ANNOUNCEMENTS

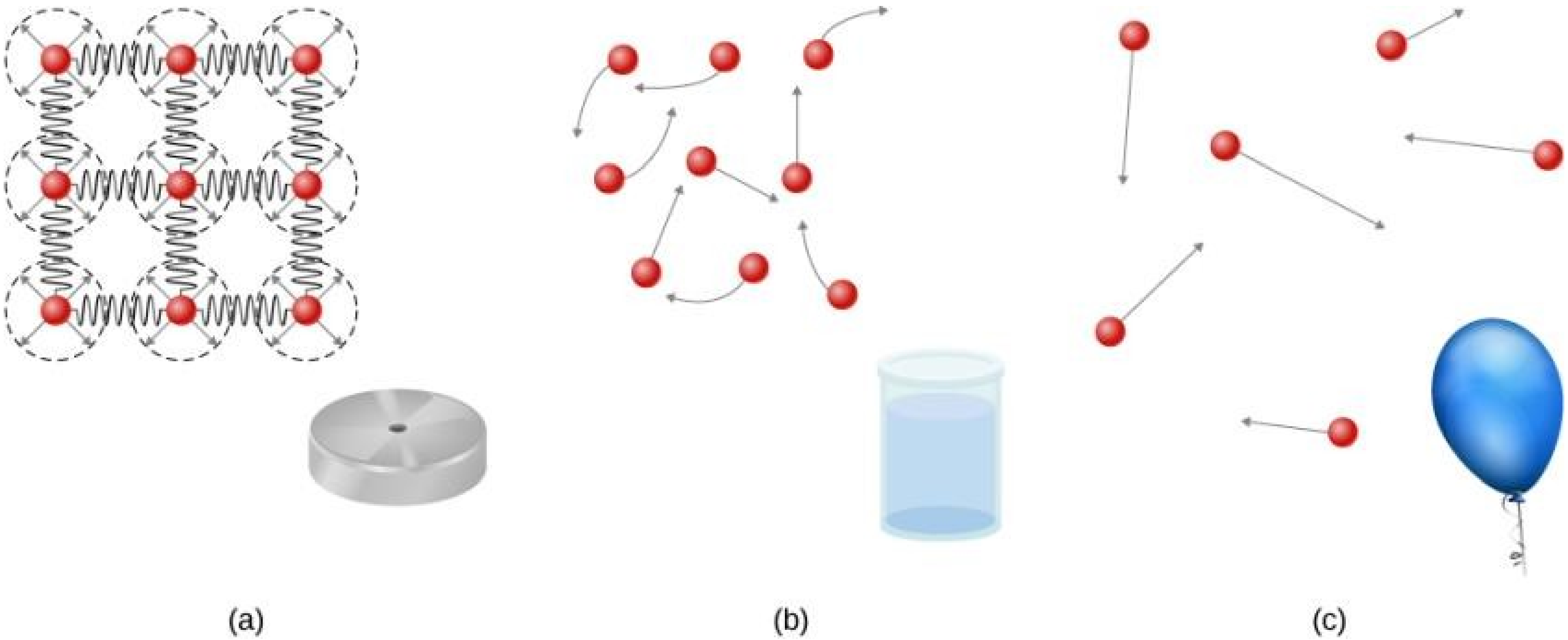
- Homework #14, due Friday, Nov. 28 before class

  Conceptual questions: Chapter 14, #8 and #16
  Problems: Chapter 14, #58, #66

- Study Chapter 14, sections 1 by Wed. November 28

- Quiz #14, Friday November 28 at the beginning of class

CHARACTERISTICS OF FLUIDS



(a) Atoms in a solid are always in close contact with neighboring atoms, held in place by forces represented here by springs.

(b) Atoms in a liquid are also in close contact but can slide over one another. Forces between the atoms strongly resist attempts to compress the atoms.

(c) Atoms in a gas move about freely and are separated by large distances. A gas must be held in a closed container to prevent it from expanding freely and escaping.

DENSITY

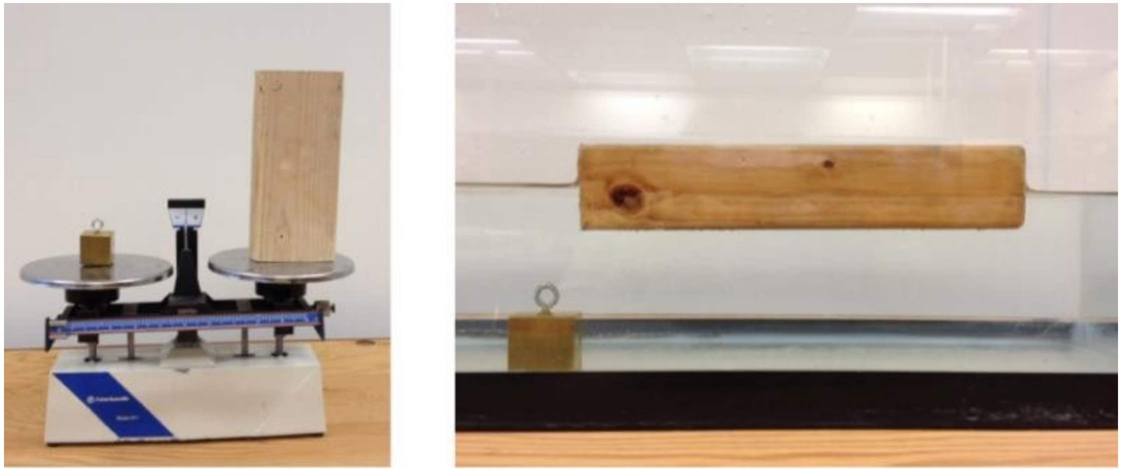
The average density of a substance or object is defined as its mass per unit volume,

$$\rho = \frac{m}{V} \tag{14.1}$$

where the Greek letter ρ (rho) is the symbol for density, m is the mass, and V is the volume.

The SI unit of density is $\mathrm{kg/m^3}$. Table 14.1 lists some representative values. The cgs unit of density is the gram per cubic centimeter, $\mathrm{g/cm^3}$, where

$$1\ \mathrm{g/cm^3} = 1000\ \mathrm{kg/m^3}.$$

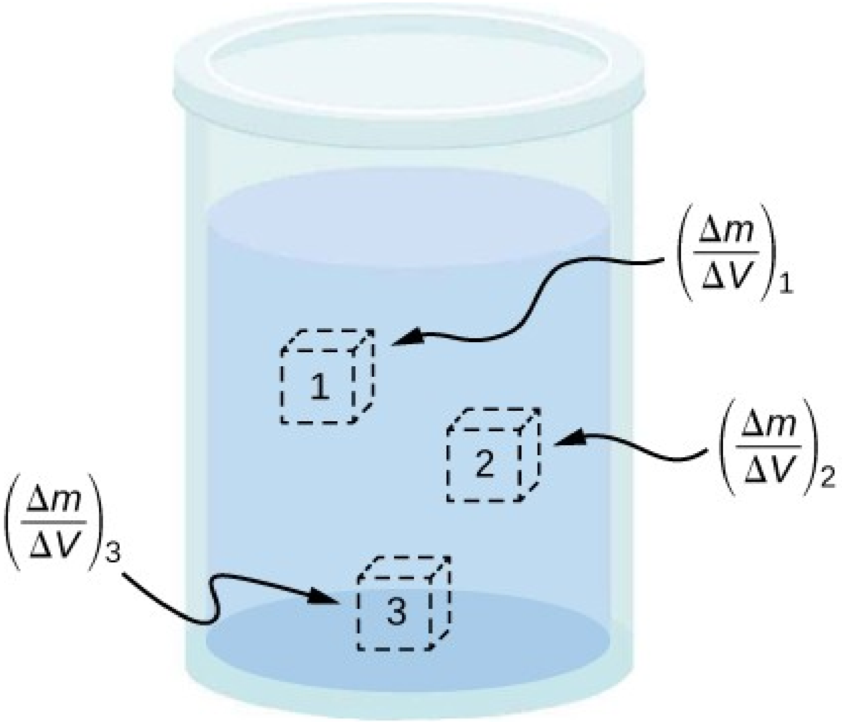


(a) (b)

(a) A block of brass and a block of wood both have the same weight and mass, but the block of wood has a much greater volume.

(b) When placed in a fish tank filled with water, the cube of brass sinks and the block of wood floats. (The block of wood is the same in both pictures; it was turned on its side to fit on the scale.)

$$\rho = \lim_{\Delta V \to 0} \frac{\Delta m}{\Delta V} \tag{14.2}$$



Density may vary throughout a heterogeneous mixture. Local density at a point is obtained from dividing mass by volume in a small volume around a given point.

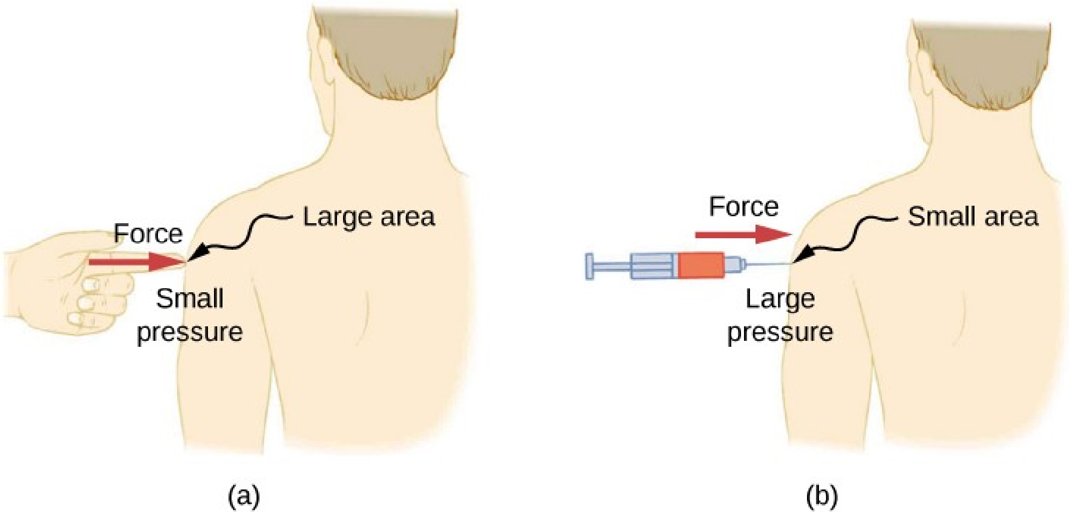
PRESSURE

Pressure (p) is defined as the normal force F per unit area A over which the force is applied, or

$$p = \frac{F}{A}. \quad (14.3)$$

To define the pressure at a specific point, the pressure is defined as the force dF exerted by a fluid over an infinitesimal element of area dA containing the point, resulting in $p = \frac{dF}{dA}$.

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



(a) A person being poked with a finger might be irritated, but the force has little lasting effect.

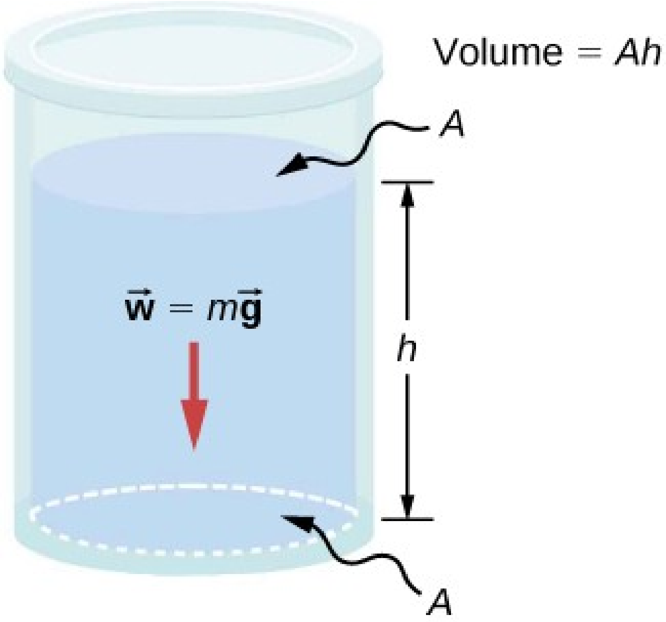
(b) In contrast, the same force applied to an area the size of the sharp end of a needle is enough to break the skin.

PRESSURE AT A DEPTH FOR A FLUID OF CONSTANT DENSITY

The pressure at a depth in a fluid of constant density is equal to the pressure of the atmosphere plus the pressure due to the weight of the fluid, or

$$p = p_0 + \rho h g, \tag{14.4}$$

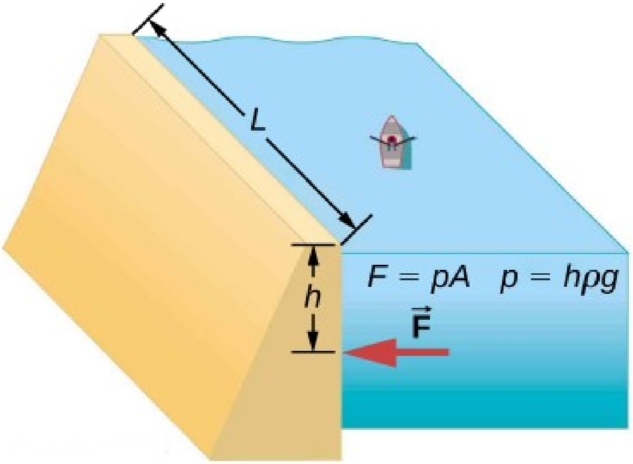
Where p is the pressure at a particular depth, p_0 is the pressure of the atmosphere, ρ is the density of the fluid, g is the acceleration due to gravity, and h is the depth.



The bottom of this container supports the entire weight of the fluid in it. The vertical sides cannot exert an upward force on the fluid (since it cannot withstand a shearing force), so the bottom must support it all.

What Force Must a Dam Withstand?

Consider the pressure and force acting on the dam retaining a reservoir of water (Figure 14.7). Suppose the dam is 500-m wide and the water is 80.0-m deep at the dam, as illustrated below. (a) What is the average pressure on the dam due to the water? (b) Calculate the force exerted against the dam.



a. The average pressure due to the weight of a fluid is

$$p = h\rho g.$$

Entering the density of water from Table 14.1 and taking *h* to be the average depth of 40.0 m, we obtain

$$\begin{aligned} p &= (40.0\ \text{m})\left(10^3\ \frac{\text{kg}}{\text{m}^3}\right)\left(9.80\frac{\text{m}}{\text{s}^2}\right) \\ &= 3.92 \times 10^5\ \frac{\text{N}}{\text{m}^2} = 392\ \text{kPa}. \end{aligned}$$

b. We have already found the value for *p*. The area of the dam is

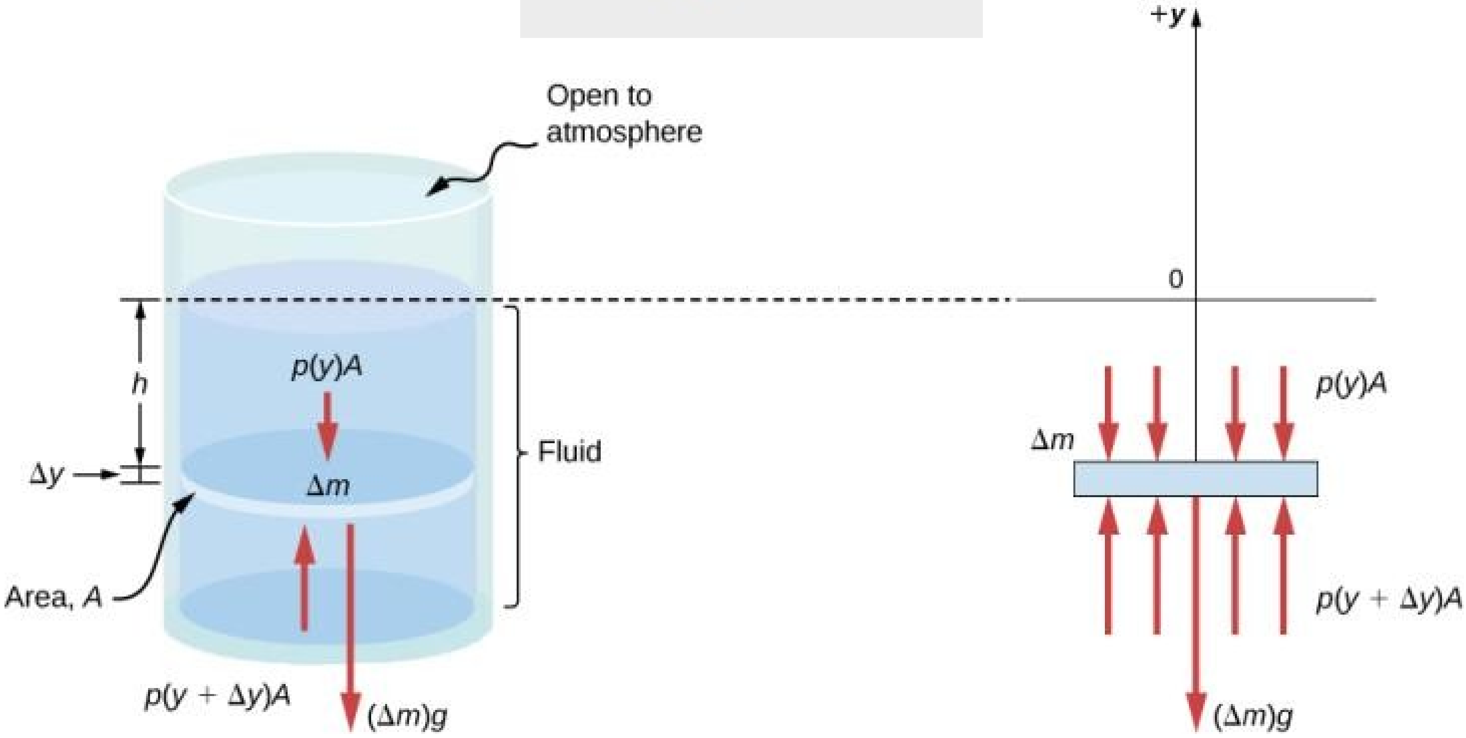
$$A = 80.0\ \text{m} \times 500\ \text{m} = 4.00 \times 10^4\ \text{m}^2,$$

so that

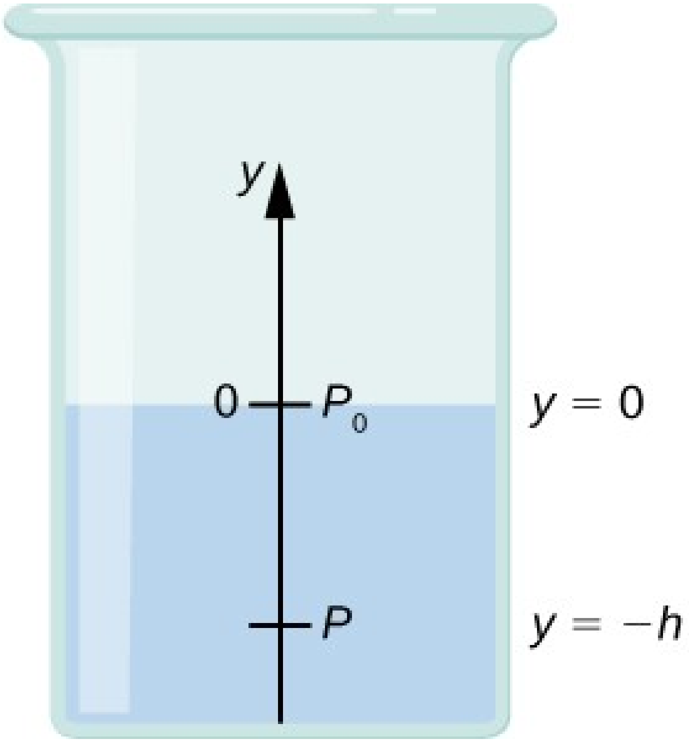
$$\begin{aligned} F &= (3.92 \times 10^5\ \text{N/m}^2)(4.00 \times 10^4\ \text{m}^2) \\ &= 1.57 \times 10^{10}\ \text{N}. \end{aligned}$$

PRESSURE IN A STATIC FLUID IN A UNIFORM GRAVITATIONAL FIELD

$$\frac{dp}{dy} = -\rho g.$$



Forces on a mass element inside a fluid. The weight of the element itself is shown in the free-body diagram.


y
0
P_0
P
y = 0
y = −h

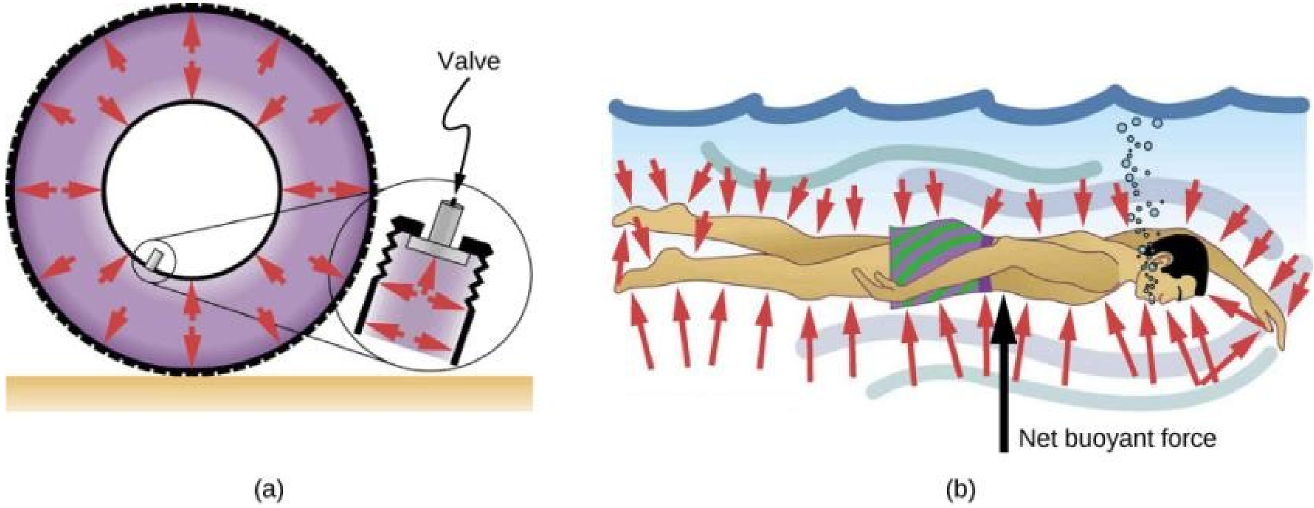
$$p = p_0 + \rho g h.$$

If a fluid can flow freely between parts of a container, it rises to the same height in each part. In the container pictured, the pressure at the bottom of each column is the same; if it were not the same, the fluid would flow until the pressures became equal.

$$p = \rho \frac{k_B T}{m} \text{ (atmosphere)},$$

$$\frac{dp}{dy} = -\rho g.$$

$$\longrightarrow \frac{dp}{dy} = -p\left(\frac{mg}{k_B T}\right), \longrightarrow p(y) = p_0 \exp(-\alpha y).$$



(a) Pressure inside this tire exerts forces perpendicular to all surfaces it contacts. The arrows represent directions and magnitudes of the forces exerted at various points.

(b) Pressure is exerted perpendicular to all sides of this swimmer, since the water would flow into the space he occupies if he were not there. The arrows represent the directions and magnitudes of the forces exerted at various points on the swimmer. Note that the forces are larger underneath, due to greater depth, giving a net upward or buoyant force. The net vertical force on the swimmer is equal to the sum of the buoyant force and the weight of the swimmer.

Most pressure gauges, like the one on the scuba tank, are calibrated to read zero at atmospheric pressure. Pressure readings from such gauges are called **gauge pressure**, which is the pressure relative to the atmospheric pressure. When the pressure inside the tank is greater than atmospheric pressure, the gauge reports a positive value.

ABSOLUTE PRESSURE

The absolute pressure, or total pressure, is the sum of gauge pressure and atmospheric pressure:

$$p_{\text{abs}} = p_{\text{g}} + p_{\text{atm}} \tag{14.11}$$

where p_{abs} is absolute pressure, p_{g} is gauge pressure, and p_{atm} is atmospheric pressure.

(a) (b) (c)

(a) Gauges are used to measure and monitor pressure in gas cylinders. Compressed gases are used in many industrial as well as medical applications.

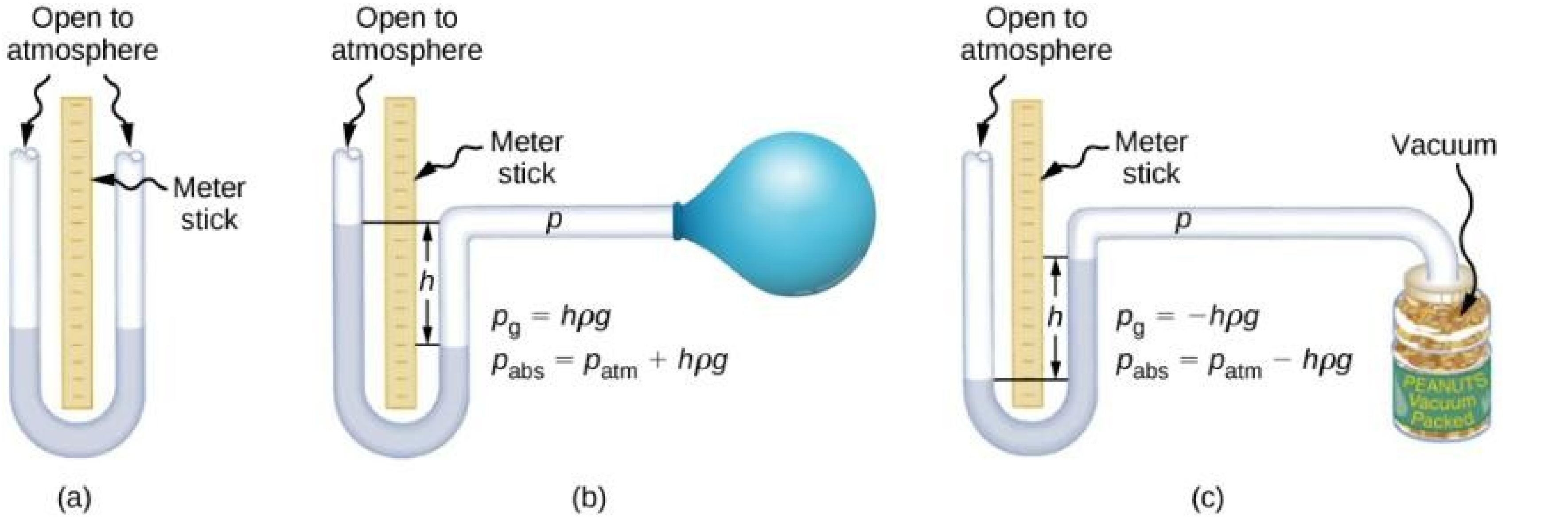
(b) Tire pressure gauges come in many different models, but all are meant for the same purpose: to measure the internal pressure of the tire. This enables the driver to keep the tires inflated at optimal pressure for load weight and driving conditions.

(c) An ionization gauge is a high-sensitivity device used to monitor the pressure of gases in an enclosed system. Neutral gas molecules are ionized by the release of electrons, and the current is translated into a pressure reading. Ionization gauges are commonly used in industrial applications that rely on vacuum systems.

UNITS

SI unit: the Pascal	$1\ \text{Pa} = 1\ \text{N/m}^2$
English unit: pounds per square inch (lb/in.^2 or psi)	$1\ \text{psi} = 6.895 \times 10^3\ \text{Pa}$
Other units of pressure	$1\ \text{atm} = 760\ \text{mmHg}$ $= 1.013 \times 10^5\ \text{Pa}$ $= 14.7\ \text{psi}$ $= 29.9\ \text{inches of Hg}$ $= 1013\ \text{mbar}$
	$1\ \text{bar} = 10^5\ \text{Pa}$
	$1\ \text{torr} = 1\ \text{mm Hg} = 133.3\ \text{Pa}$

MANOMETERS



An open-tube manometer has one side open to the atmosphere.

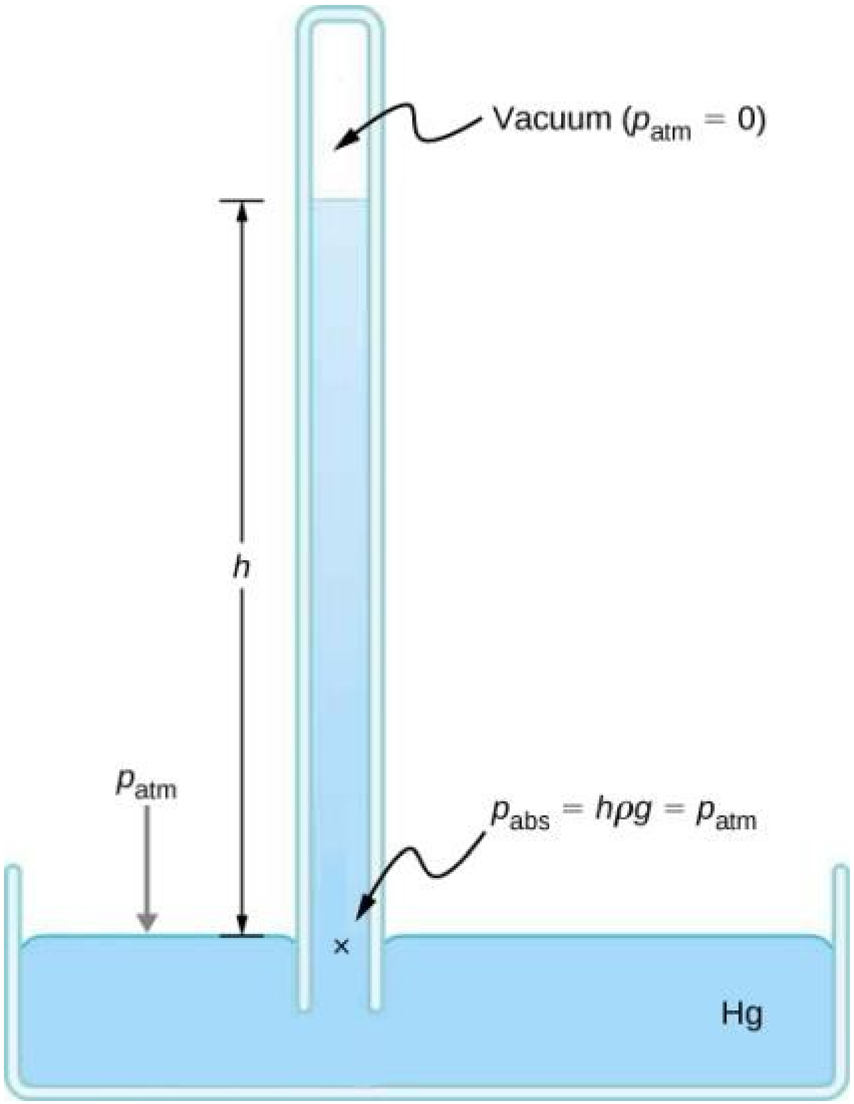
(a) Fluid depth must be the same on both sides, or the pressure each side exerts at the bottom will be unequal and liquid will flow from the deeper side.

(b) A positive gauge pressure $p_g = h\rho g$ transmitted to one side of the manometer can support a column of fluid of height h.

(c) Similarly, atmospheric pressure is greater than a negative gauge pressure p_g by an amount $h\rho g$. The jar's rigidity prevents atmospheric pressure from being transmitted to the peanuts.

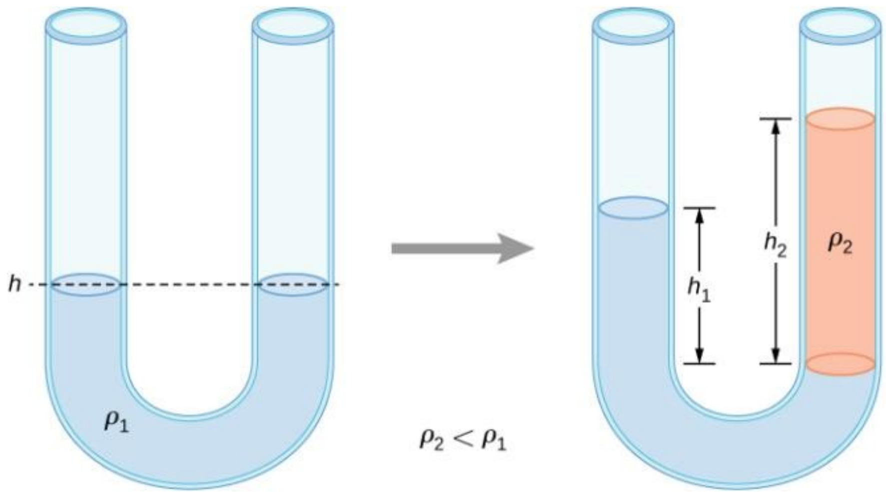
BAROMETERS

A mercury barometer measures atmospheric pressure. The pressure due to the mercury's weight, $h\rho g$, equals atmospheric pressure. The atmosphere is able to force mercury in the tube to a height h because the pressure above the mercury is zero.



Fluid Heights in an Open U-Tube

A U-tube with both ends open is filled with a liquid of density ρ_1 to a height *h* on both sides (Figure 14.14). A liquid of density $\rho_2 < \rho_1$ is poured into one side and Liquid 2 settles on top of Liquid 1. The heights on the two sides are different. The height to the top of Liquid 2 from the interface is h_2 and the height to the top of Liquid 1 from the level of the interface is h_1. Derive a formula for the height difference.



Since the two points are in Liquid 1 and are at the same height, the pressure at the two points must be the same. Therefore, we have

$$p_0 + \rho_1 g h_1 = p_0 + \rho_2 g h_2.$$

Hence,

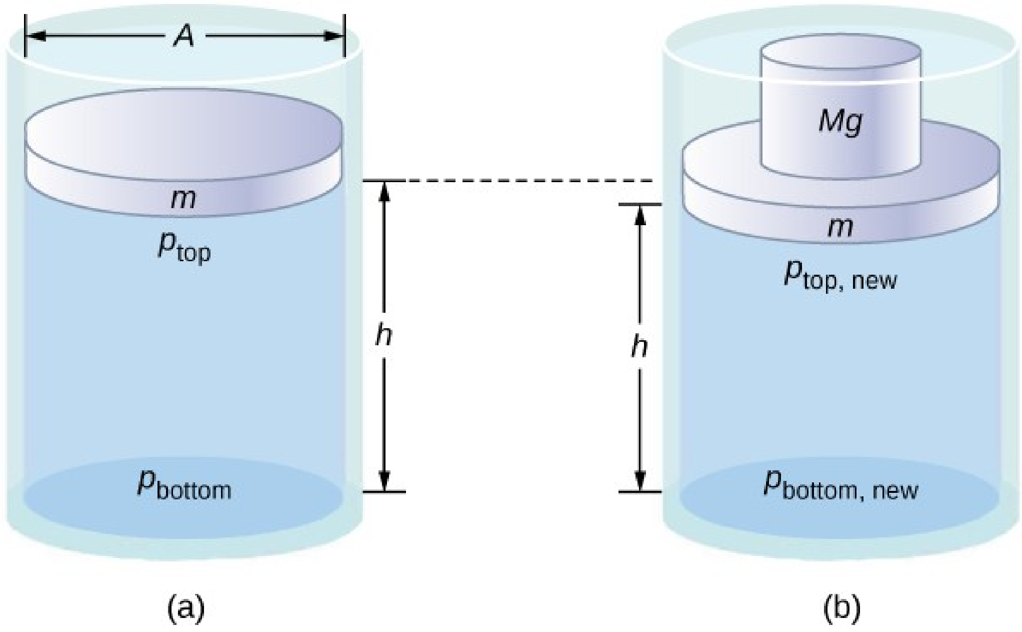
$$\rho_1 h_1 = \rho_2 h_2.$$

This means that the difference in heights on the two sides of the U-tube is

$$h_2 - h_1 = \left(1 - \frac{p_1}{p_2}\right) h_2.$$

Pascal's Principle

Pascal's principle (also known as Pascal's law) states that when a change in pressure is applied to an enclosed fluid, it is transmitted undiminished to all portions of the fluid and to the walls of its container. In an enclosed fluid, since atoms of the fluid are free to move about, they transmit pressure to all parts of the fluid *and* to the walls of the container. Any change in pressure is transmitted undiminished.



Pressure in a fluid changes when the fluid is compressed.

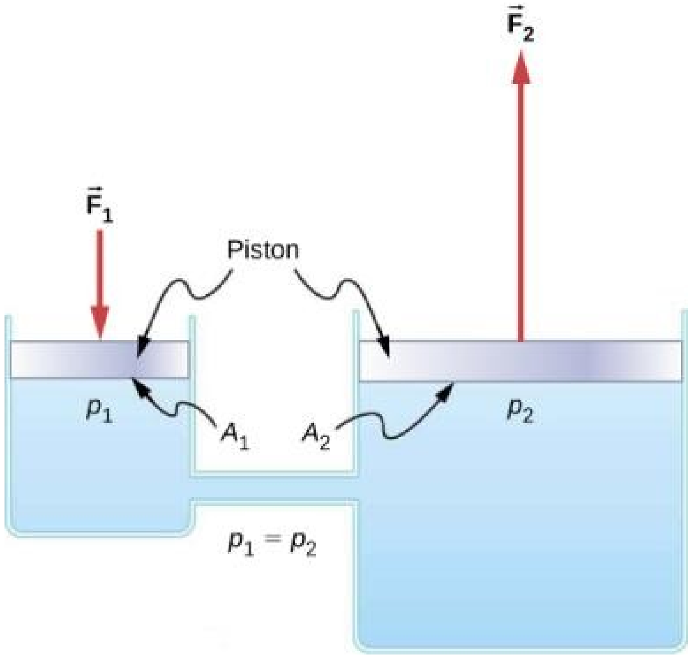
(a) The pressure at the top layer of the fluid is different from pressure at the bottom layer.

(b) The increase in pressure by adding weight to the piston is the same everywhere, for example, $p_{top\ new} - p_{top} = p_{bottom\ new} - p_{bottom}$.

$$\Delta p = \Delta p_{top} = \Delta p_{bottom} = \Delta p_{everywhere}.$$

$$\Delta p_{top} = \frac{Mg}{A}.$$

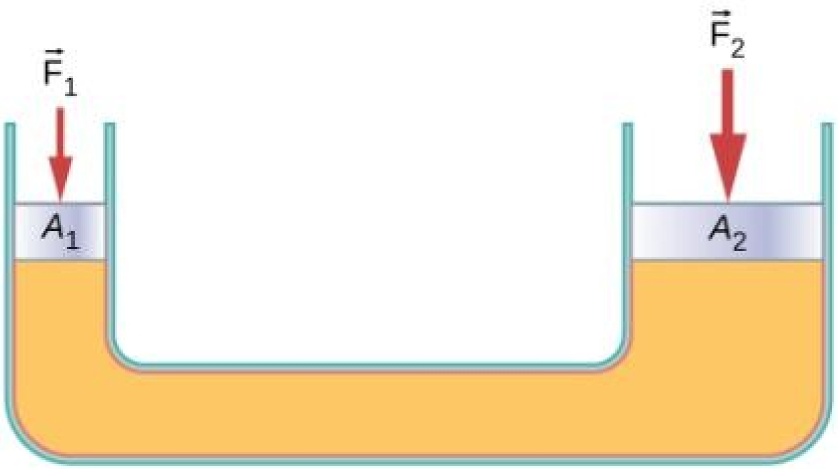
APPLICATIONS OF PASCAL'S PRINCIPLE AND HYDRAULIC SYSTEMS



A typical hydraulic system with two fluid-filled cylinders, capped with pistons and connected by a tube called a hydraulic line. A downward force $\vec{\mathbf{F}}_1$ on the left piston creates a change in pressure that is transmitted undiminished to all parts of the enclosed fluid. This results in an upward force $\vec{\mathbf{F}}_2$ on the right piston that is larger than $\vec{\mathbf{F}}_1$ because the right piston has a larger surface area.

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}.$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}.$$



(a)

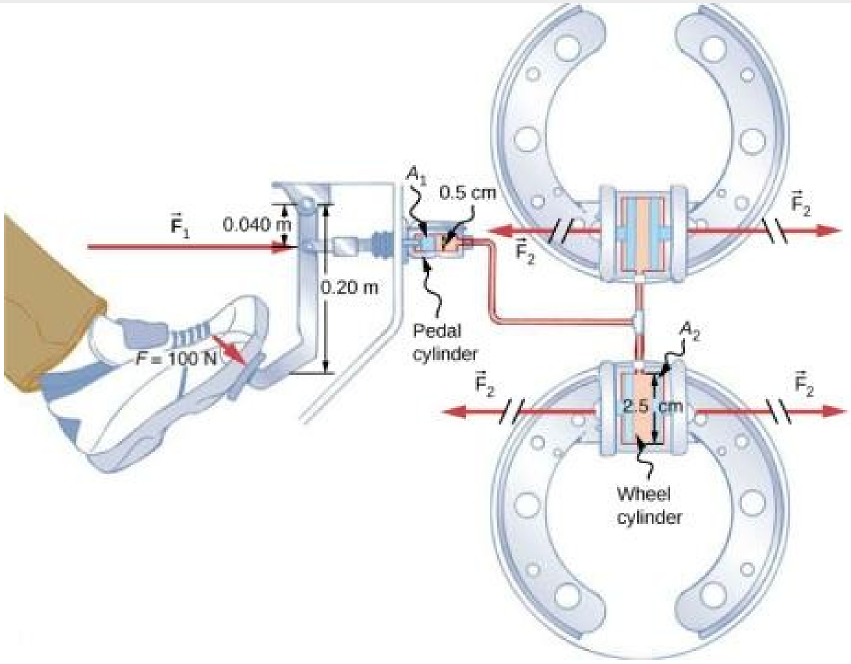
(b)

(a) A hydraulic jack operates by applying forces (F_1 , F_2) to an incompressible fluid in a U-tube, using a movable piston (A_1, A_2) on each side of the tube.

(b) Hydraulic jacks are commonly used by car mechanics to lift vehicles so that repairs and maintenance can be performed.

Calculating Force on Wheel Cylinders: Pascal Puts on the Brakes

Consider the automobile hydraulic system shown in Figure 14.18. Suppose a force of 100 N is applied to the brake pedal, which acts on the pedal cylinder (acting as a "master" cylinder) through a lever. A force of 500 N is exerted on the pedal cylinder. Pressure created in the pedal cylinder is transmitted to the four wheel cylinders. The pedal cylinder has a diameter of 0.500 cm and each wheel cylinder has a diameter of 2.50 cm. Calculate the magnitude of the force F_2 created at each of the wheel cylinders.



Hydraulic brakes use Pascal's principle. The driver pushes the brake pedal, exerting a force that is increased by the simple lever and again by the hydraulic system. Each of the identical wheel cylinders receives the same pressure and, therefore, creates the same force output F_2. The circular cross-sectional areas of the pedal and wheel cylinders are represented by A_1 and A_2, respectively.