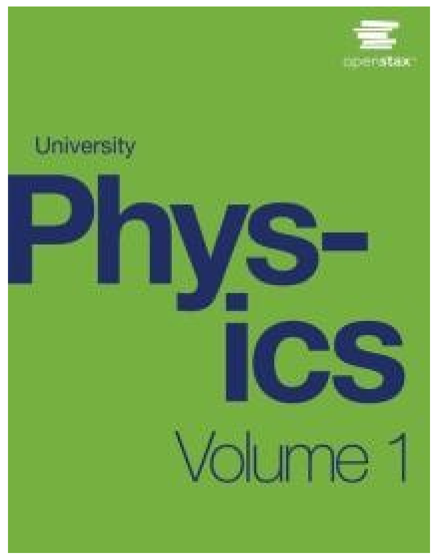
UNIVERSITY PHYSICS

Chapter 14 FLUID MECHANICS

PowerPoint Image Slideshow



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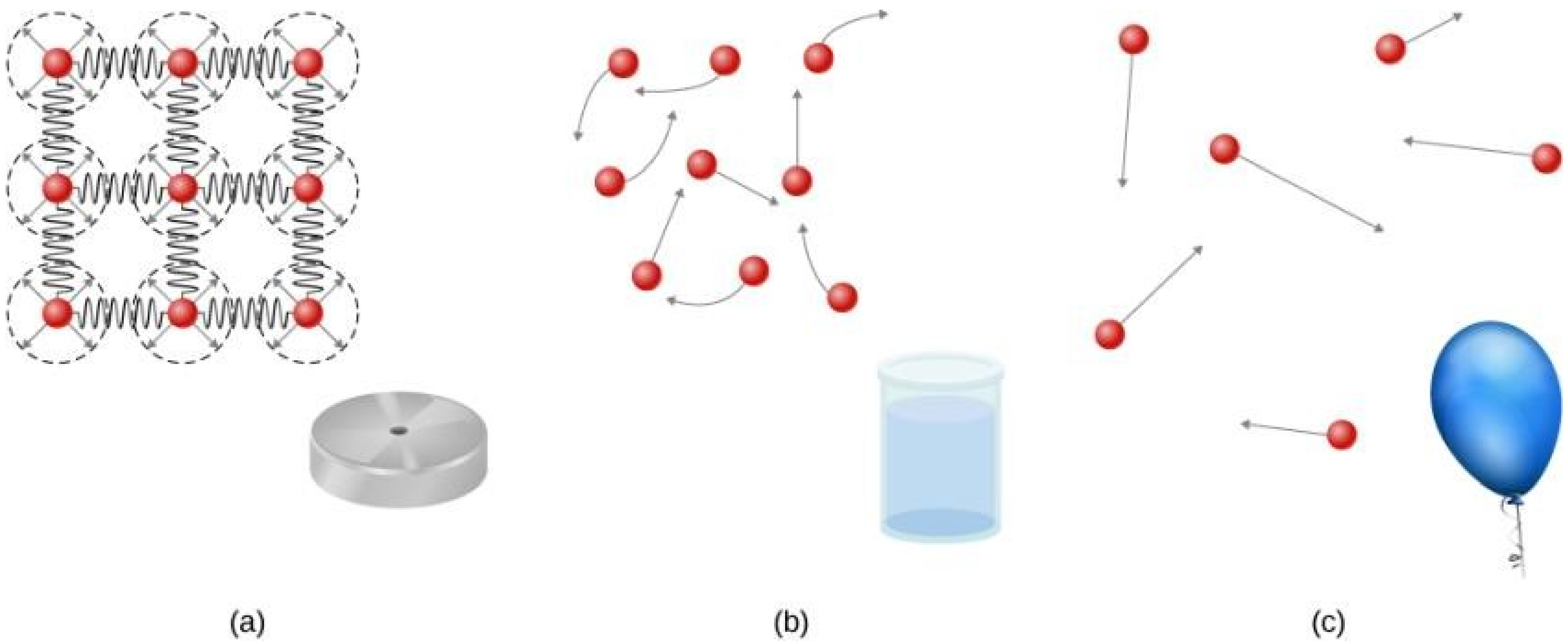
Definition of a fluid

FIGURE 14.2



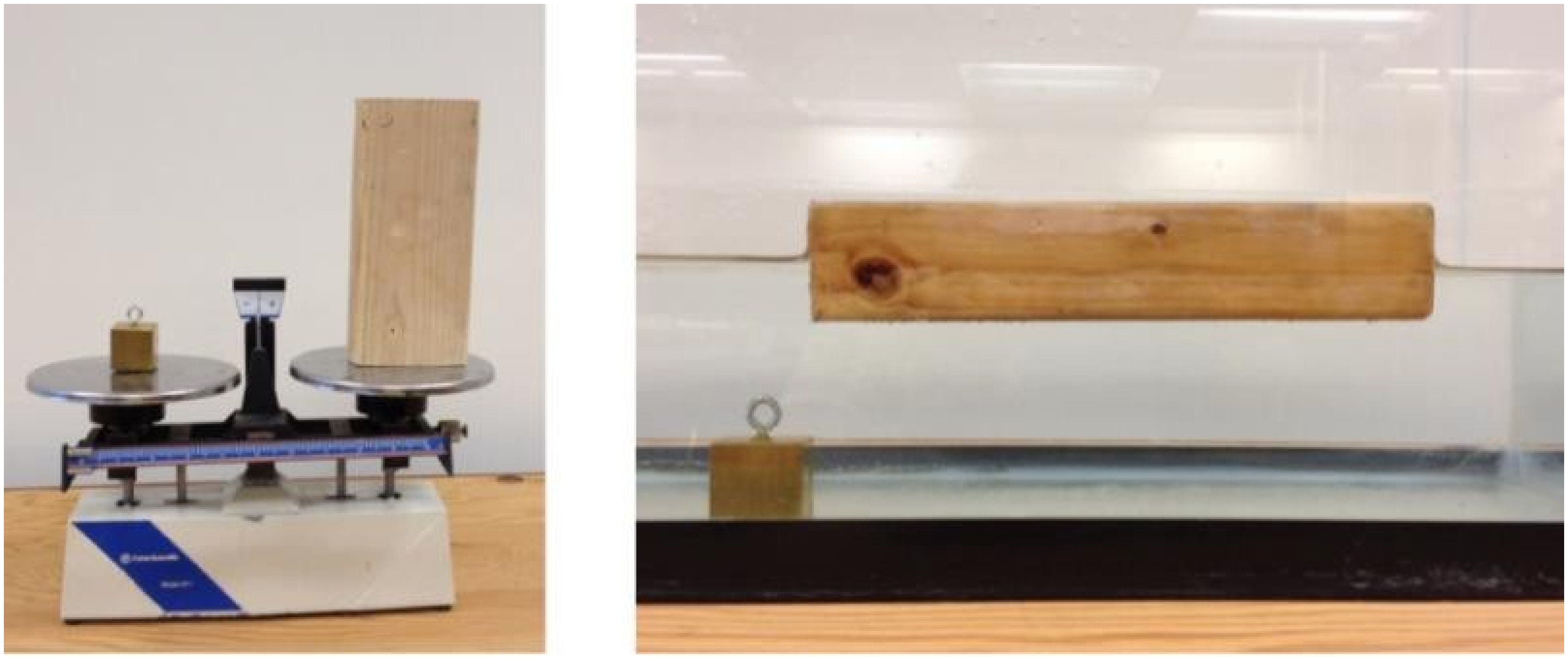
(a) Atoms in a solid are always in close contact with neighboring atoms, held in place by forces represented here by springs.

(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

FIGURE 14.3

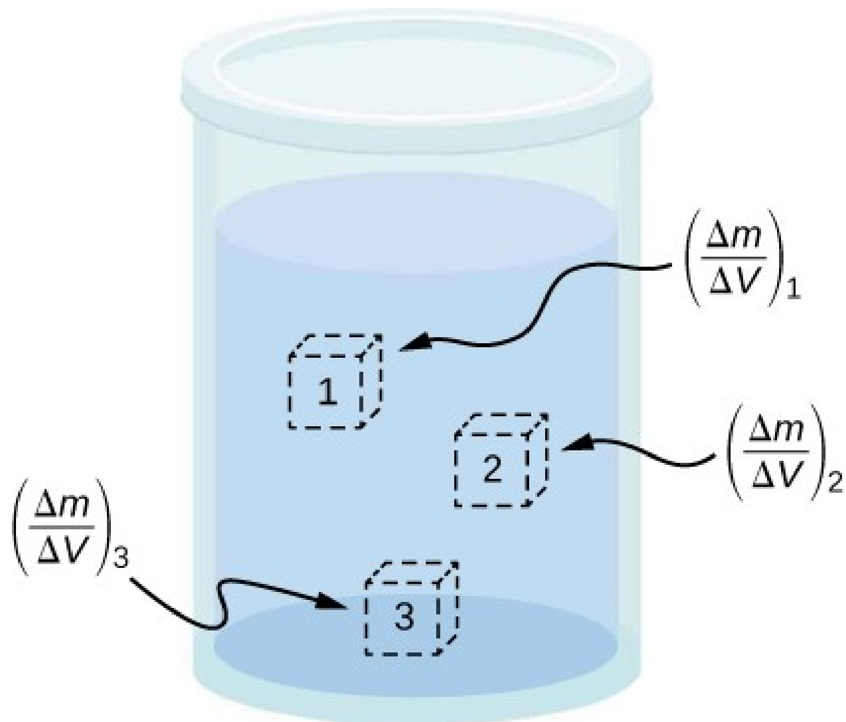


(a) (b)

(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.)

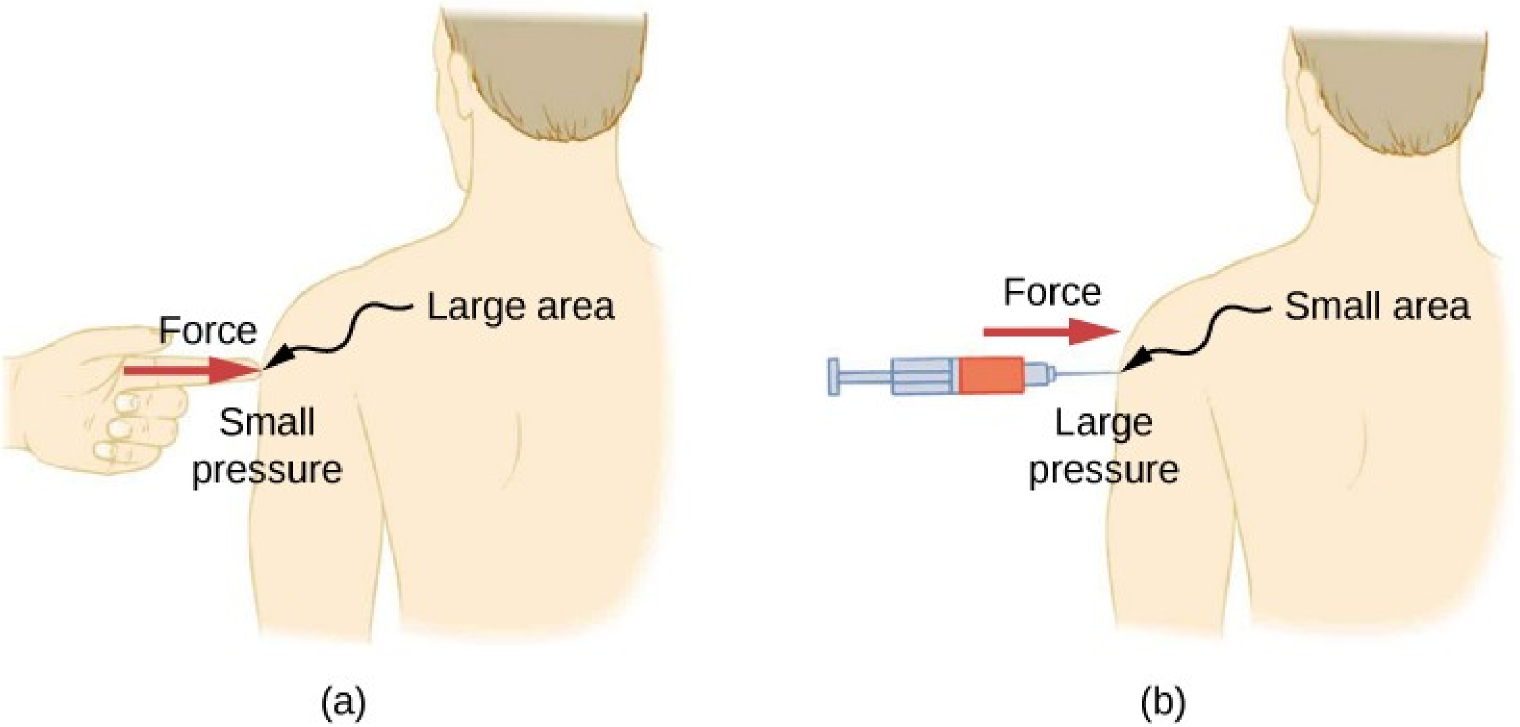
FIGURE 14.4



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

FIGURE 14.5



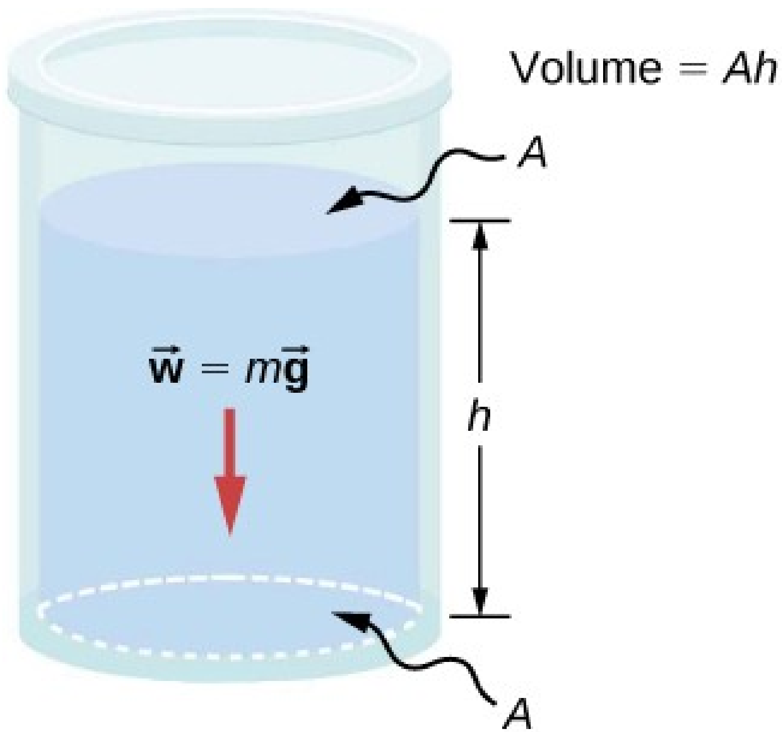
(a) A person being poked with a finger might be irritated, but the force has little lasting effect.

(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 in a fluid

$$\rho = mgh$$

FIGURE 14.6



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.

EXAMPLE 14.1

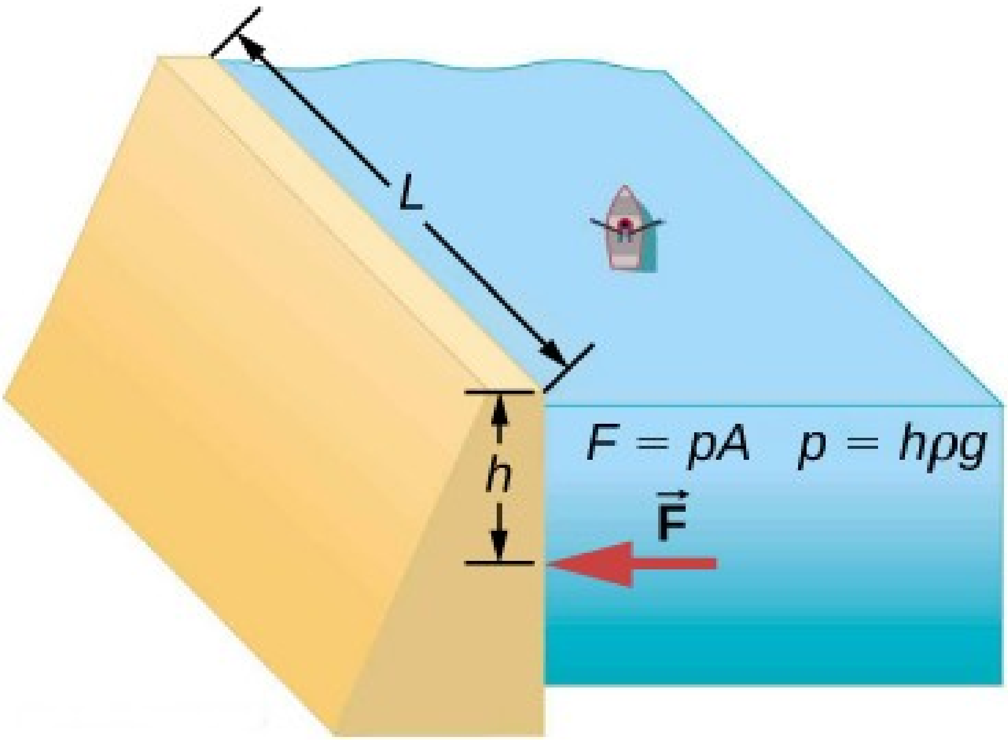
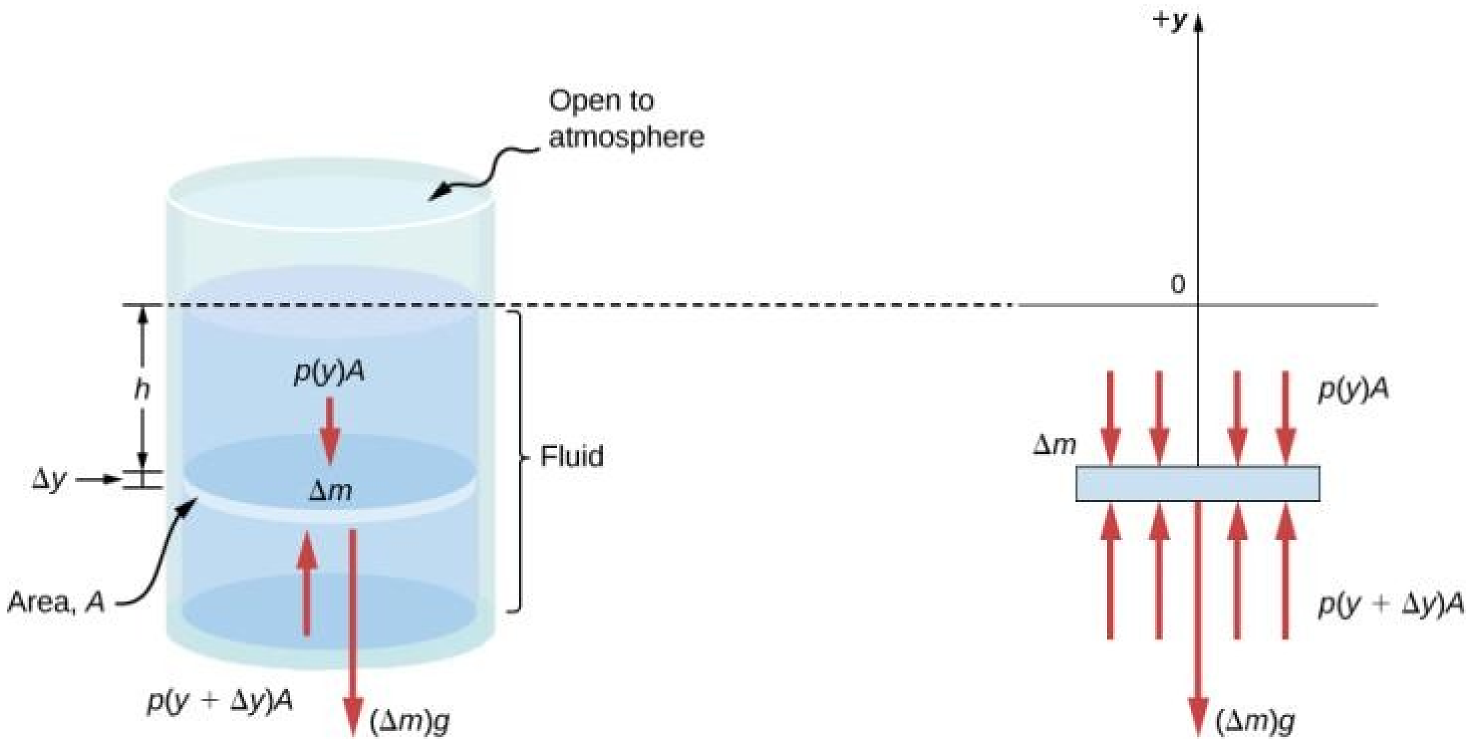


FIGURE 14.8



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

FIGURE 14.9

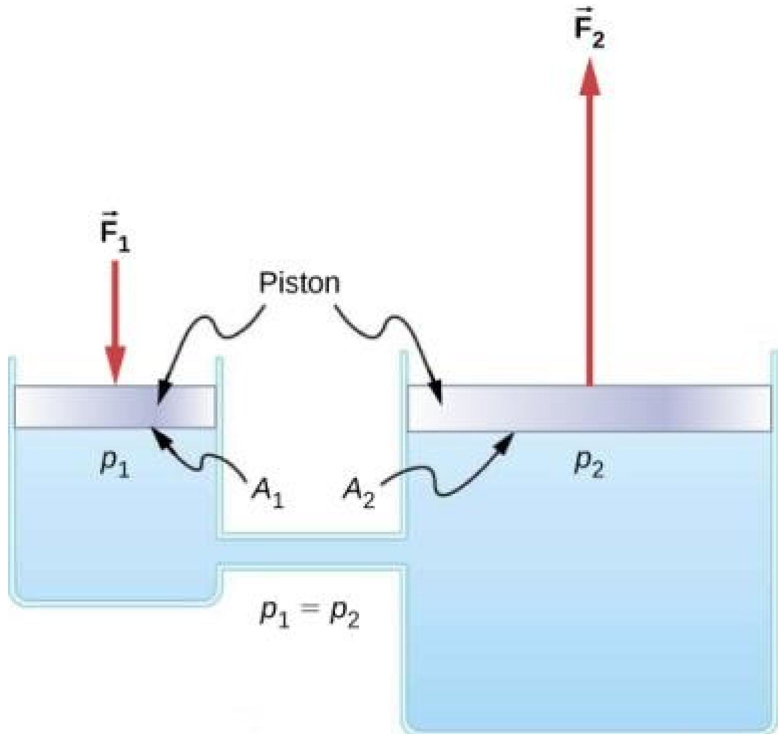
If a fluid can flow freely between parts of a container, it rises to the same height in each part. In the container pictured, the pressure at the bottom of each column is the same; if it were not the same, the fluid would flow until the pressures became equal.

Pascal's principle

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

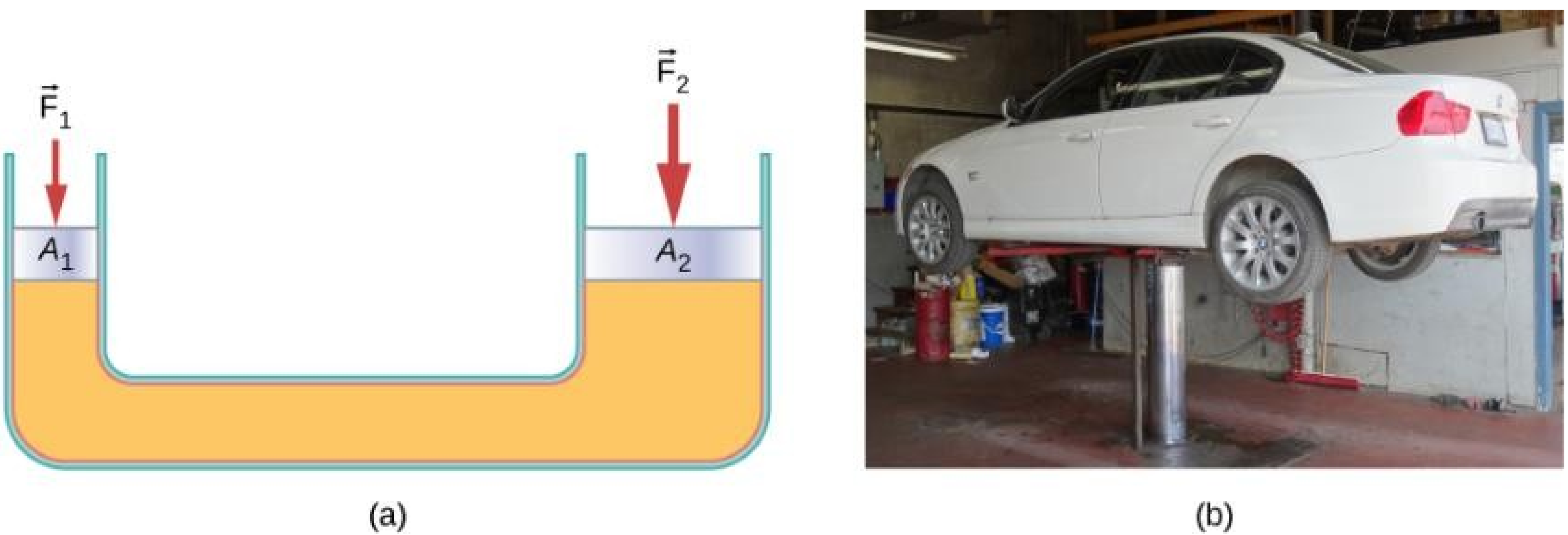
FIGURE 14.16

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



A typical hydraulic system with two fluid-filled cylinders, capped with pistons and connected by a tube called a hydraulic line. A downward force 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 on the right piston that is larger than because the right piston has a larger surface area.

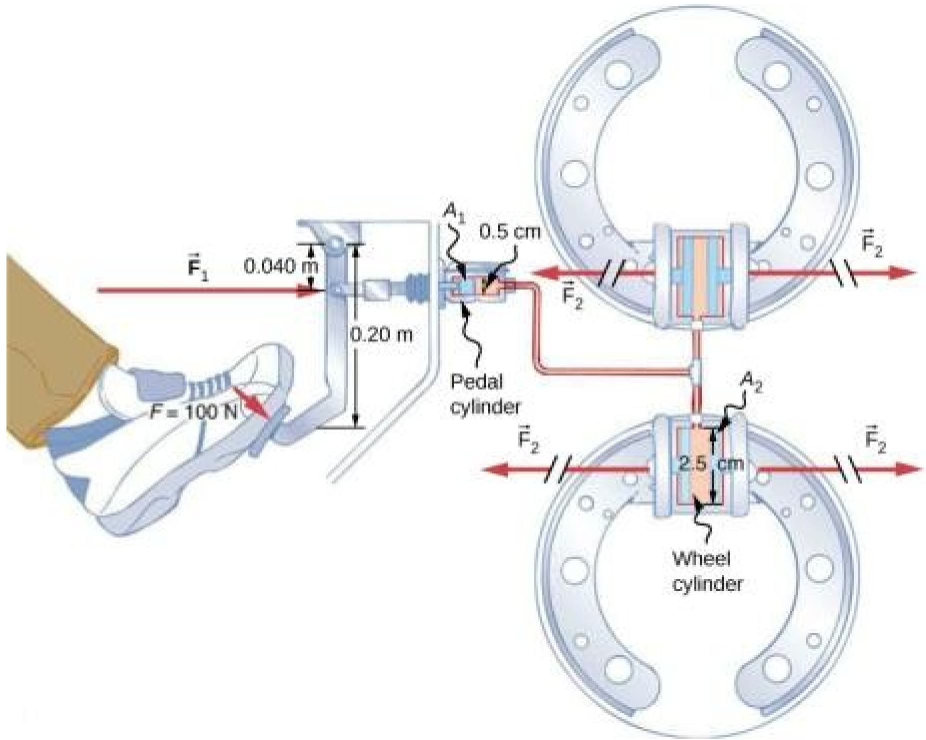
FIGURE 14.17



(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.

FIGURE 14.18

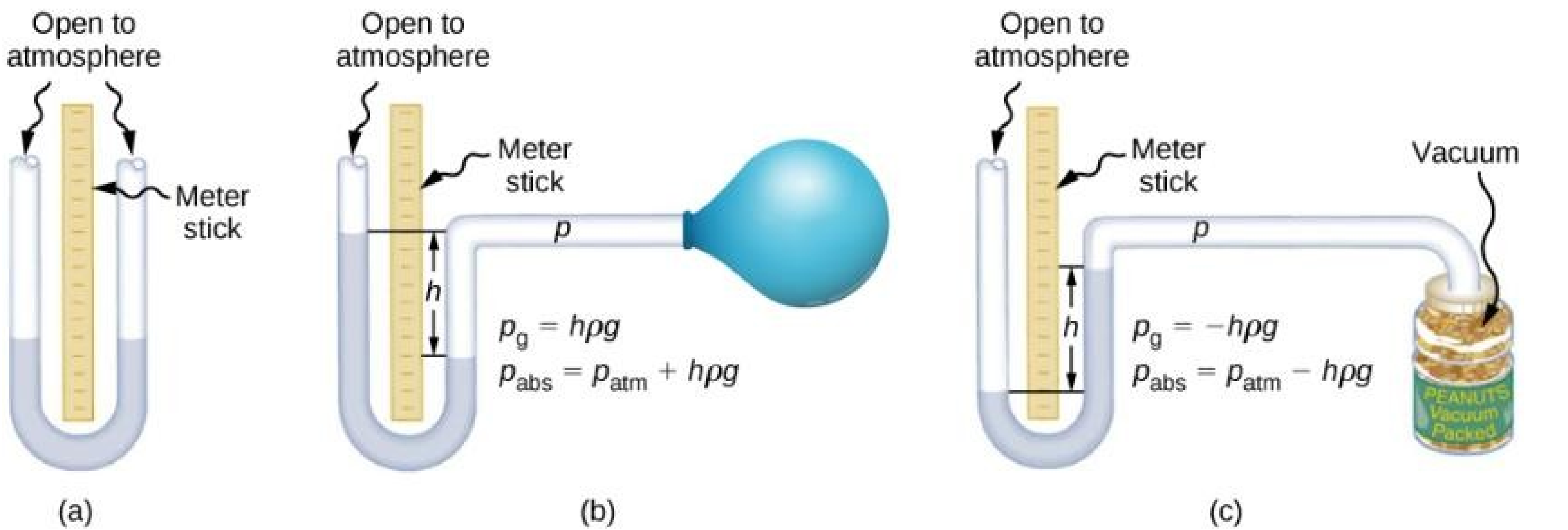


Hydraulic brakes use Pascal's principle. The driver pushes the brake pedal, exerting a force that is increased by the simple lever and again by the hydraulic system. Each of the identical wheel cylinders receives the same pressure and, therefore, creates the same force output F_2. The circular cross-sectional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

Bernoulli's Equation

$$P + \frac{1}{2}\rho v^2 + \rho g\, y = constant$$

FIGURE 14.12



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.

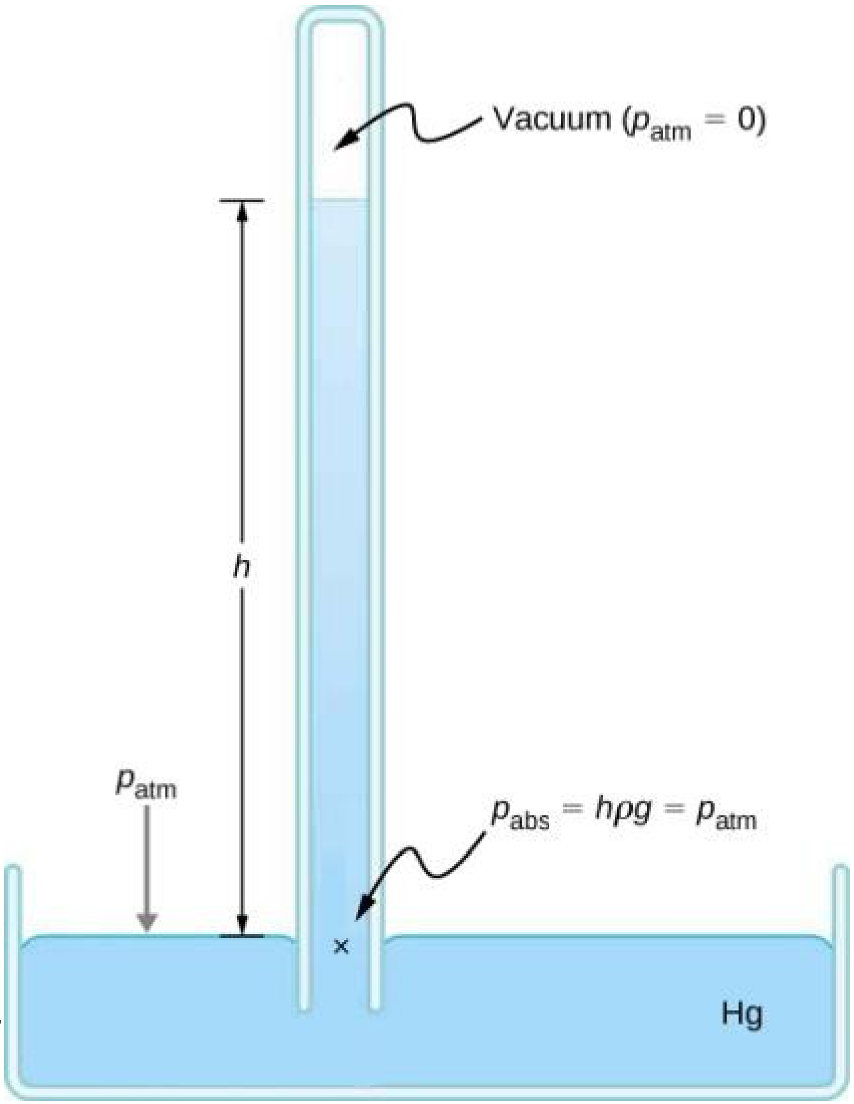
(b) A positive gauge pressure $p_g = hg$ transmitted to one side of the manometer can support a column of fluid of height h.

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

$$P+\frac{1}{2}\rho v^{2}+\rho g\, y=constant$$

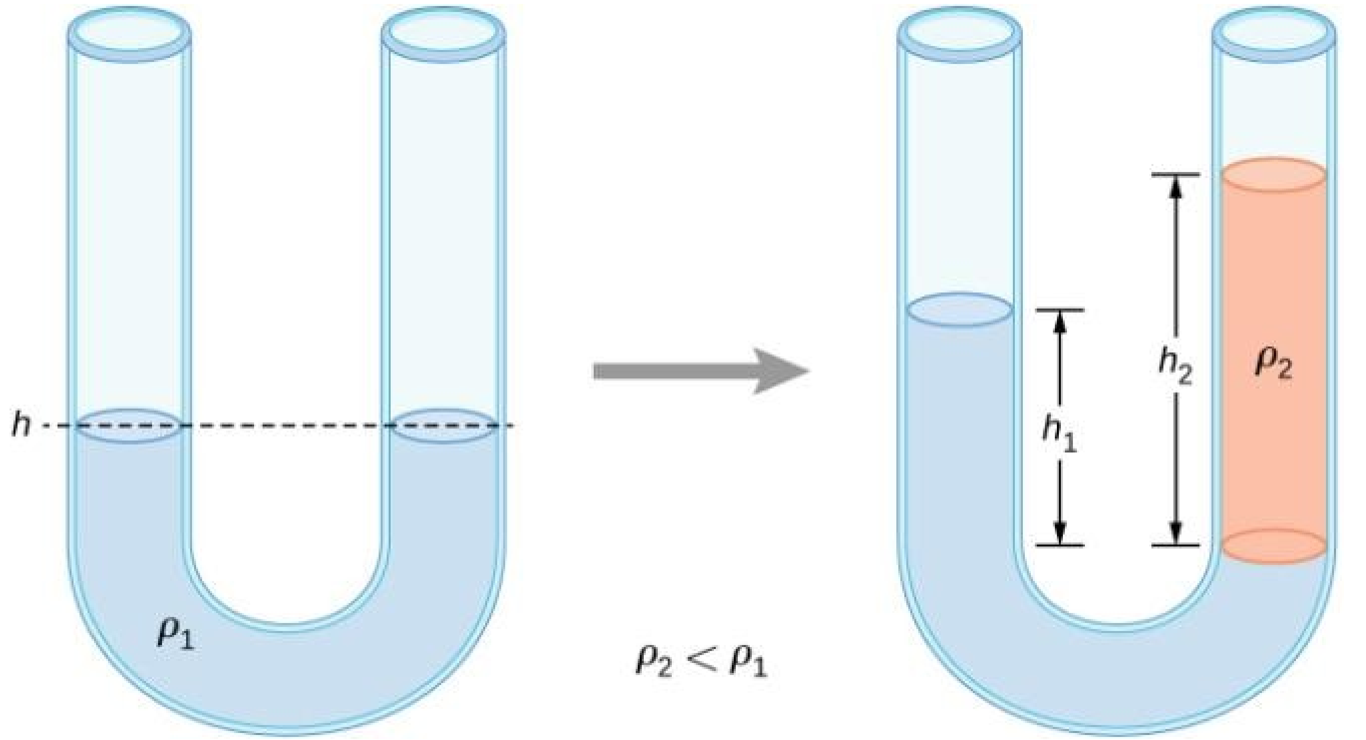
FIGURE 14.13

A mercury barometer measures atmospheric pressure. The pressure due to the mercury's weight, *hg*, 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.



$$P + \frac{1}{2}\rho v^2 + \rho g y = constant$$

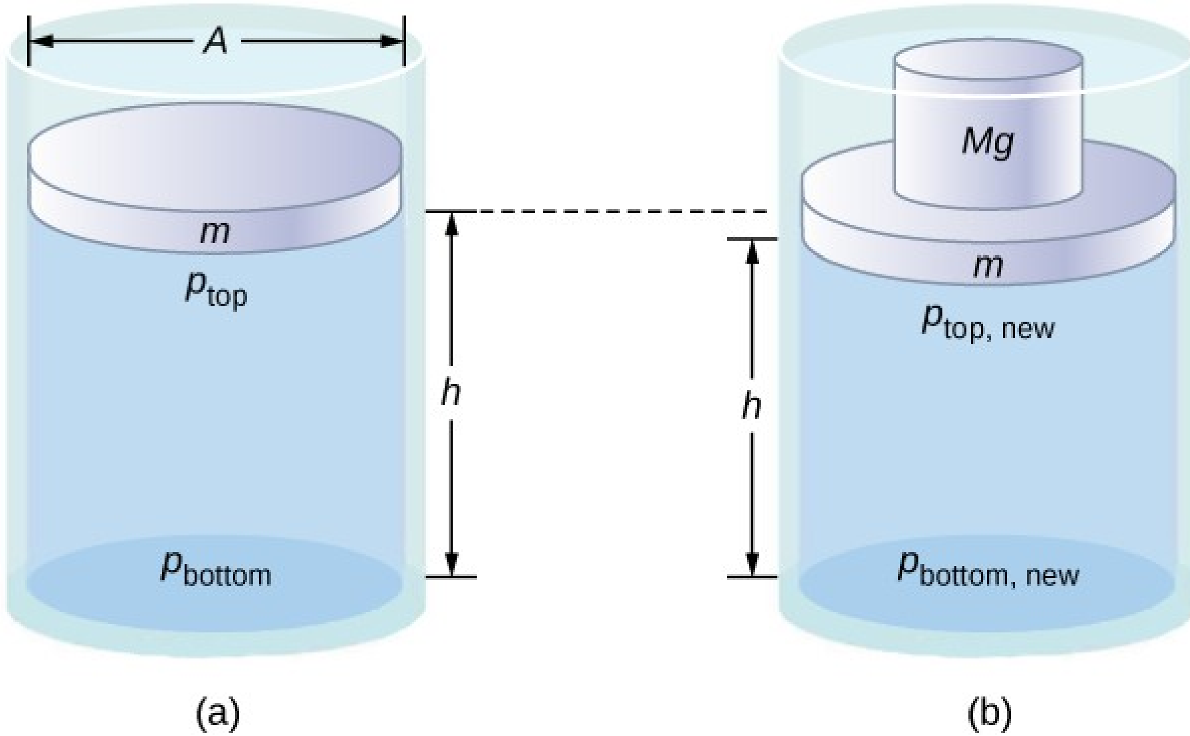
FIGURE 14.14



Two liquids of different densities are shown in a U-tube.

$$P + \frac{1}{2}\rho v^2 + \rho g y = constant$$

FIGURE 14.15



Pressure in a fluid changes when the fluid is compressed.

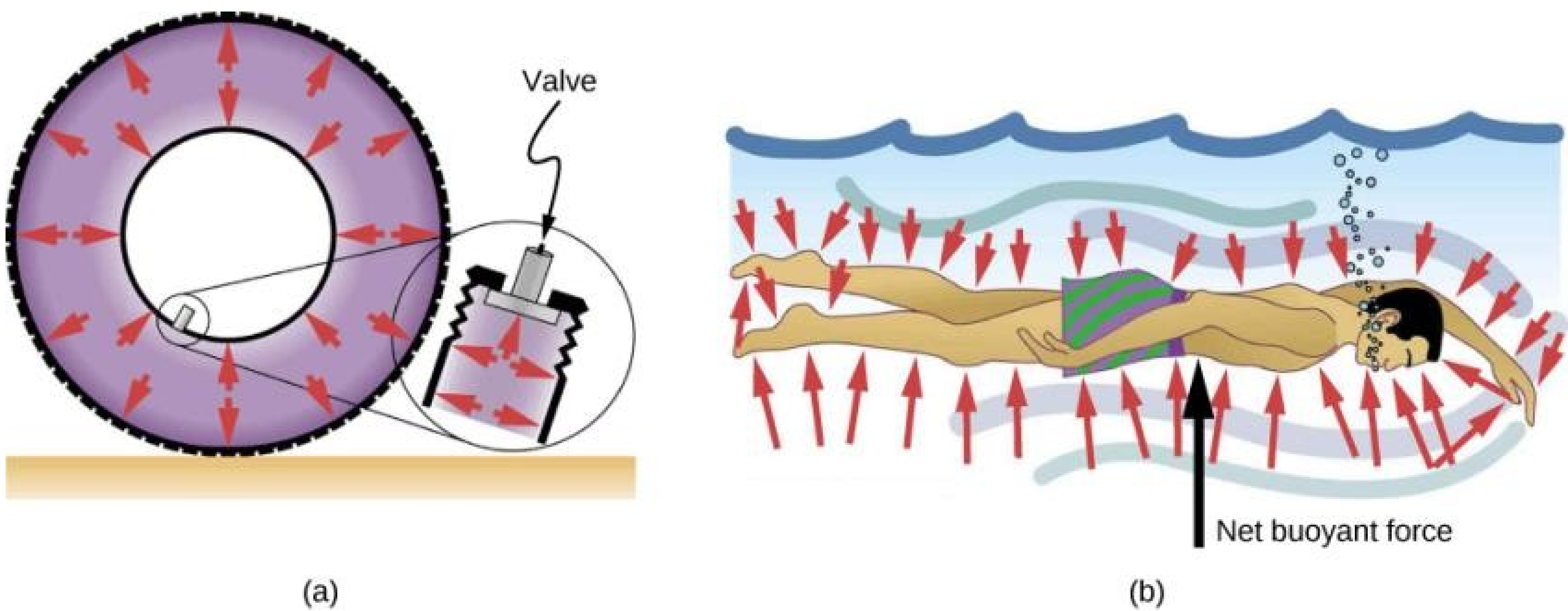
(a) The pressure at the top layer of the fluid is different from pressure at the bottom layer.

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

$$P + \frac{1}{2}\rho v^2 + \rho g y = constant$$

Buoyant force

FIGURE 14.10



(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.

FIGURE 14.19

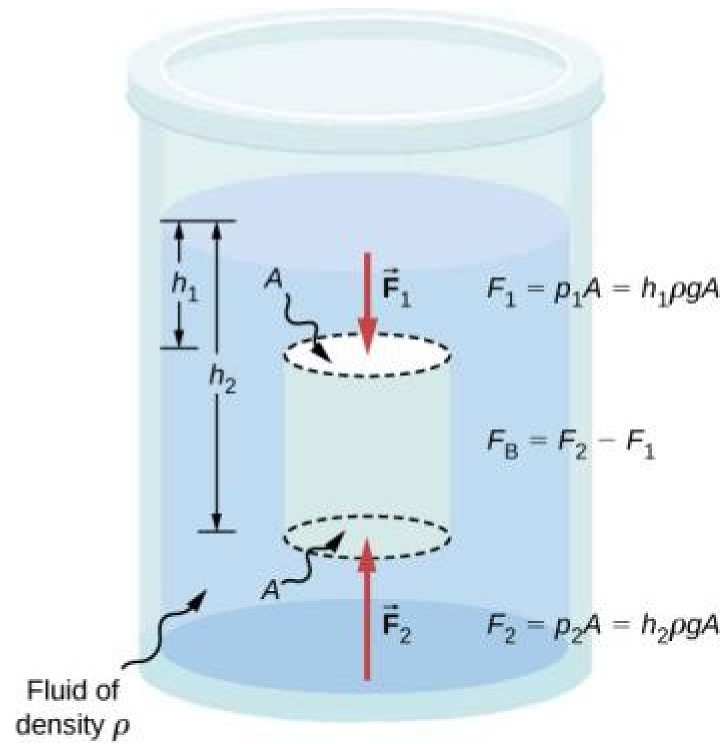
(a) (b) (c)

(a) Even objects that sink, like this anchor, are partly supported by water when submerged.

(b) Submarines have adjustable density (ballast tanks) so that they may float or sink as desired.

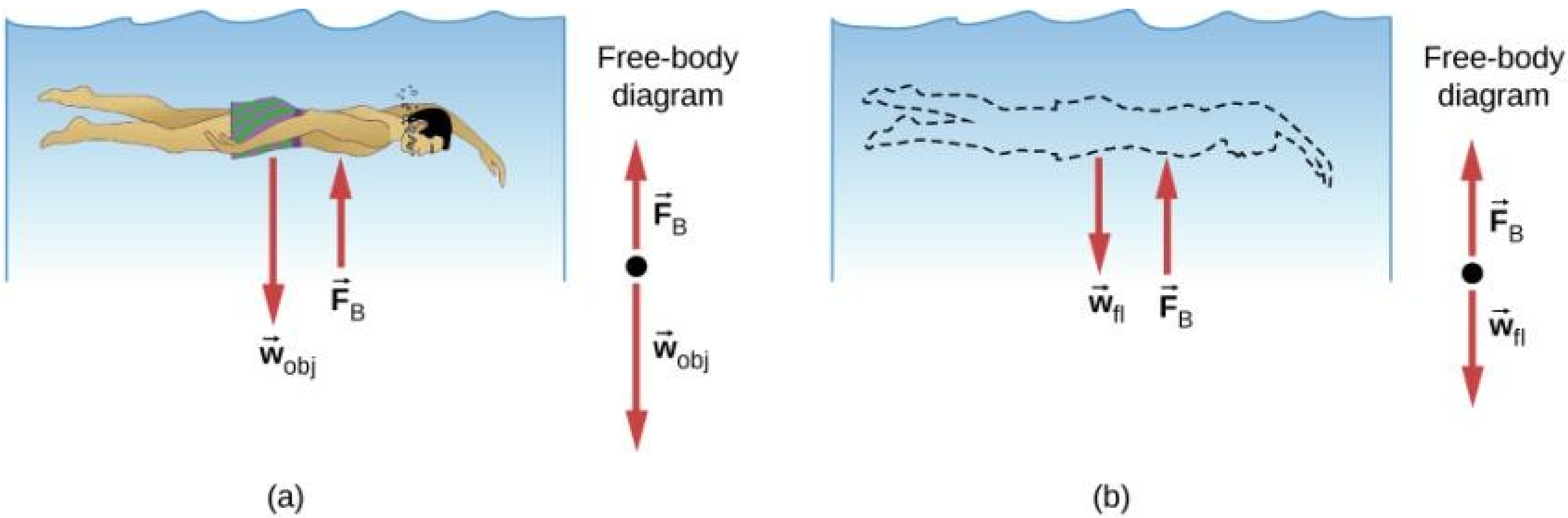
(c) Helium-filled balloons tug upward on their strings, demonstrating air's buoyant effect.(credit b: modification of work by Allied Navy; credit c: modification of work by "Crystl"/Flickr)

FIGURE 14.20



Pressure due to the weight of a fluid increases with depth because $p = hpg$. This change in pressure and associated upward force on the bottom of the cylinder are greater than the downward force on the top of the cylinder. The differences in the force results in the buoyant force F_B. (Horizontal forces cancel.)

FIGURE 14.21



(a) An object submerged in a fluid experiences a buoyant force F_B. If F_B is greater than the weight of the object, the object rises. If F_B is less than the weight of the object, the object sinks.

(b) If the object is removed, it is replaced by fluid having weight w_{fl}. Since this weight is supported by surrounding fluid, the buoyant force must equal the weight of the fluid displaced.

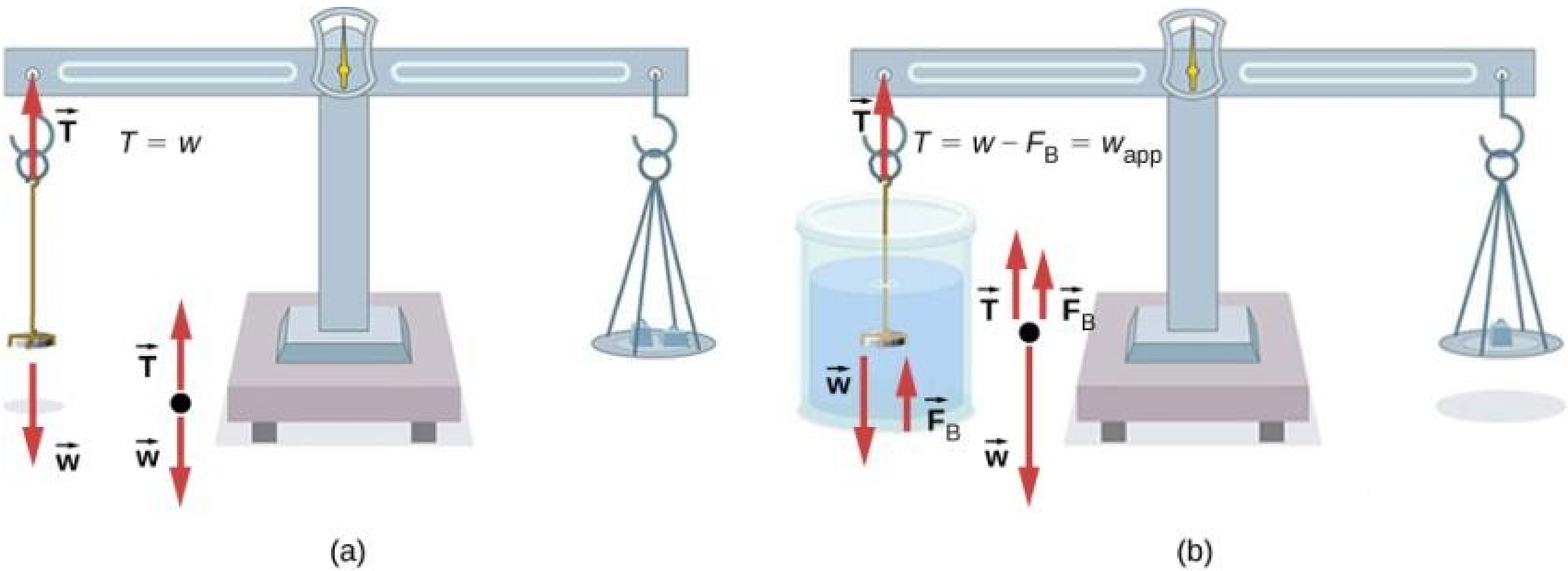
FIGURE 14.22

(a)

(b)

An unloaded ship (a) floats higher in the water than a loaded ship (b).

FIGURE 14.23



(a) A coin is weighed in air.

(b) The apparent weight of the coin is determined while it is completely submerged in a fluid of known density. These two measurements are used to calculate the density of the coin.

Fluid dynamics

$$A_1 v_1 = A_2 v_2$$

FIGURE 14.24

The velocity vectors show the flow of wind in Hurricane Arthur. Notice the circulation of the wind around the eye of the hurricane. Wind speeds are highest near the eye. The colors represent the relative vorticity, a measure of turning or spinning of the air.

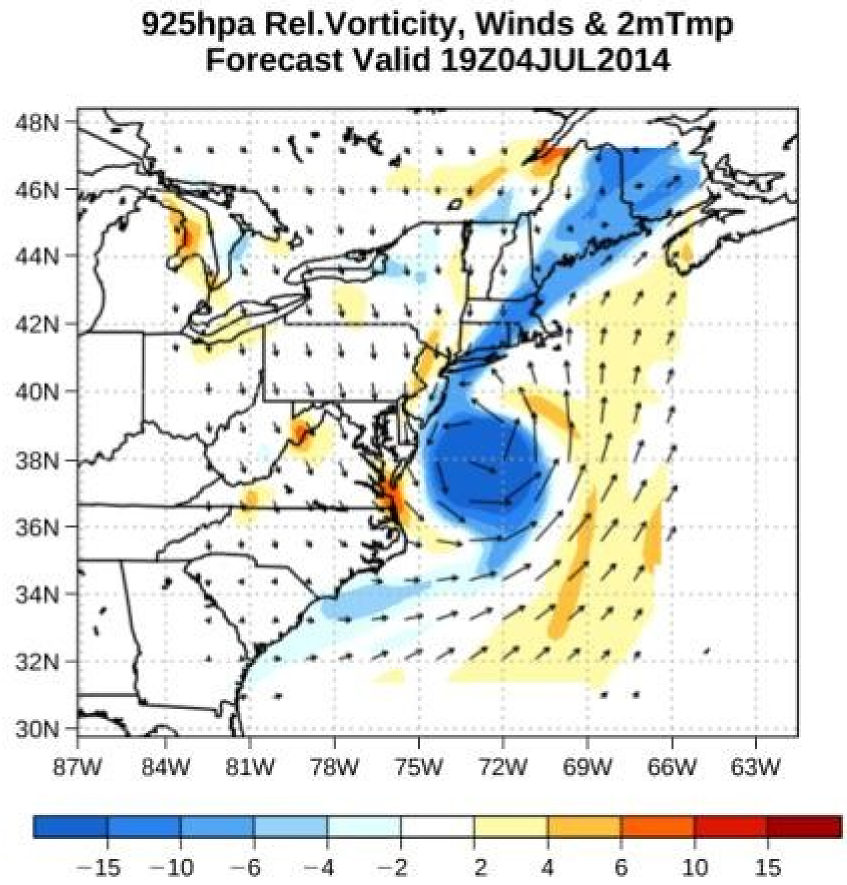
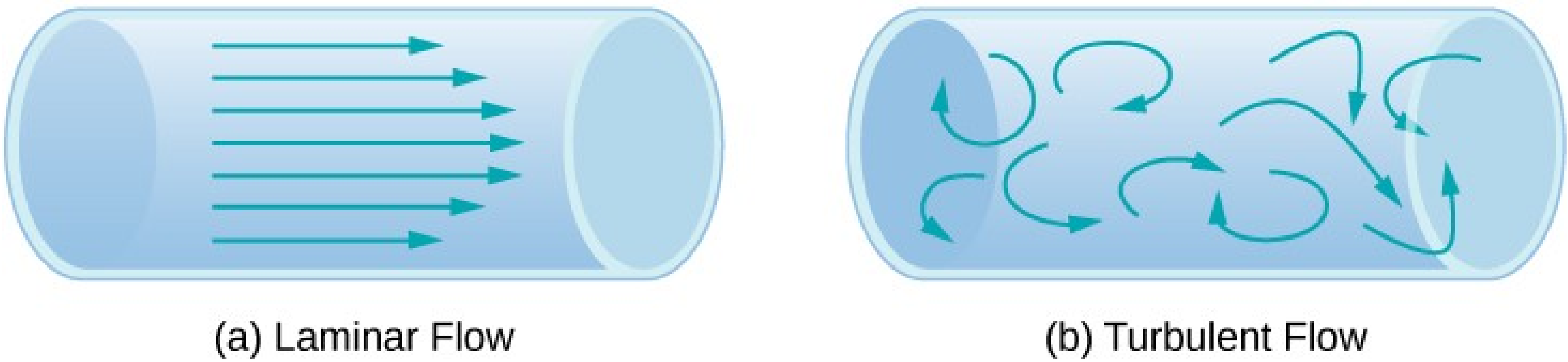


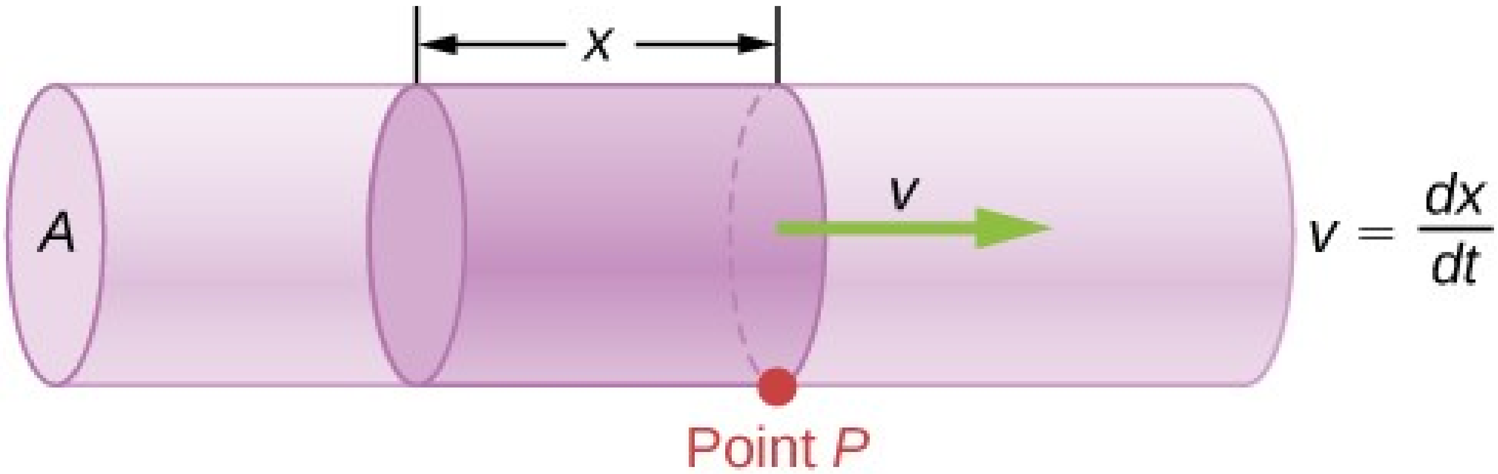
FIGURE 14.25



(a) Laminar flow can be thought of as layers of fluid moving in parallel, regular paths.

(b) In turbulent flow, regions of fluid move in irregular, colliding paths, resulting in mixing and swirling.

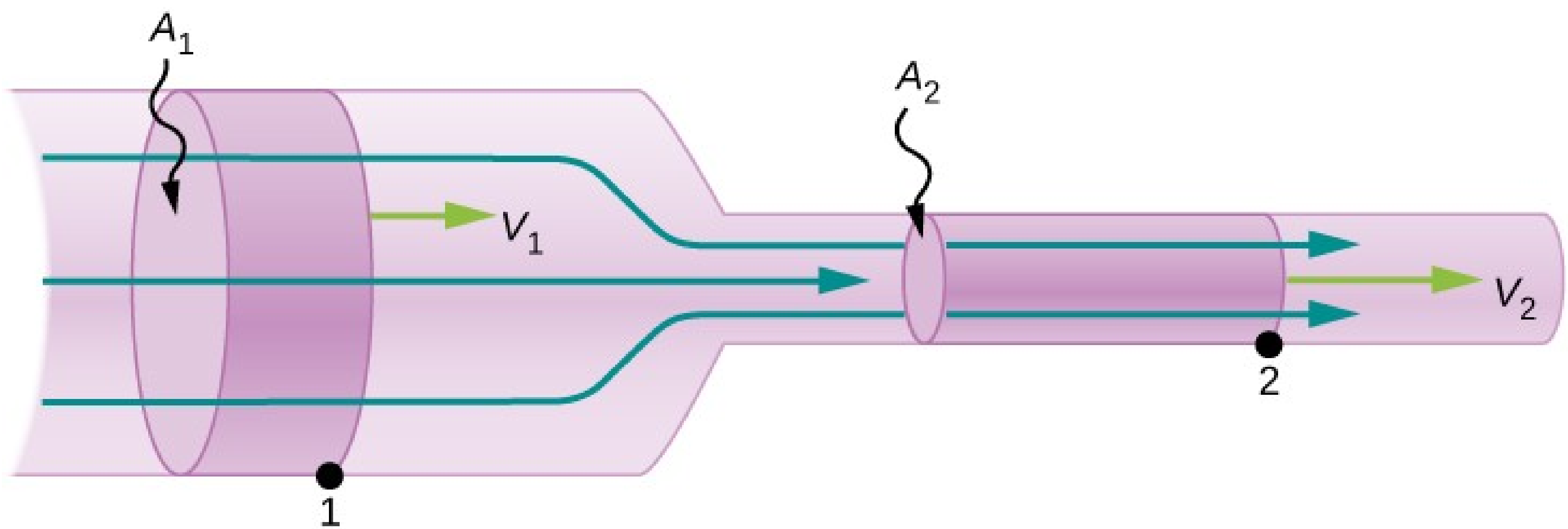
FIGURE 14.26



$$Q = \frac{dV}{dt} = \frac{d}{dt}(Ax) = A\frac{dx}{dt} = Av$$

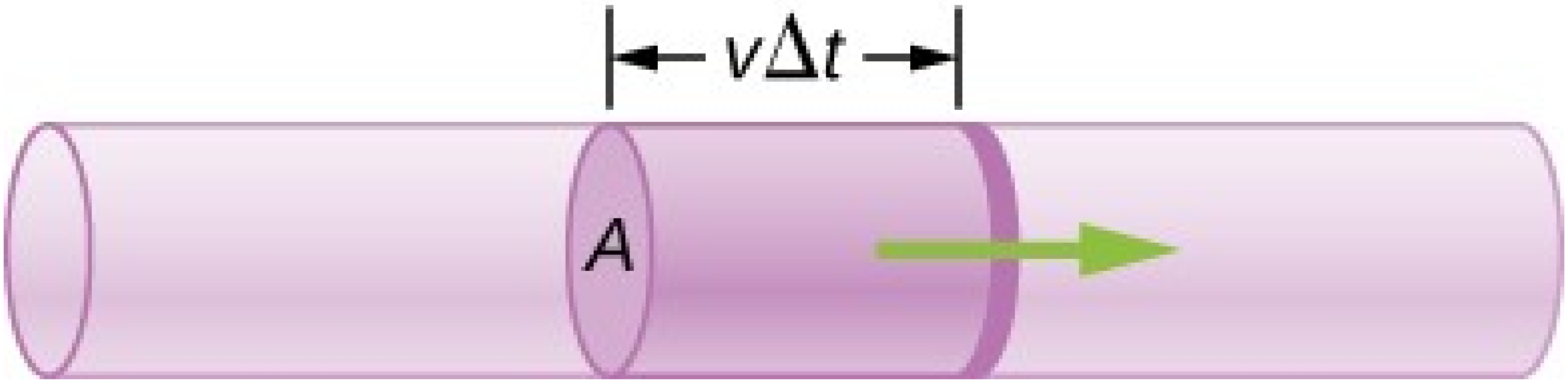
Flow rate is the volume of fluid flowing past a point through the area *A* per unit time. Here, the shaded cylinder of fluid flows past point *P* in a uniform pipe in time *t*.

FIGURE 14.27



When a tube narrows, the same volume occupies a greater length. For the same volume to pass points 1 and 2 in a given time, the speed must be greater at point 2. The process is exactly reversible. If the fluid flows in the opposite direction, its speed decreases when the tube widens. (Note that the relative volumes of the two cylinders and the corresponding velocity vector arrows are not drawn to scale.)

FIGURE 14.28

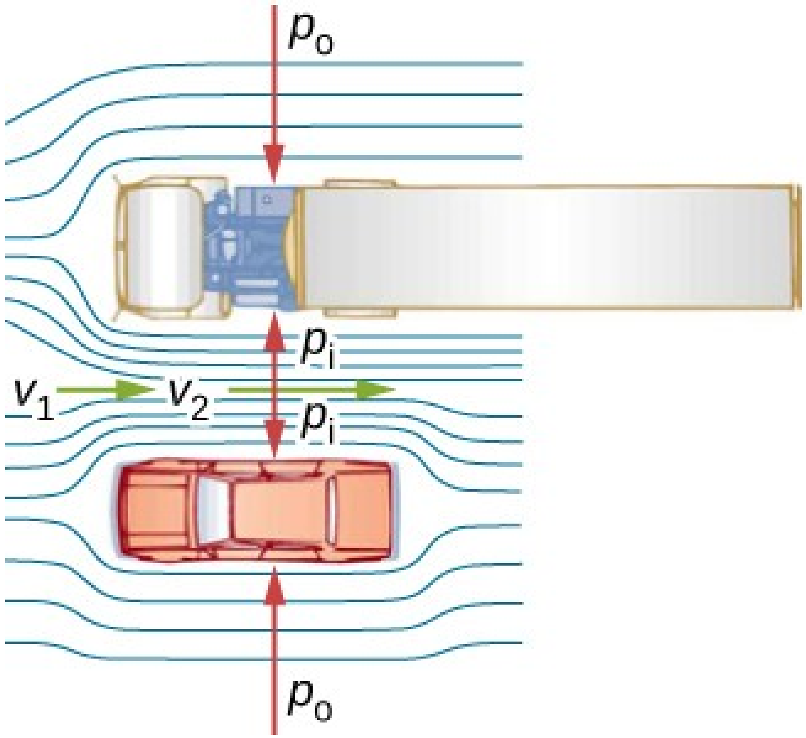


Geometry for deriving the equation of continuity. The amount of liquid entering the cross-sectional (shaded) area must equal the amount of liquid leaving the cross-sectional area if the liquid is incompressible.

Bernoulli's Equation

$$P + \frac{1}{2}\rho v^2 + \rho g\, y = constant$$

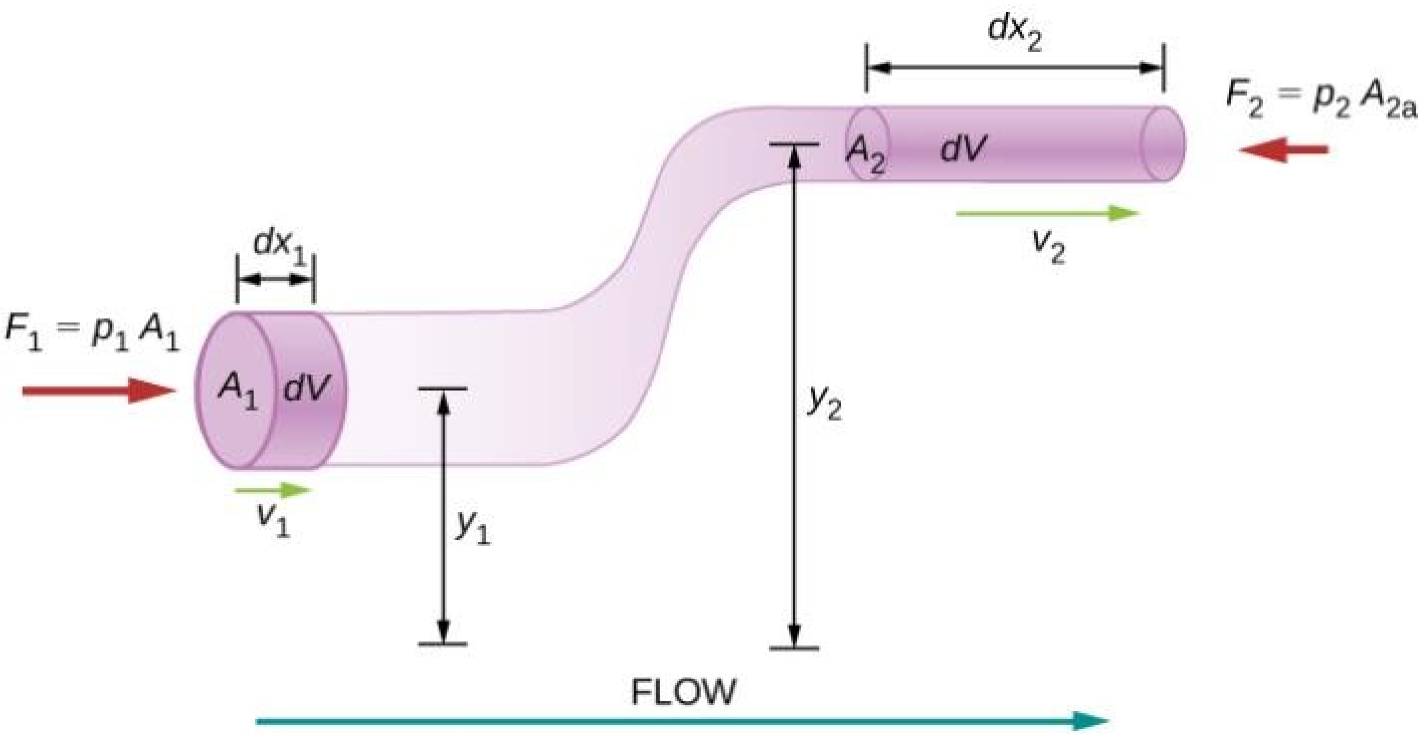
FIGURE 14.29



An overhead view of a car passing a truck on a highway. Air passing between the vehicles flows in a narrower channel and must increase its speed (v_2 is greater than v_1), causing the pressure between them to drop (p_i is less than p_o). Greater pressure on the outside pushes the car and truck together.

$$P+\frac{1}{2}\rho v^2+\rho g\, y=constant$$

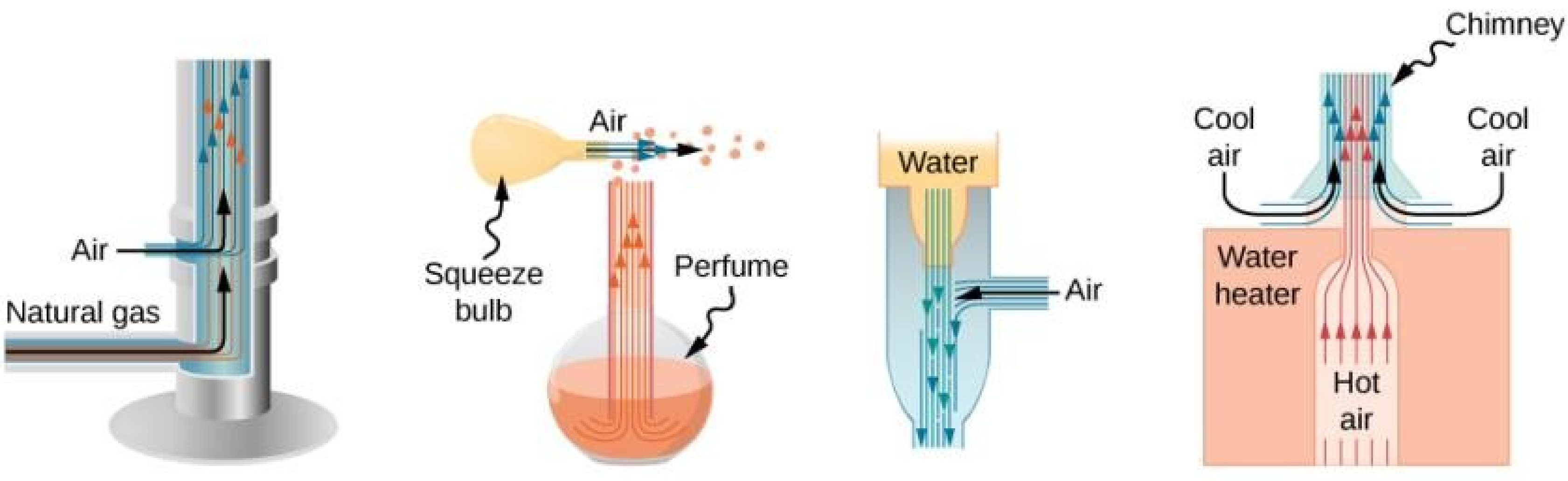
FIGURE 14.30



The geometry used for the derivation of Bernoulli's equation.

$$P + \frac{1}{2}\rho v^2 + \rho g\, y = constant$$

FIGURE 14.31



(a) (b) (c) (d)

$$P+\frac{1}{2}\rho v^2+\rho g y = constant$$

Entrainment devices use increased fluid speed to create low pressures, which then entrain one fluid into another.

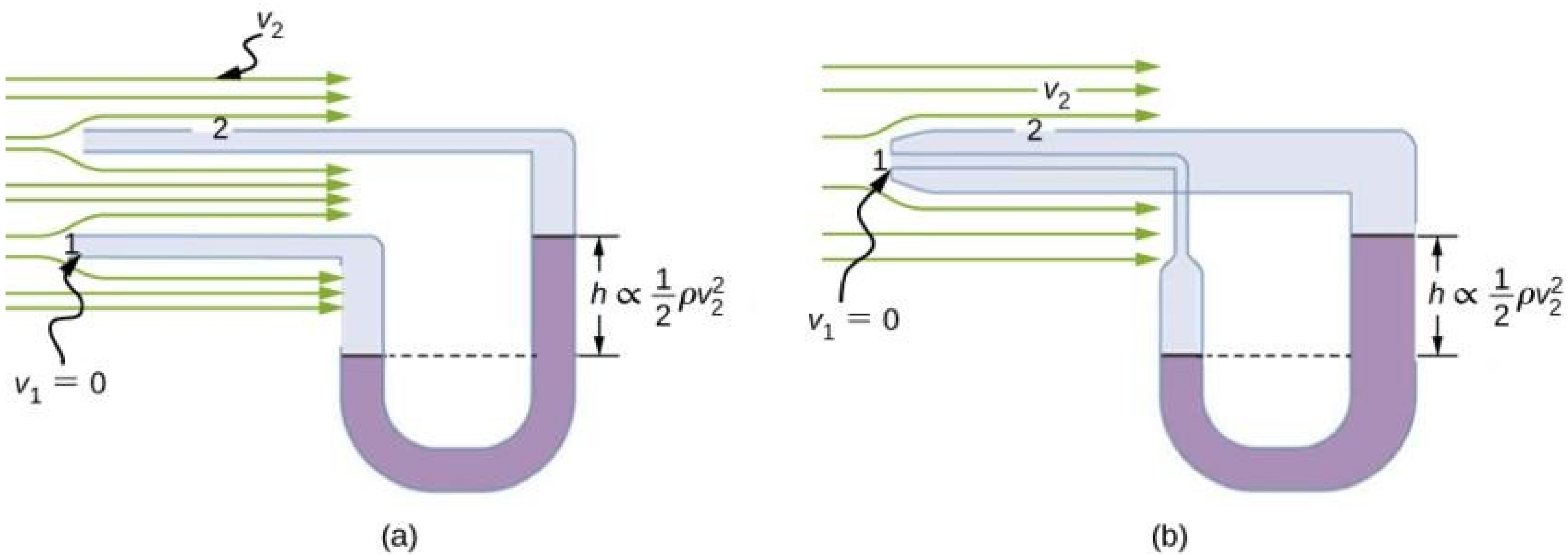
(a) A Bunsen burner uses an adjustable gas nozzle, entraining air for proper combustion.

(b) An atomizer uses a squeeze bulb to create a jet of air that entrains drops of perfume. Paint sprayers and carburetors use very similar techniques to move their respective liquids.

(c) A common aspirator uses a high-speed stream of water to create a region of lower pressure. Aspirators may be used as suction pumps in dental and surgical situations or for draining a flooded basement or producing a reduced pressure in a vessel.

(d) The chimney of a water heater is designed to entrain air into the pipe leading through the ceiling.

FIGURE 14.32



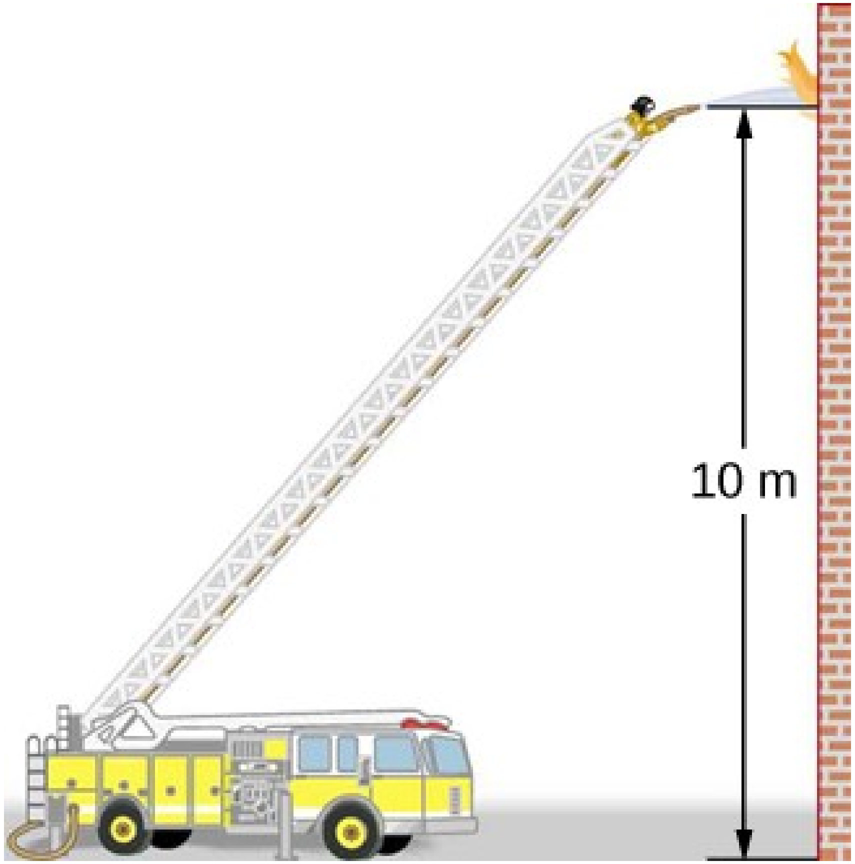
Measurement of fluid speed based on Bernoulli's principle.

(a) A manometer is connected to two tubes that are close together and small enough not to disturb the flow. Tube 1 is open at the end facing the flow. A dead spot having zero speed is created there. Tube 2 has an opening on the side, so the fluid has a speed *v* across the opening; thus, pressure there drops. The difference in pressure at the manometer is , so *h* is proportional to .

(b) This type of velocity measuring device is a Prandtl tube, also known as a pitot tube.

$$P+\frac{1}{2}\rho v^2+\rho g\, y=constant$$

FIGURE 14.33



Pressure in the nozzle of this fire hose is less than at ground level for two reasons: The water has to go uphill to get to the nozzle, and speed increases in the nozzle. In spite of its lowered pressure, the water can exert a large force on anything it strikes by virtue of its kinetic energy. Pressure in the water stream becomes equal to atmospheric pressure once it emerges into the air.

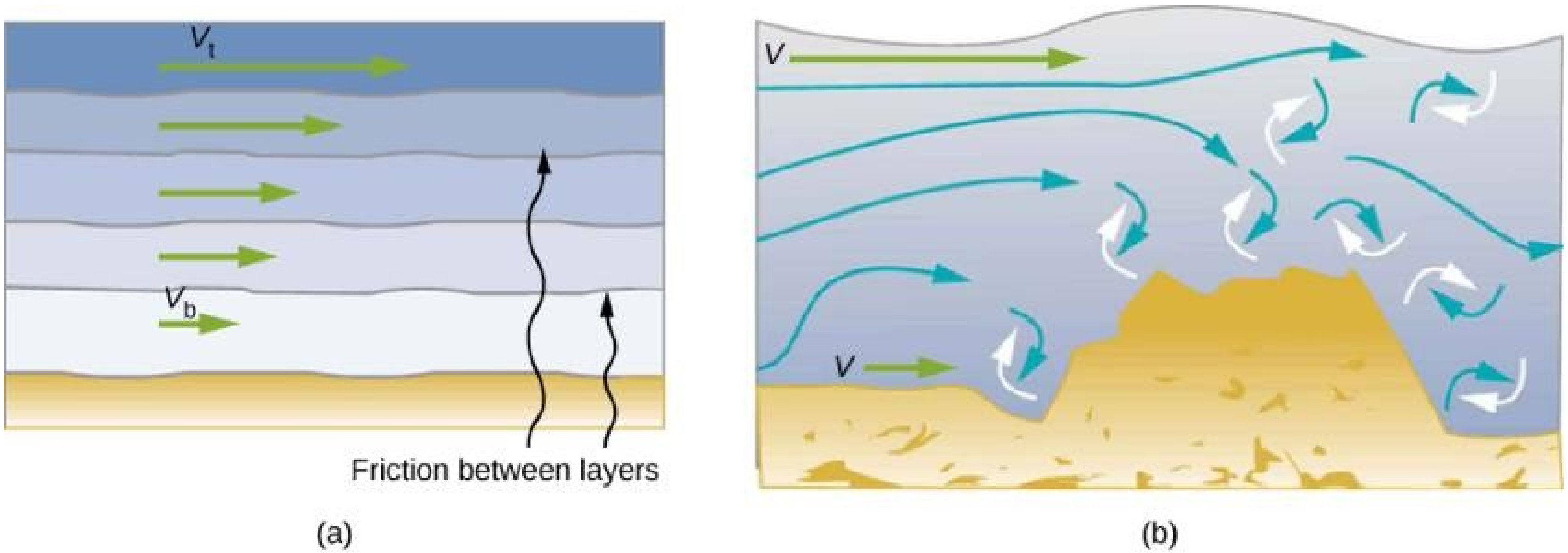
$$P+\frac{1}{2}\rho v^2+\rho g\,y=constant$$

Viscosity & Turbulence

$$N_R = \frac{2\rho v r}{\eta}$$

$$Q = \frac{(p_2 - p_1)\pi r^4}{8\eta l}$$

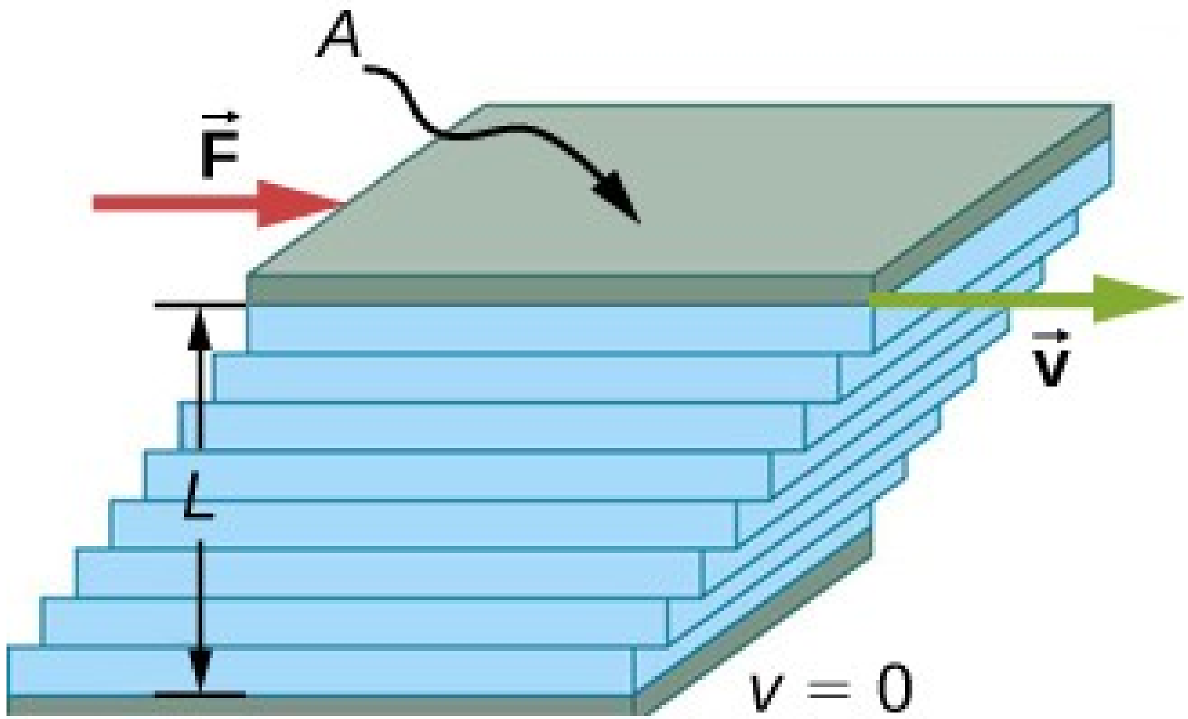
FIGURE 14.34



(a) Laminar flow occurs in layers without mixing. Notice that viscosity causes drag between layers as well as with the fixed surface. The speed near the bottom of the flow (v_b) is less than speed near the top (v_t) because in this case, the surface of the containing vessel is at the bottom.

(b) An obstruction in the vessel causes turbulent flow. Turbulent flow mixes the fluid. There is more interaction, greater heating, and more resistance than in laminar flow.

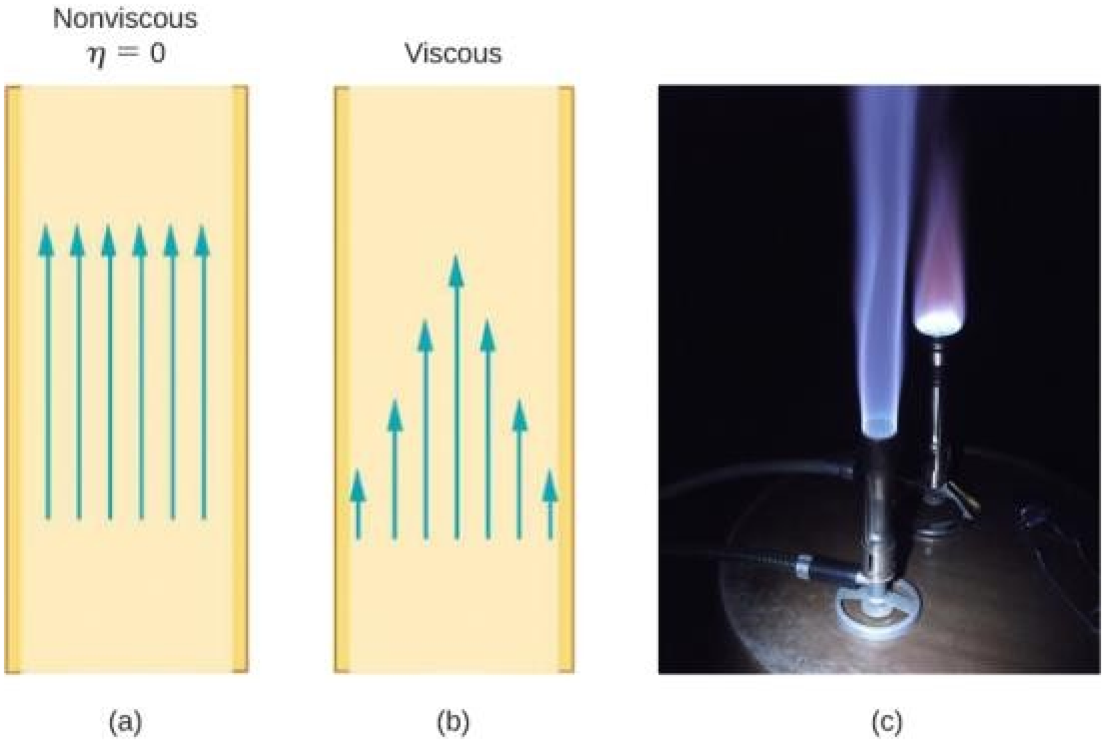
FIGURE 14.36



Measurement of viscosity for laminar flow of fluid between two plates of area *A*. The bottom plate is fixed. When the top plate is pushed to the right, it drags the fluid along with it.

$$\eta = \frac{F L}{v A}$$

FIGURE 14.37

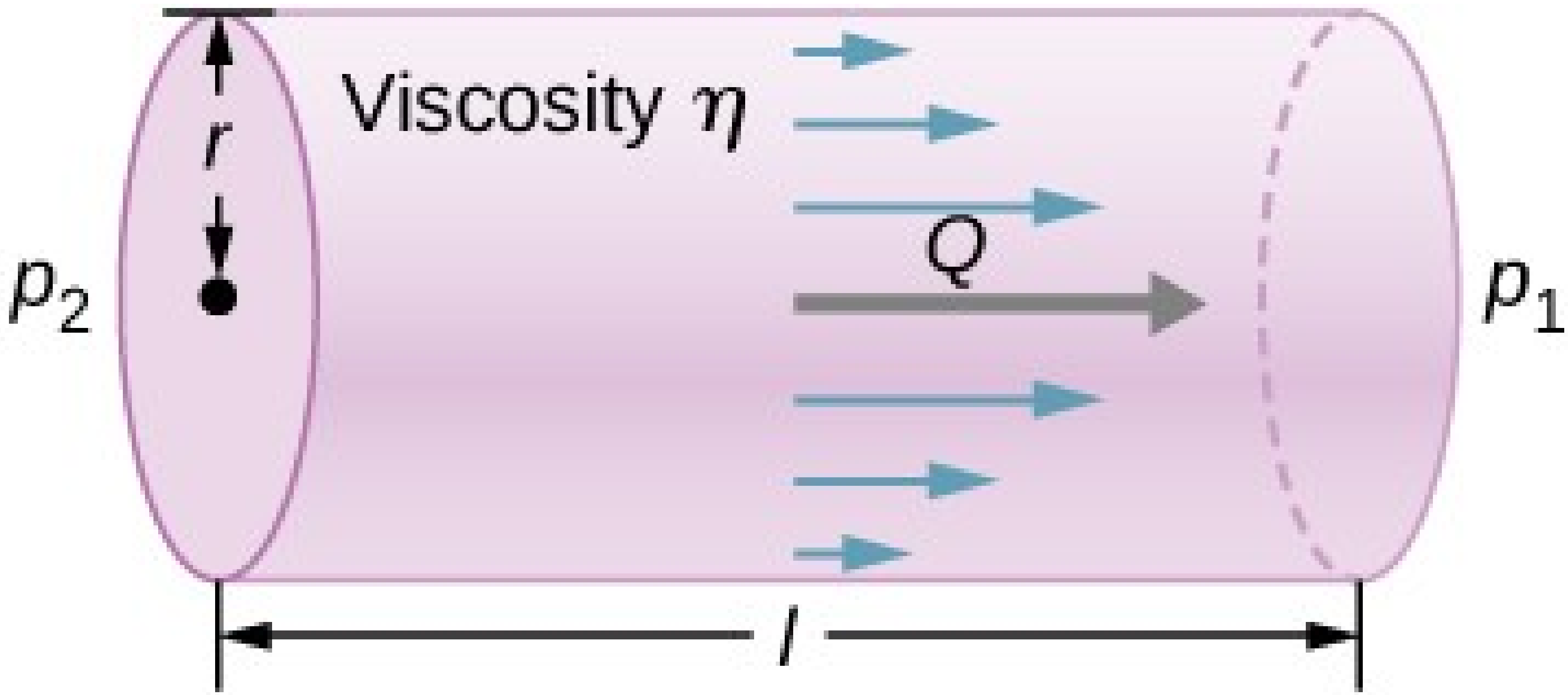


(a) If fluid flow in a tube has negligible resistance, the speed is the same all across the tube.

(b) When a viscous fluid flows through a tube, its speed at the walls is zero, increasing steadily to its maximum at the center of the tube.

(c) The shape of a Bunsen burner flame is due to the velocity profile across the tube. (credit c: modification of work by Jason Woodhead)

FIGURE 14.38



Poiseuille's law applies to laminar flow of an incompressible fluid of viscosity through a tube of length *l* and radius *r*. The direction of flow is from greater to lower pressure. Flow rate *Q* is directly proportional to the pressure difference $p_2 - p_1$, and inversely proportional to the length *l* of the tube and viscosity of the fluid. Flow rate increases with radius by a factor of r^4.

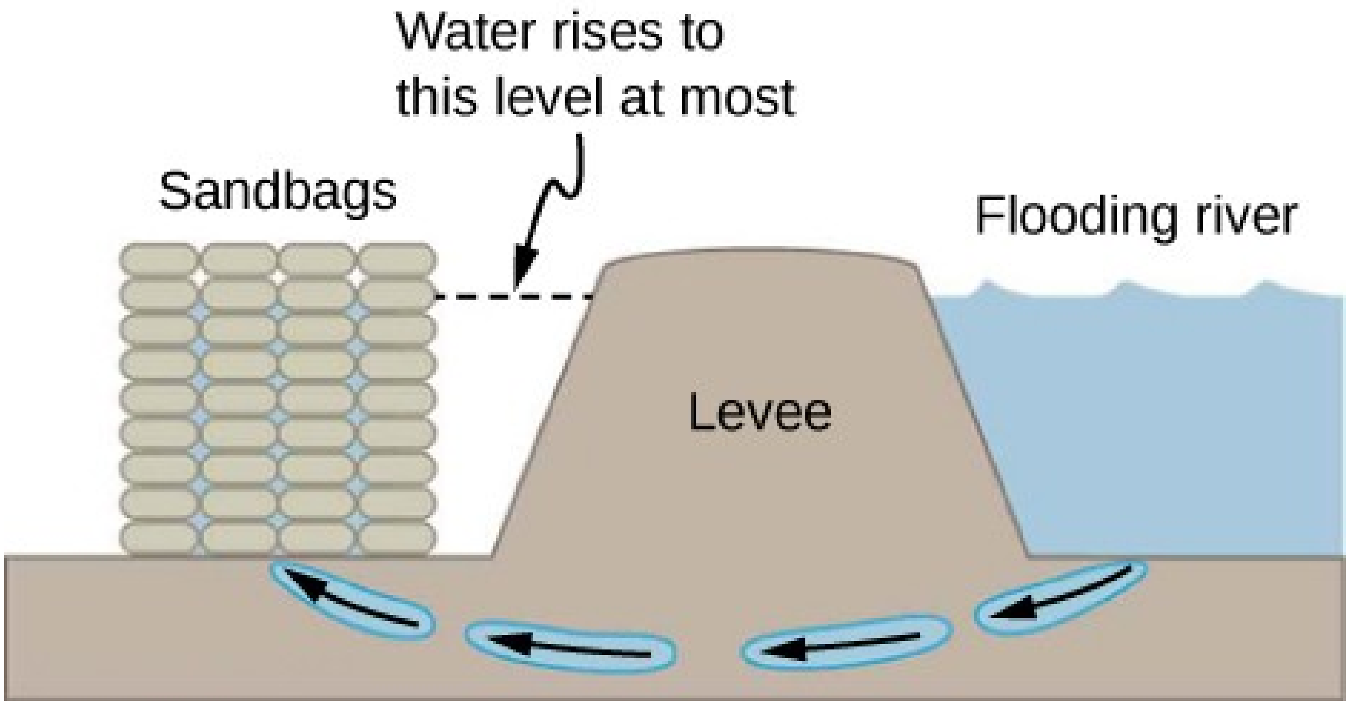
$$Q = \frac{(p_2 - p_1)\pi r^4}{8\eta l}$$

Sample Problems

EXERCISE 4

The image shows a glass of ice water filled to the brim. Will the water overflow when the ice melts? Explain your answer.

EXERCISE 11

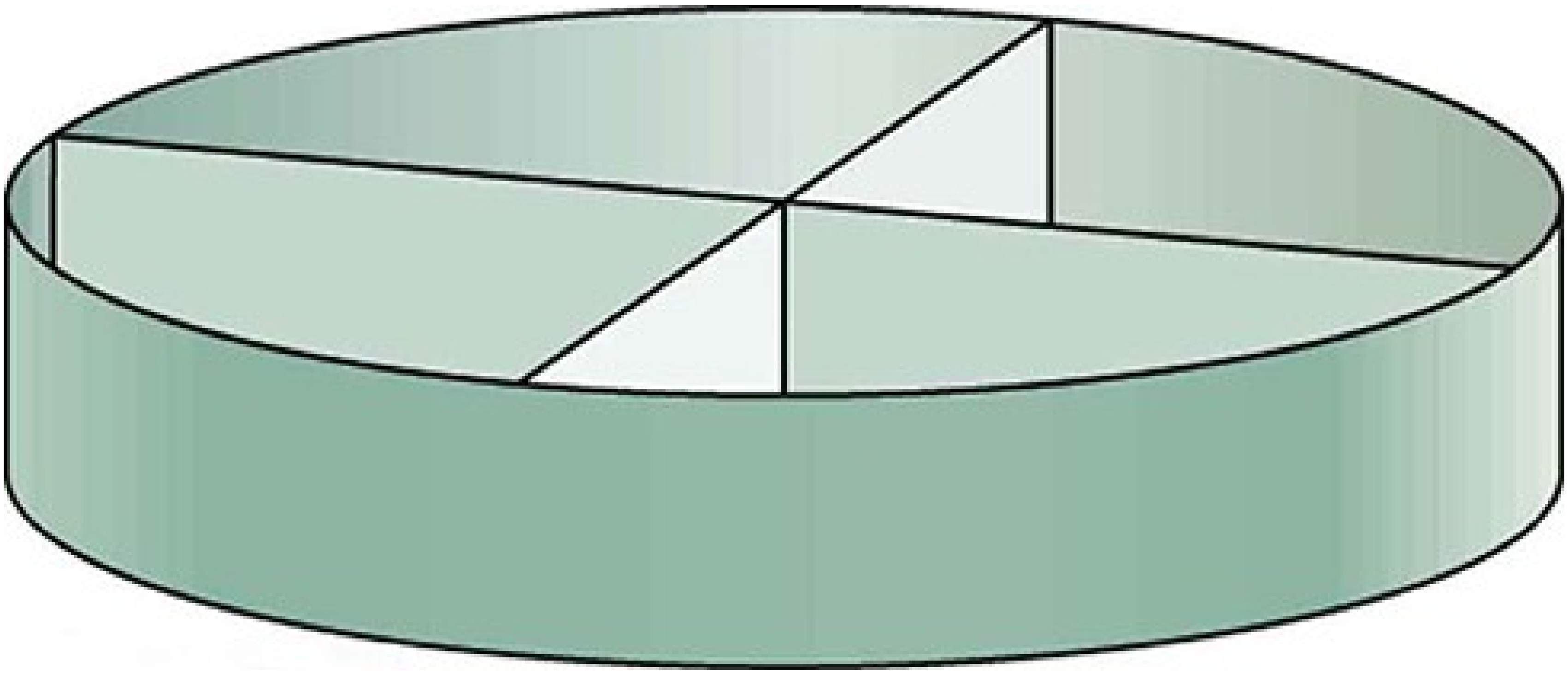


The image shows how sandbags placed around a leak outside a river levee can effectively stop the flow of water under the levee. Explain how the small amount of water inside the column of sandbags is able to balance the much larger body of water behind the levee.

EXERCISE 34

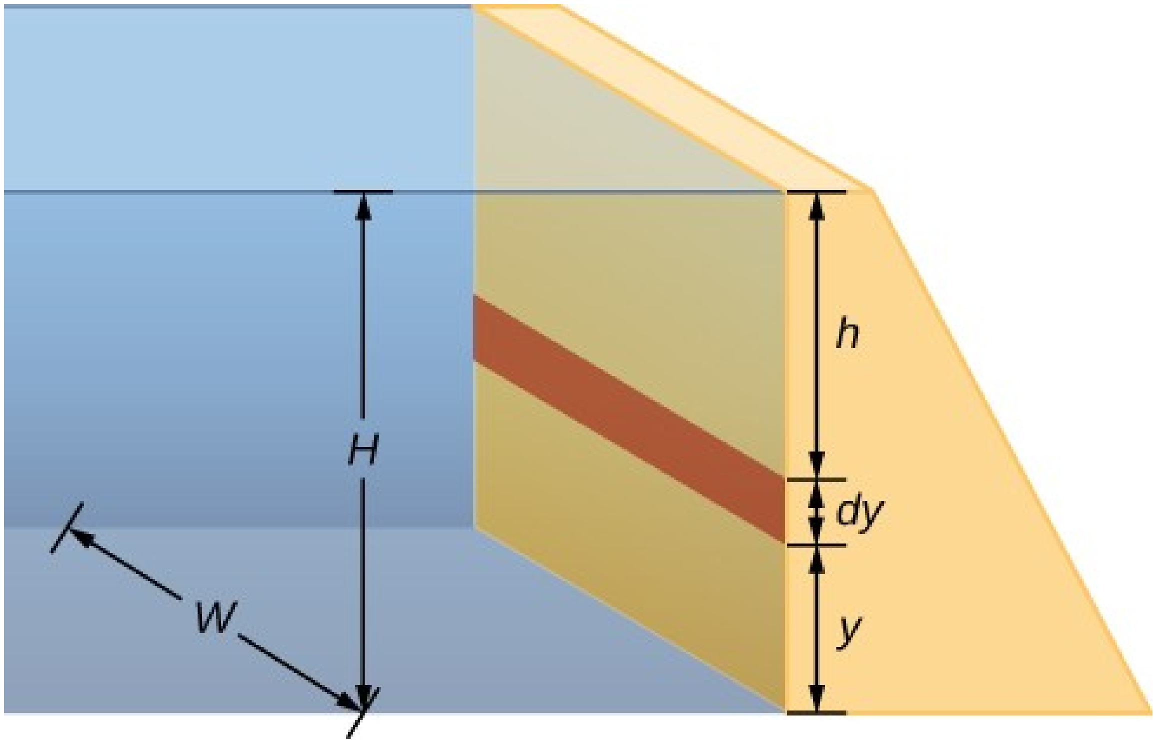
The old rubber boot shown below has two leaks. To what maximum height can the water squirt from Leak 1? How does the velocity of water emerging from Leak 2 differ from that of Leak 1? Explain your responses in terms of energy.

EXERCISE 40



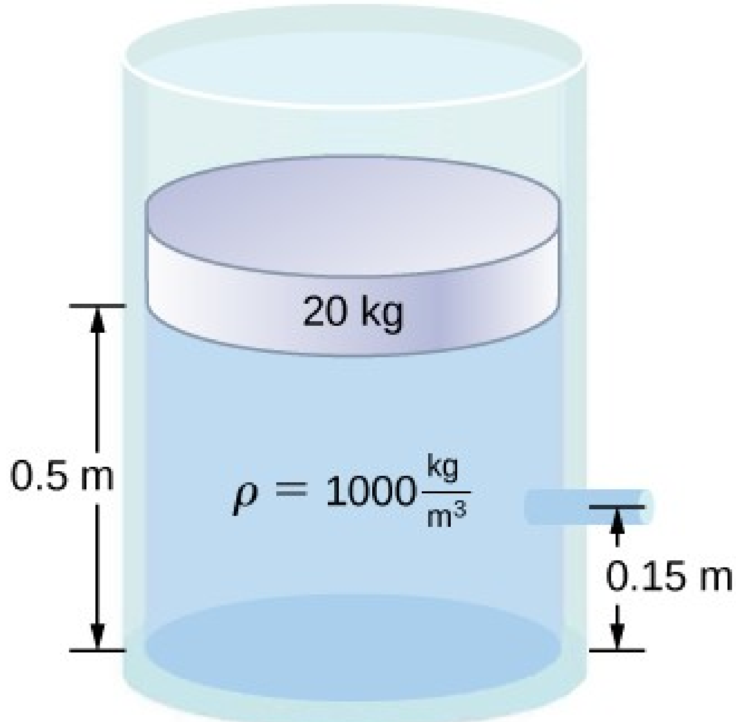
Sink drains often have a device such as that shown below to help speed the flow of water. How does this work?

EXERCISE 55



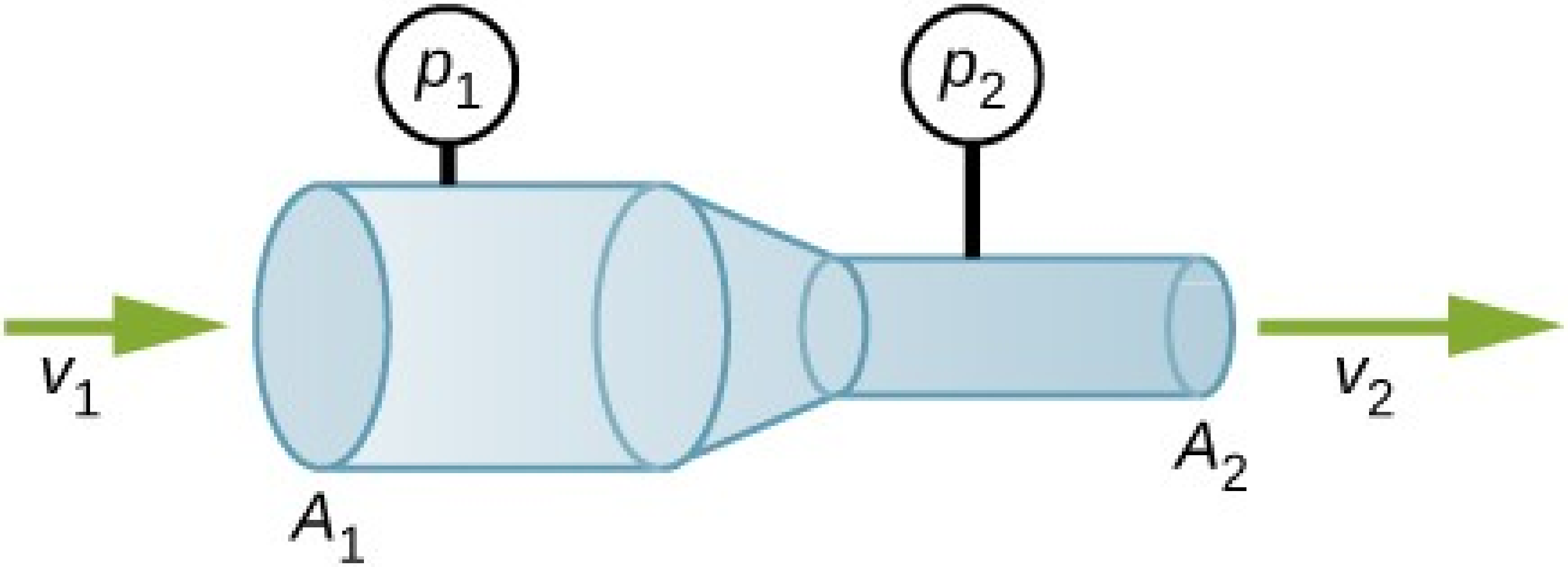
A dam is used to hold back a river. The dam has a height H and a width W Assume that the density of the water is 1 g/cm^3 (a) Determine the net force on the dam. (b) Why does the thickness of the dam increase with depth?

EXERCISE 89



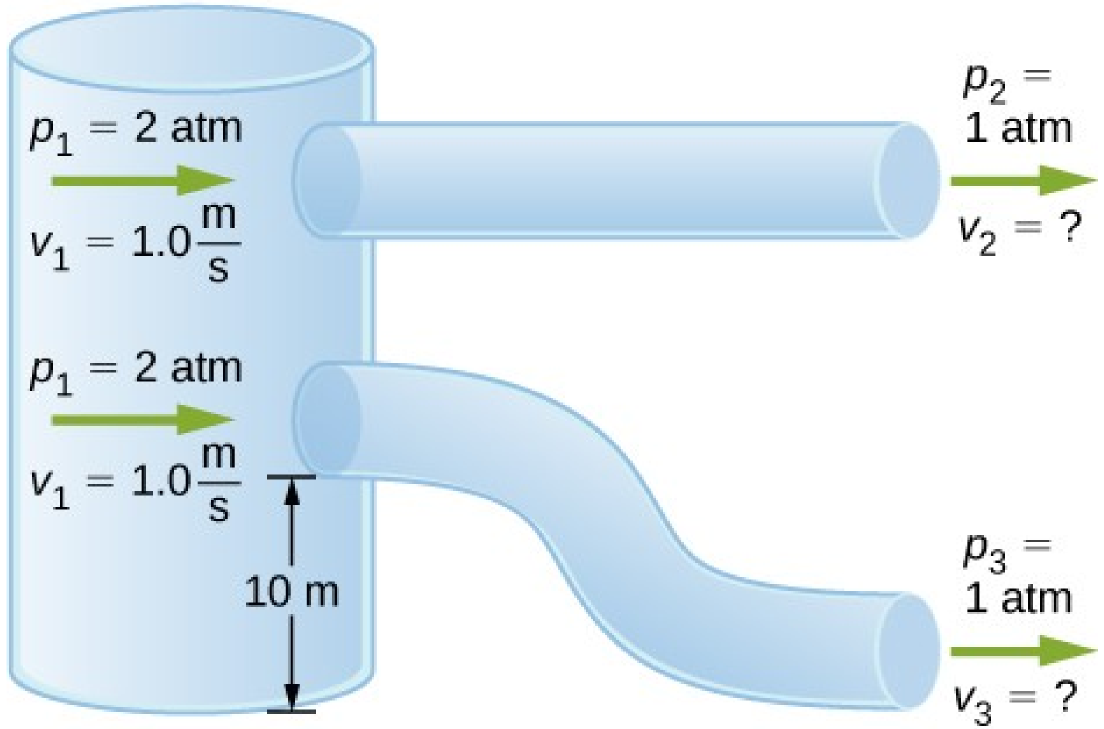
A container of water has a cross-sectional area of $A = 0.1 \text{ m}^2$. A piston sits on top of the water (see the following figure). There is a spout located 0.15 m from the bottom of the tank, open to the atmosphere, and a stream of water exits the spout. The cross sectional area of the spout is (a) What is the velocity of the water as it leaves the spout? (b) If the opening of the spout is located 1.5 m above the ground, how far from the spout does the water hit the floor? Ignore all friction and dissipative forces.

EXERCISE 90



A fluid of a constant density flows through a reduction in a pipe. Find an equation for the change in pressure, in terms of , and the density.

EXERCISE 128



Two pipes of equal and constant diameter leave a water pumping station and dump water out of an open end that is open to the atmosphere (see the following figure). The water enters at a pressure of two atmospheres and a speed of . One pipe drops a height of 10 m. What is the velocity of the water as the water leaves each pipe?