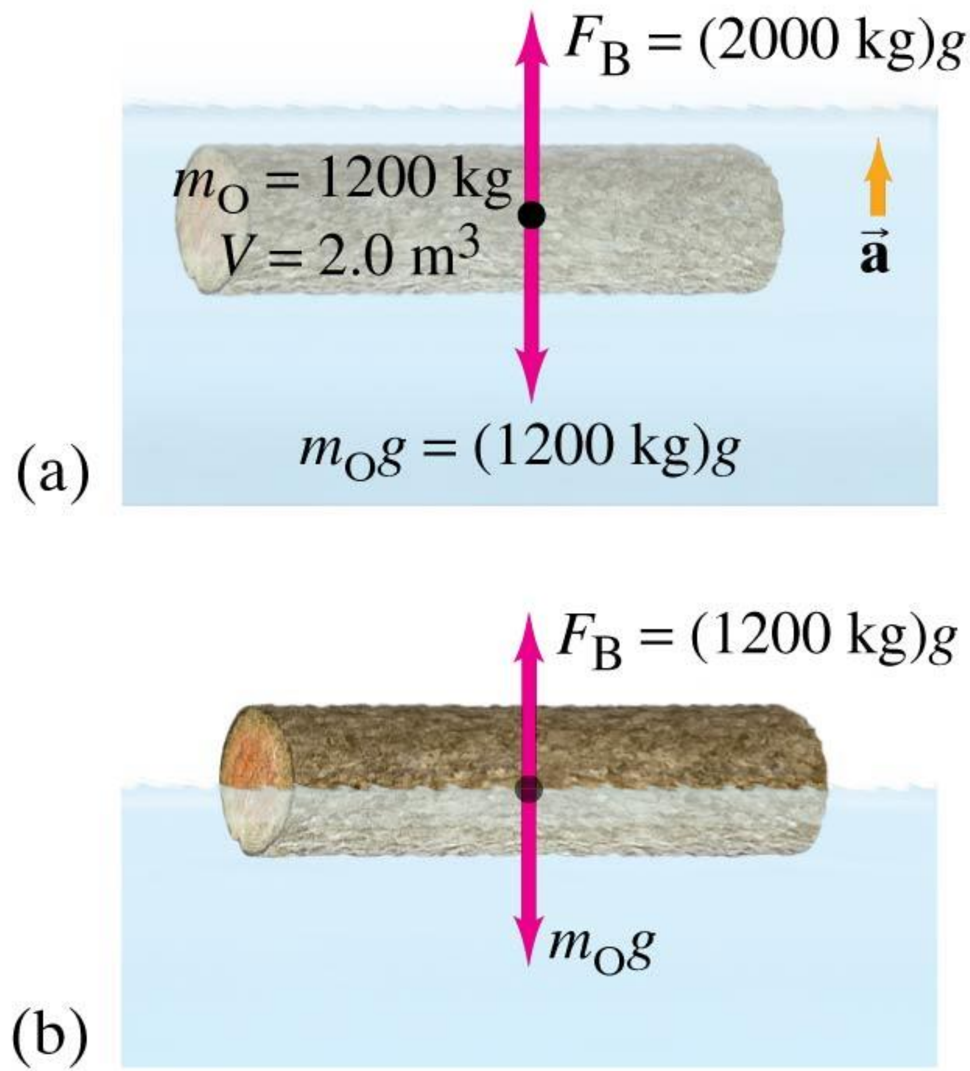
10-7 Buoyancy and Archimedes' Principle

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 cm^3 How much force is needed to lift it (without acceleration)?

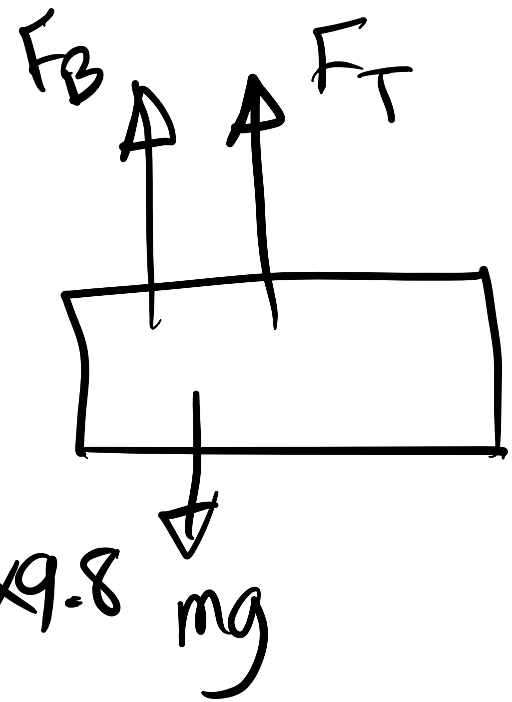
$$F_T + F_B - mg = 0$$

$$F_T = mg - F_B$$

$$= mg - \rho_F V_{obj}\, g$$

$$= 70 \times 9.8 - 1000 \times 30000 \times 10^{-6} \times 9.8$$

$$= 392\ N$$



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?

$$W = 14.7(g) = 14.7(9.8)$$

$$W' = 13.4(g) = 13.4(9.8)$$

$$F_B = W - W' = 1.3(9.8) = 12.74\ N$$

$$\rho_F = 1000$$

$$g = 9.8$$

$$12.74 = \rho_F V_{obj}\, g$$

$$14.7 = \rho_{obj} V_{obj}$$

$$\div$$

$$\frac{12.74}{14.7} = \frac{\rho_F\, g}{\rho_{obj}} \Rightarrow \rho_{obj} = 11300\ kg/m$$

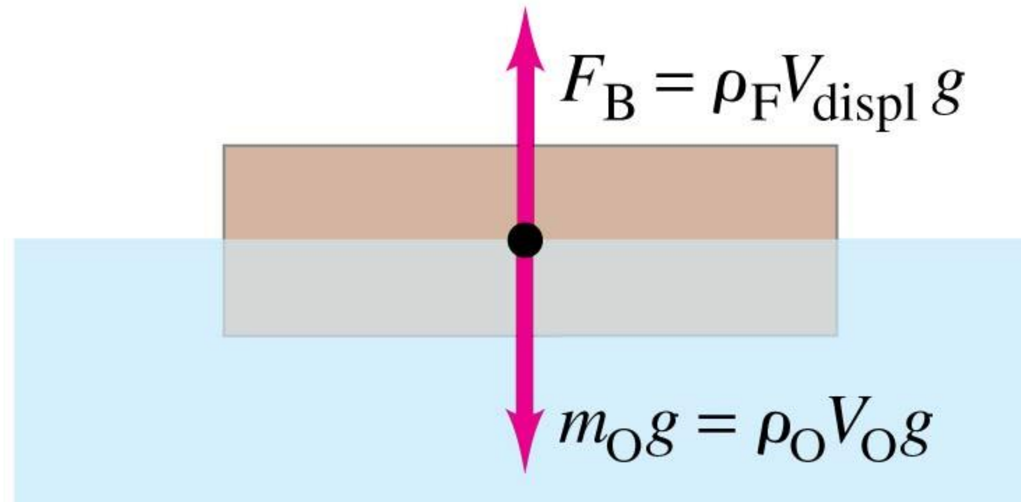
10-7 Buoyancy and Archimedes' Principle

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

$$F_B = mg$$

$$\rho_F V_{disp} g = \rho_{obj} V_{obj} g$$

$$\rho_F V_{disp} = \rho_{obj} V_{obj}$$



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?

$$\rho_F V_{disp} = \rho_{obj} V_{obj}$$

$$\frac{V_{disp}}{V_{obj}} = \frac{\rho_{obj}}{\rho_F}$$

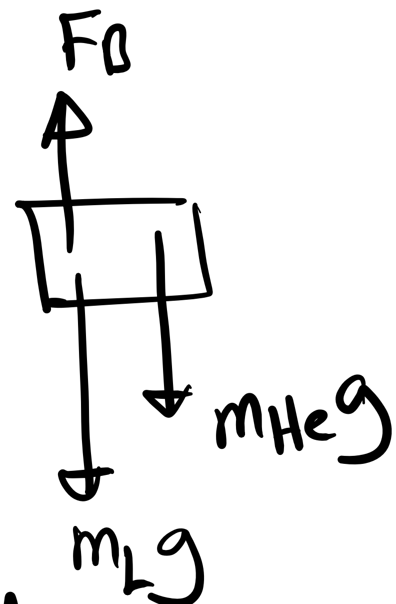
$$= \frac{0.917}{1.025} = 89\%$$

Volume above water = 11%

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)?

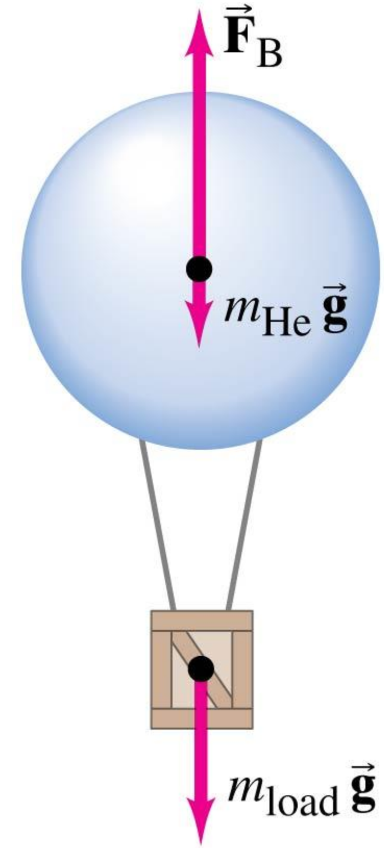
$$F_B = m_L g + m_{He} g$$

$$\rho_F V_{obj} g = m_L g + \rho_{He} V_{obj} g$$



$$(1.29) V_{obj} = 180 + 0.179 V_{obj}$$

$$V_{obj} = 162 \text{ m}^3$$



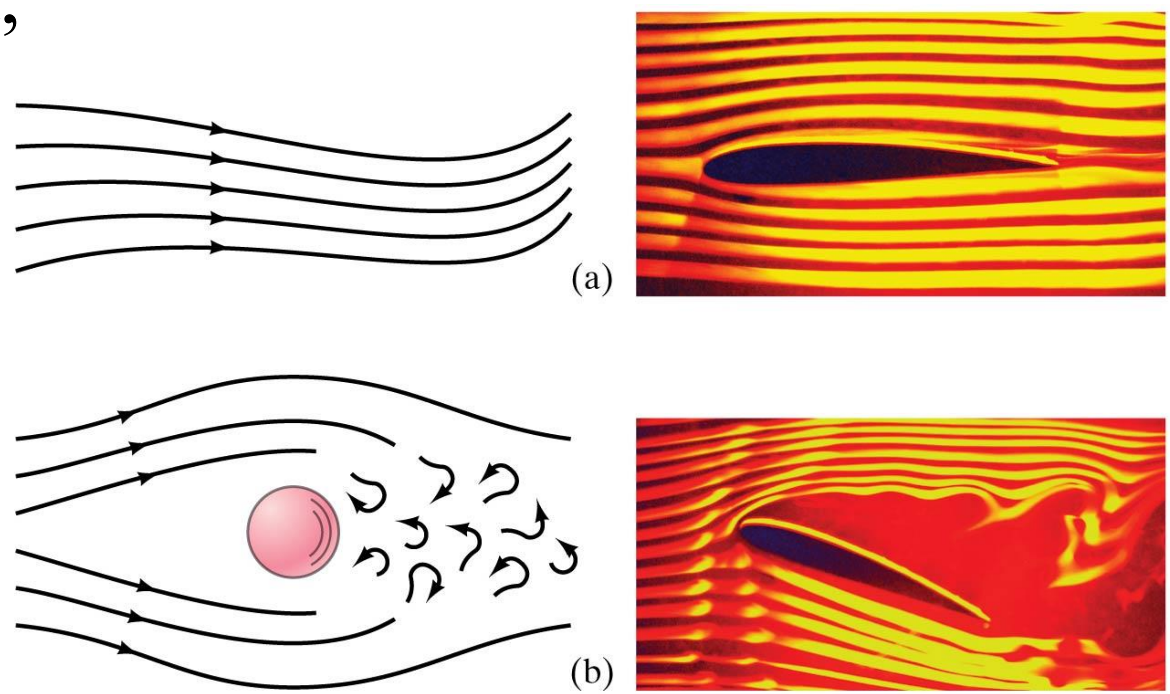
$\rho_{He} = 0.179$ kg/m³

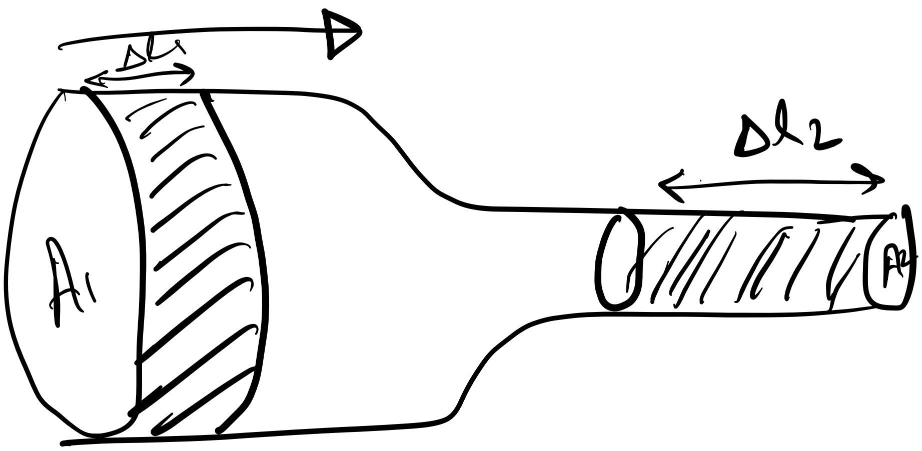
$\rho_{air} = 1.29$ kg/m³

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.





$$\Delta m_1 = \Delta m_2$$

$$\rho \Delta V_1 = \rho \Delta V_2$$

$$\rho A_1 \Delta l_1 = \rho A_2 \Delta l_2$$

Δt : time required by Δm_1 to occupy volume ΔV_1

= time required by Δm_2 to occupy volume ΔV_2

$$\rho A_1 \Delta l_1 = \rho A_2 \Delta l_2$$

divide by Δt

$$\rho A_1 \frac{\Delta l_1}{\Delta t} = \rho A_2 \frac{\Delta l_2}{\Delta t}$$

$$\cancel{\rho} A_1 v_1 = \cancel{\rho} A_2 v_2$$

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

Volume flow rate → $Av = m^2 \cdot \frac{m}{s} = \frac{m^3}{s}$

mass flow rate → $\rho A v = \frac{kg}{m^3} \cdot \frac{m^3}{s} = \frac{kg}{s}$

We will deal with laminar flow.

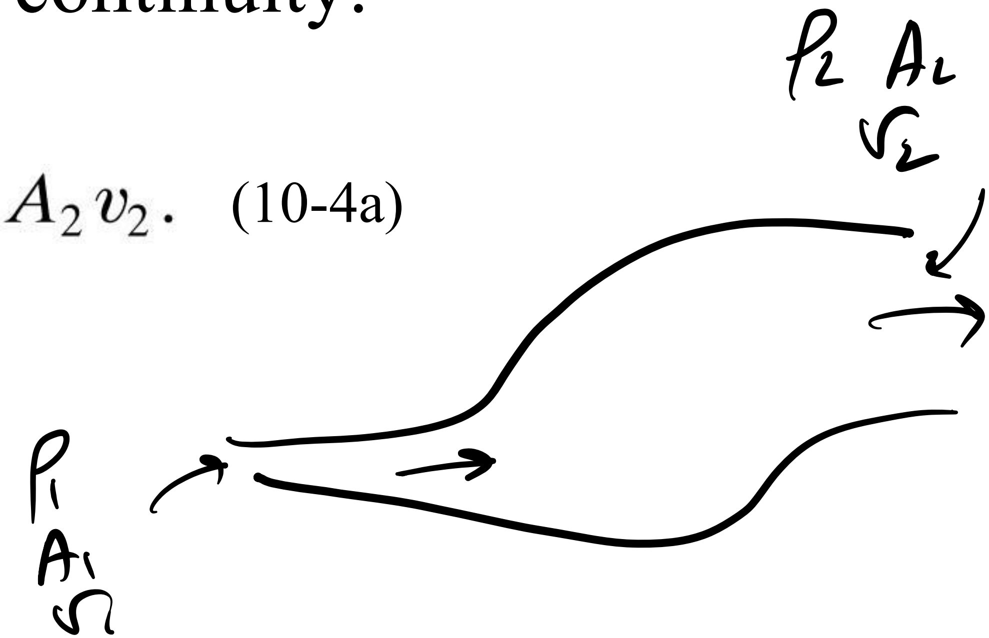
The ~~mass flow rate~~ is the mass that passes a given point per unit time. The flow rates at any two points must be equal, as long as no fluid is being added or taken away.

This gives us the equation of continuity:

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

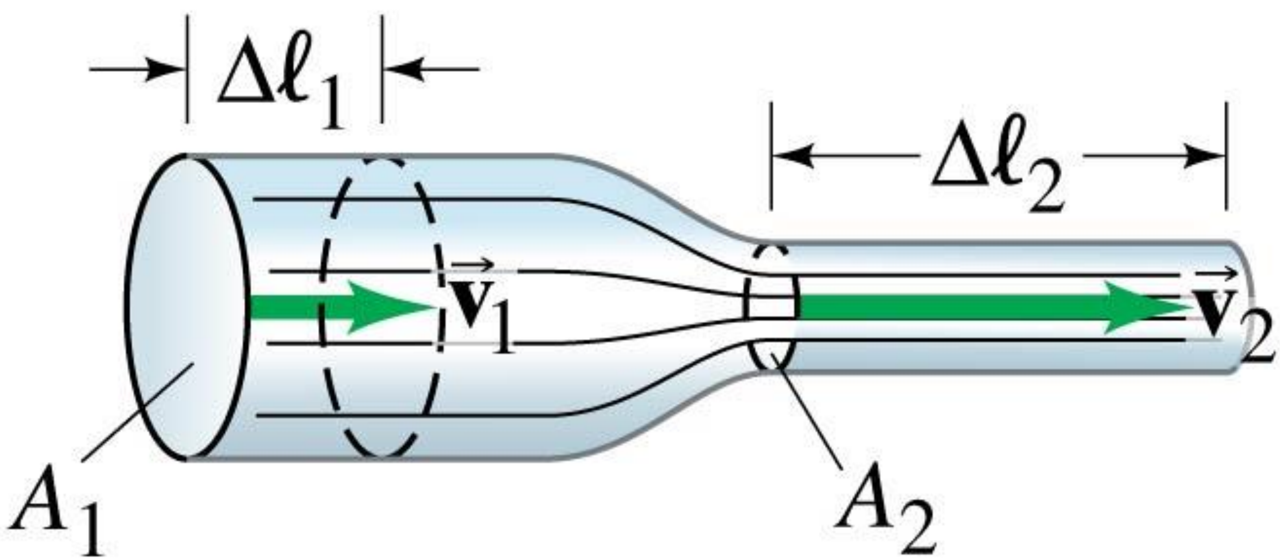
if $\rho_1 = \rho_2$

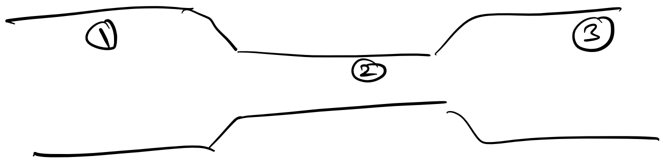
$$A_1 v_1 = A_2 v_2$$



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.





$A_1 = 0.1\ m^2$

$A_2 = 0.05\ m^2$

$v_1 = 4\ m/s$

$v_2 = ?$

$A_1 v_1 = A_2 v_2$

$(0.1)(4) = (0.05) v_2$

$v_2 = 8\ m/s$

if $v_3 = 6\ m/s$

what is A_3?

$A_1 v_1 = A_3 v_3$

$(0.1)(4) = (A_3)\, 6$

$A_3 = \frac{0.4}{6}\ m^2 = 0.067\ m^2$

what is volume flow rate in the tube

volume flow rate $= A_1 v_1$

OR

$A_2 v_2$

OR

$A_3 v_3$

$= 0.4\ m^3/s$

if the mass flow rate is 40 kg/s

what is ρ?

mass flow rate $= \rho \times$ volume flow rate

$40 = \rho\,(0.4)$

$\rho = 100\ kg/m^3$

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 4×10^{-4} cm, and blood flows through it at a speed of about 5×10^{-4} m/s. Estimate the number of capillaries that are in the body.

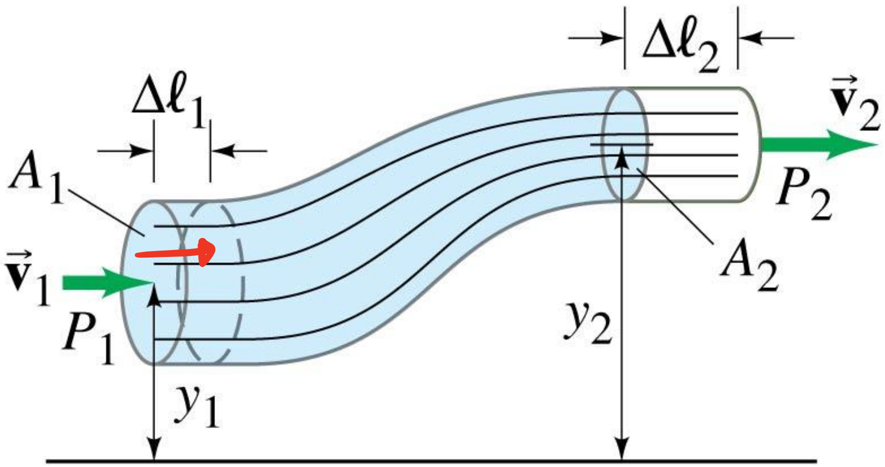
$$A_1 v_1 = n A_2 v_2$$

$$\pi (1.2)^2 \cdot 0.4 = n\, \pi (4\times10^{-4})^2 (5\times10^{-4})$$

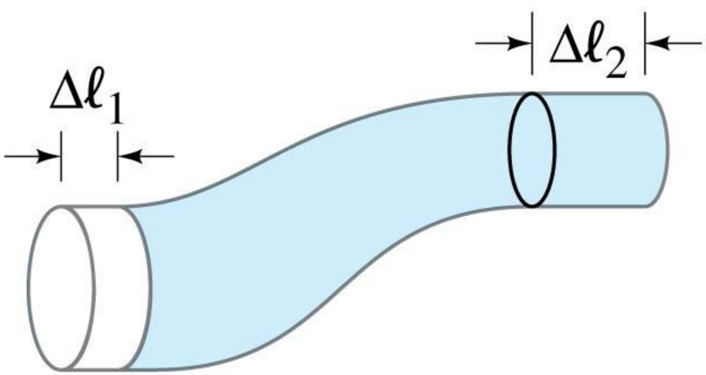
$$n = \frac{(1.2)^2 (0.4)}{16\times10^{-8} \times 5\times10^{-4}}$$

$$= 7.2\times10^{9}$$

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:

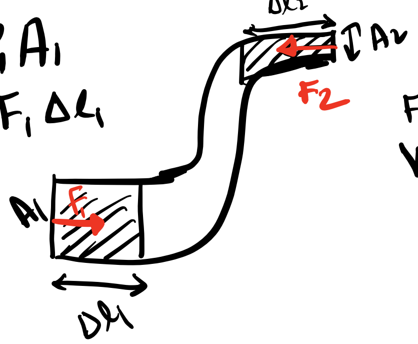
$$P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2 = P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 . \quad (10\text{-}5)$$

$A_1 v_1 = A_2 v_2$

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

$F_1 = P_1 A_1$

$W_1 = F_1 \Delta l_1$



$A_1 \Delta l_1 = A_2 \Delta l_2$

$F_2 = P_2 A_2$

$W_2 = -F_2 \Delta l_2$

$$W_{NC} = F_1 \Delta l_1 - F_2 \Delta l_2$$
$$= P_1 A_1 \Delta l_1 - P_2 A_2 \Delta l_2$$
$$= P_1 V - P_2 V$$

$$W_{NC} = \Delta E_k + \Delta PE$$

$$\frac{P_1 V}{V} - \frac{P_2 V}{V} = \frac{1}{2}\frac{m v_2^2}{V} - \frac{1}{2}\frac{m v_1^2}{V} + \frac{m g y_2}{V} - \frac{m g y_1}{V}$$

$$P_1 - P_2 = \frac{1}{2}\rho v_2^2 - \frac{1}{2}\rho v_1^2 + \rho g y_2 - \rho g y_1$$

$$\boxed{P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2}$$

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 m/s through a 4.0-cm-diameter pipe in the basement under a pressure of 3.0 atm, what will be the flow speed and pressure in a 2.6-cm-diameter pipe on the second floor 5.0 m above? Assume the pipes do not divide into branches.

$P = 3\,atm$

$A_1 v_1 = A_2 v_2$

$\pi (2)^2 0.5 = \pi (1.3)^2 v_2$

$v_2 = 1.18\,m/s$

$P_1 = 3\,atm$

$v_1 = 0.5\,m/s$

$r_1 = 2\,cm$

$y_1 = 0$

$P_2 = ?$

$v_2 = ?$

$r_2 = 1.3\,cm$

$y_2 = 5\,m$

$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$

$3 \times 1.03 \times 10^5 + \frac{1}{2} \times 1000 \times 0.5^2 + 0$

$= P_2 + \frac{1}{2} \times 1000 \times 1.18^2 + 1000 \times 9.8 \times 5$

$P_2 =$

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:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$

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

$A_2 \gg A_1$

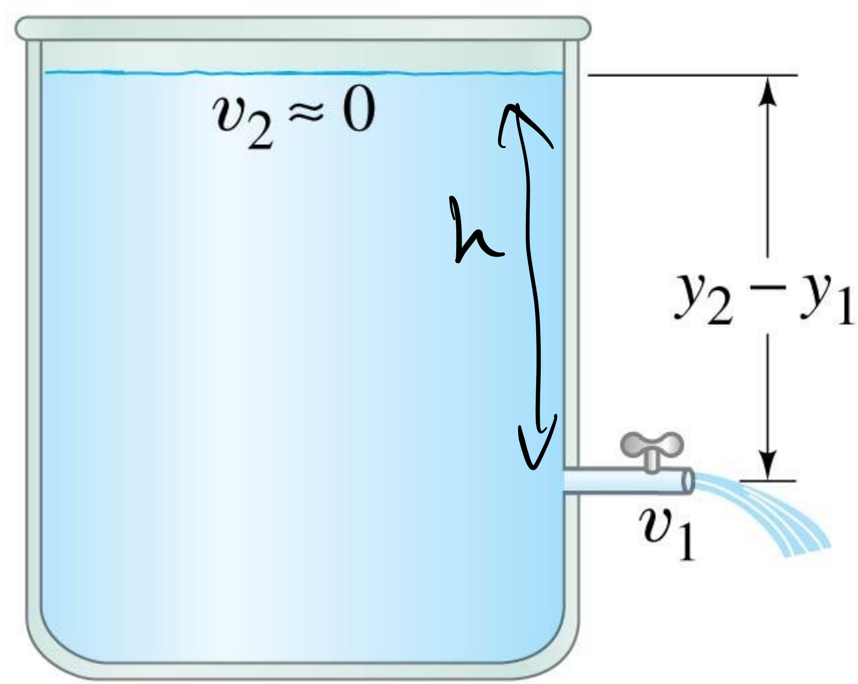
$v_2 \ll v_1$

or

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

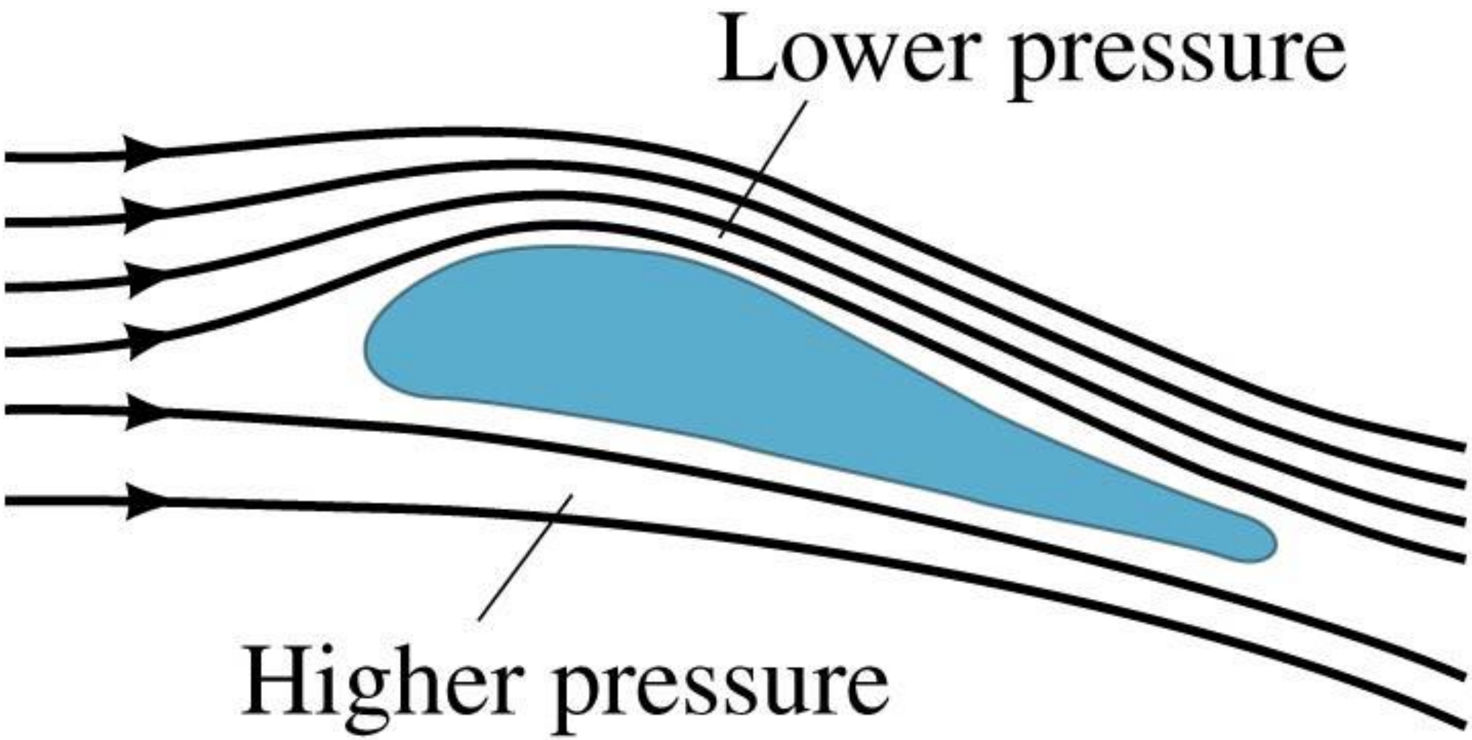
$$v_1 = \sqrt{2gh}$$

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

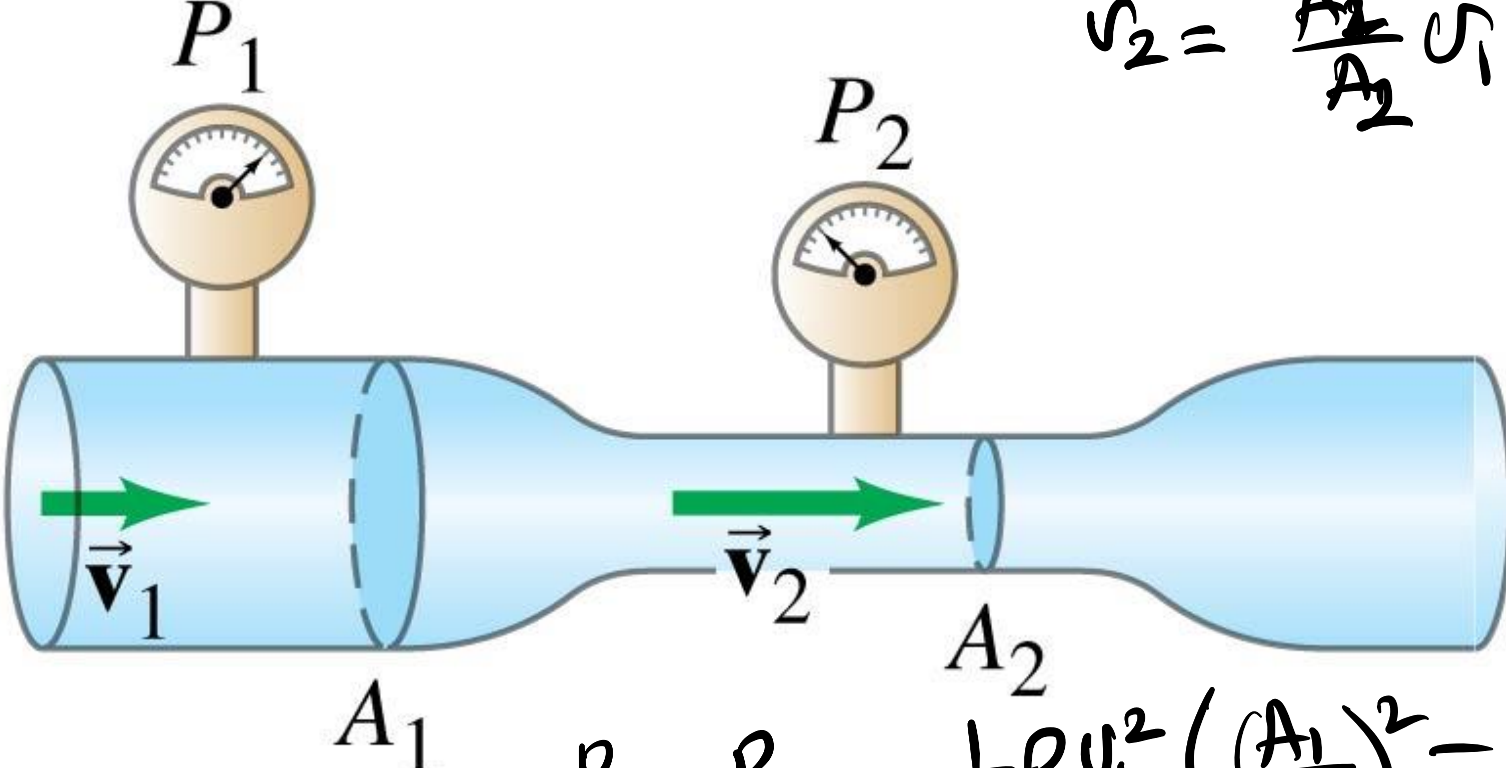
$$P_1 + \frac{1}{2}\rho v_1^2 + \cancel{\rho g y_1} = P_2 + \frac{1}{2}\rho v_2^2 + \cancel{\rho g y_2}$$

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

$$P_1 - P_2 = \frac{1}{2}\rho v_2^2 - \frac{1}{2}\rho v_1^2$$

$$A_1 v_1 = A_2 v_2$$

$$v_2 = \frac{A_1}{A_2} v_1$$



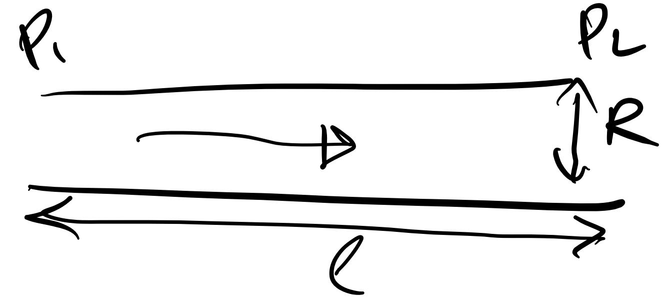
$$P_1 - P_2 = \frac{1}{2}\rho v_1^2\left(\left(\frac{A_1}{A_2}\right)^2 - 1\right)$$

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.

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



unit m^3/s

***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.

$$Q_1 = \frac{\pi (R_1)^4 (P_1 - P_2)}{8 \eta l}$$

$$Q_2 = \frac{\pi (R_2)^4 (P_1 - P_2)}{8 \eta l}$$

$$\frac{Q_2}{Q_1} = \frac{\pi R_2^4 (P_1 - P_2)}{8 \eta l} \cdot \frac{8 \eta l}{\pi R_1^4 (P_1 - P_2)}$$

$$= \left(\frac{R_2}{R_1}\right)^4 = \left(\frac{\frac{5}{16}}{\frac{3}{16}}\right)^4 = \frac{625}{81}$$

$$Q_1 = \frac{V}{\Delta t_1} \Rightarrow \Delta t_1 = \frac{V}{Q_1}$$

$$Q_2 = \frac{V}{\Delta t_2} \Rightarrow \Delta t_2 = \frac{V}{Q_2}$$

$$\frac{\Delta t_2}{\Delta t_1} = \frac{Q_1}{Q_2} = \frac{81}{625}$$

*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 cm^3 of blood per minute. How high h should the bottle be placed above the needle? Obtain ρ and η from the Tables. Assume the blood pressure is 78 torr above atmospheric pressure.

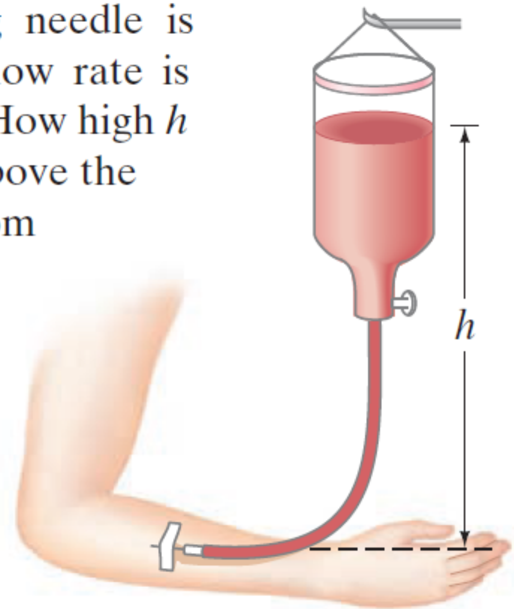


FIGURE 10–54
Problem 60.

$l = 25\times10^{-3}$ m
$R = 0.4\times10^{-3}$ m
$Q = \frac{2\times10^{-6}}{60} = 0.033\times10^{-6}$ m^3/s
$P_2 = 78\times133$ Pa
$\rho = 1.05\times10^{3}$ kg/m^3
$\eta = 4\times10^{-3}$ Pa.s

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

$$0.033\times10^{-6} = \frac{\pi(0.4\times10^{-3})^4 (P_1 - P_2)}{8\times4\times10^{-3}\times25\times10^{-3}}$$

$P_1 - P_2 \simeq 330$ Pa

$P_1 - 78\times133 = 330$
$P_1 \simeq 10\,700$ Pa
$P_1 = \rho g h$
$10700 = 1.05\times9.8\times h$
$h \sim 1$m

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.

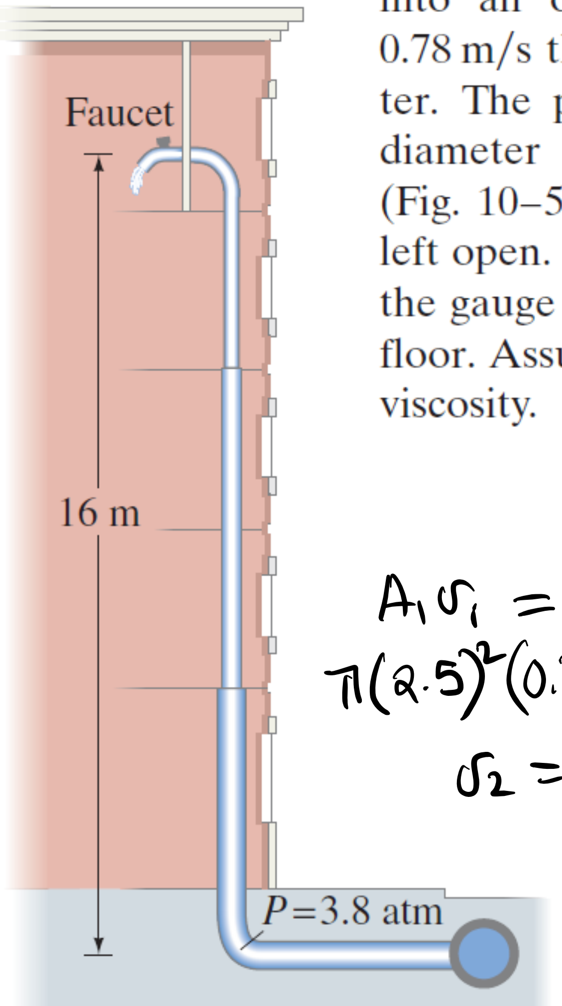


FIGURE 10–53 Problem 48.

$P_1 = 3.8 \times 1.03 \times 10^5$ Pa
$y_1 = 0$
$v_1 = 0.78$ m/s
$R_1 = 2.5$ cm
$P_2 = ?$
$y_2 = 16$ m
$v_2 = ?$
$R_2 = 1.4$ cm

$$A_1 v_1 = A_2 v_2$$
$$\pi(2.5)^2(0.78) = \pi(1.4)^2 v_2$$
$$v_2 = 2.5 \text{ m/s}$$

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$
$$3.8 \times 1.03 \times 10^5 + \frac{1}{2} \times 1000 \times 0.78^2 + 0$$
$$= P_2 + \frac{1}{2} \times 1000 \times 2.5^2 + 1000 \times 9.8 \times 16$$
$$P_2 \simeq 2.2 \text{ atm}$$

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.

$b = 930\,kg$

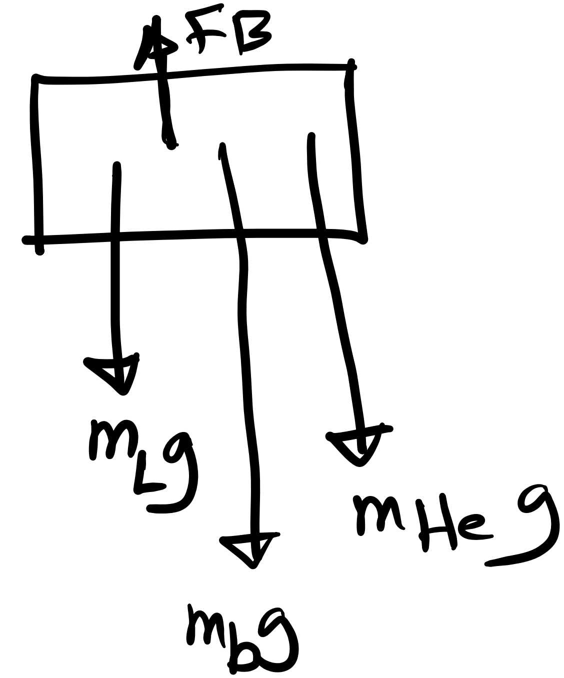
$$F_B = m_L g + m_b g + m_{He} g$$

$$\rho_{air} V_{obj} g = m_L g + m_b g + \rho_{He} V_{obj} g$$

$$m_L = (\rho_{air} - \rho_{He}) V_{obj} - m_b$$

$$= (1.27 - 0.179)\left(\frac{4}{3}\right)(\pi)(7.15)^3 - 930$$

$$= 740\ kg$$



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° 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?

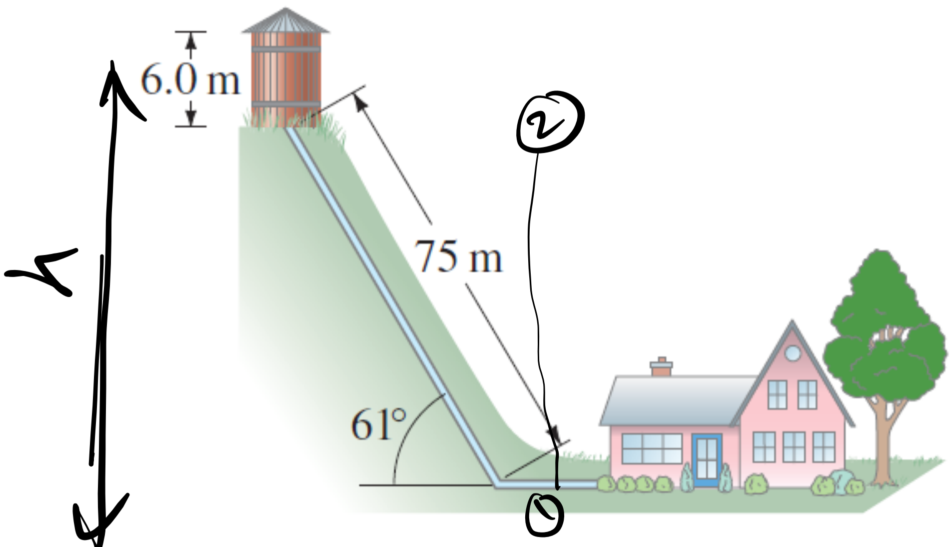


FIGURE 10–49 Problem 17.

$h = 6 + 75\sin 61$

$= 71.6$

$P = \rho g h$

$= 1000 \times 9.8 \times 71.6$

$= 7.1 \times 10^5$ Pa

$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$

$P_1 = P_2 =$ atmospheric pressure

$\frac{1}{2}\rho v_1^2 = \rho g y_2$

$y_2 = \frac{v_1^2}{2g}$

but

$$v_1^2 = 2gh$$

$$\therefore \quad y_2 = \frac{v_1^2}{2g} = \frac{\cancel{2g}h}{\cancel{2g}}$$

$$y_2 = h$$

$$= 71.6 \text{ m}$$