ANNOUNCEMENTS

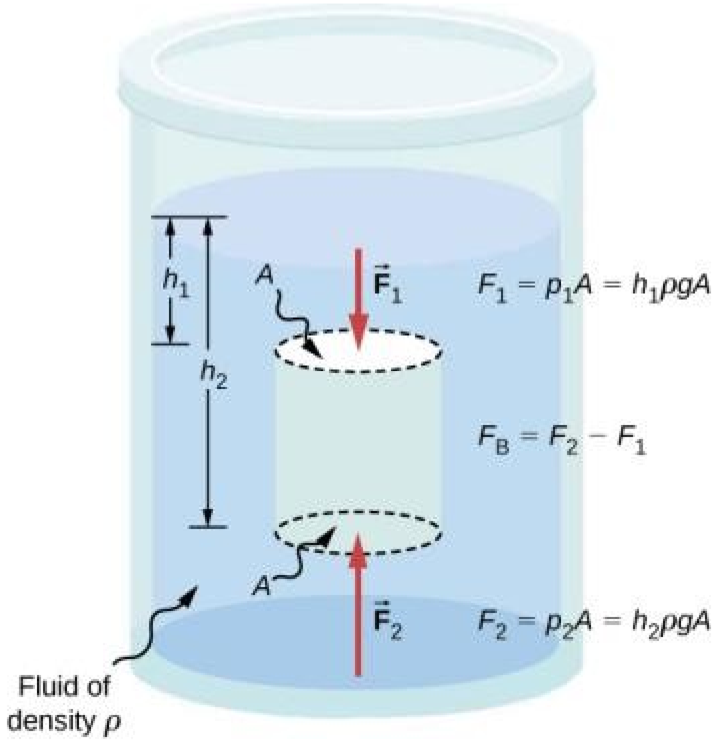
- Homework #14, due Wednesday, Nov. 28 before class

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

- Study Chapter 14 by Wednesday

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

BUOYANT FORCE



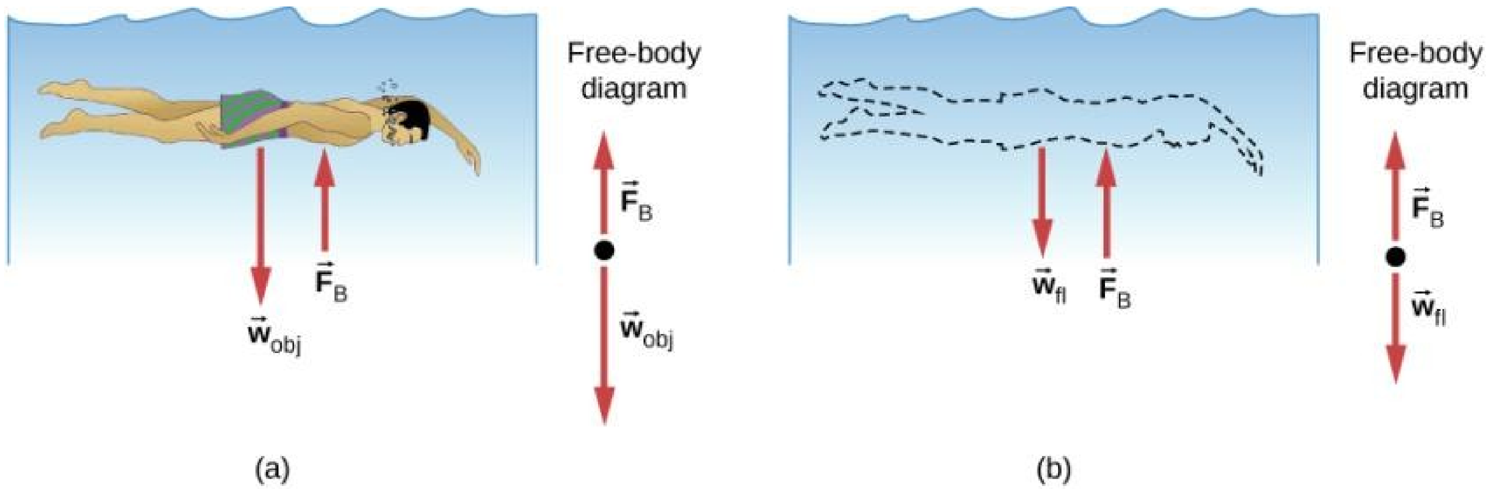
Pressure due to the weight of a fluid increases with depth because $p = h\rho g$. This change in pressure and associated upward force on the bottom of the cylinder are greater than the downward force on the top of the cylinder. The differences in the force results in the buoyant force F_B. (Horizontal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

ARCHIMEDES' PRINCIPLE

The buoyant force on an object equals the weight of the fluid it displaces. In equation form, **Archimedes' principle** is

$$F_{\mathrm{B}} = w_{\mathrm{fl}},$$

where F_{B} is the buoyant force and w_{fl} is the weight of the fluid displaced by the object.



(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.

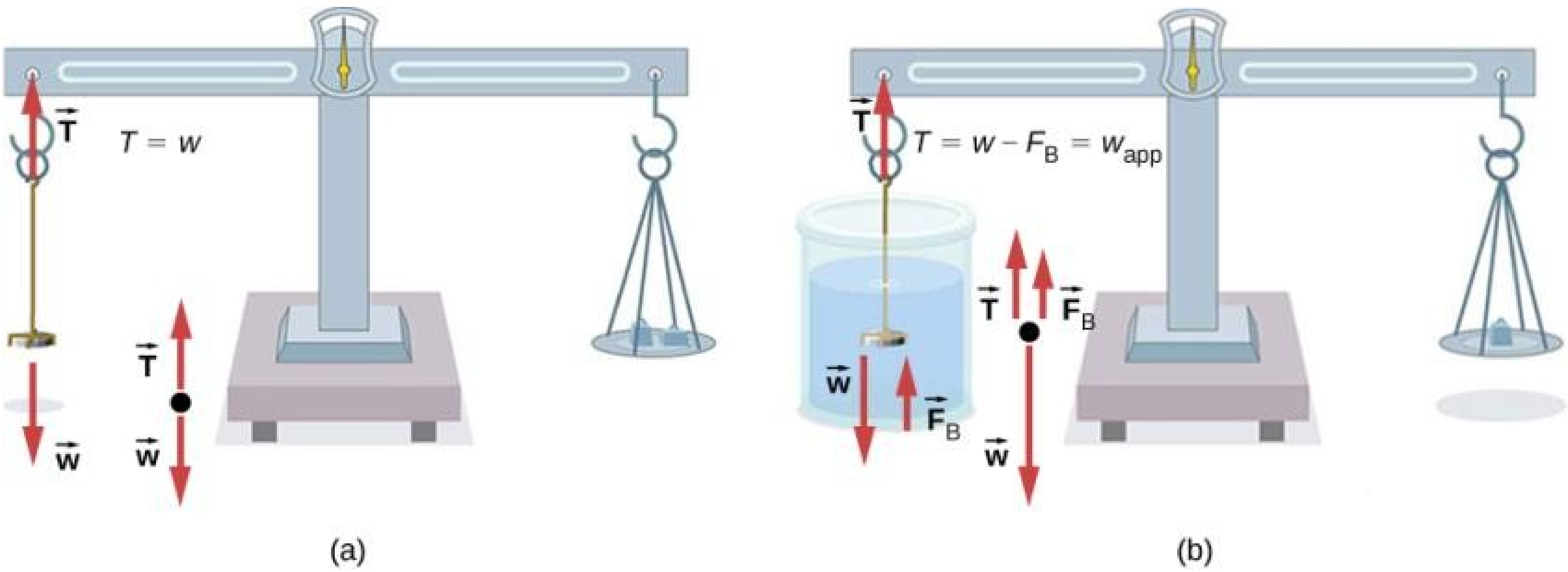
(b) If the object is removed, it is replaced by fluid having weight w_{fl}. Since this weight is supported by surrounding fluid, the buoyant force must equal the weight of the fluid displaced.

(a) (b)

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

$$\text{fraction submerged} = \frac{\rho_{\text{obj}}}{\rho_{\text{fl}}}.$$

MEASURING DENSITIES

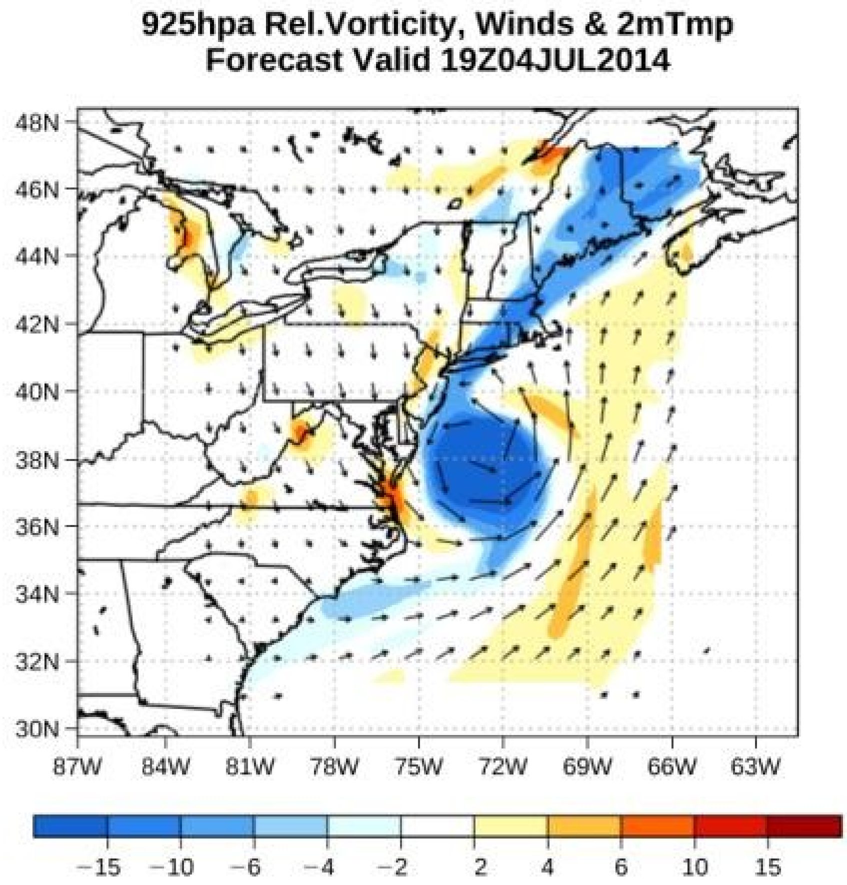


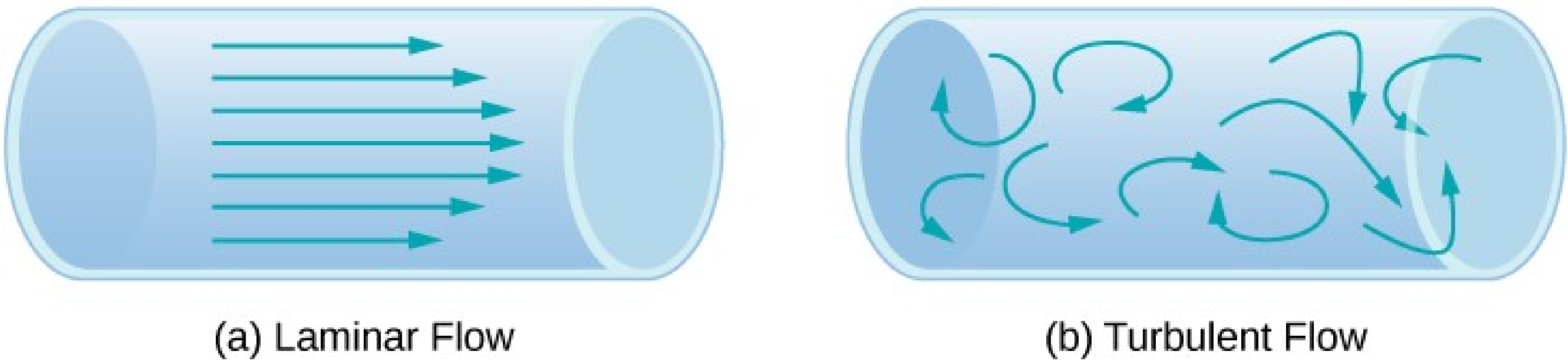
(a) A coin is weighed in air.

(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.

FIGURE 14.24

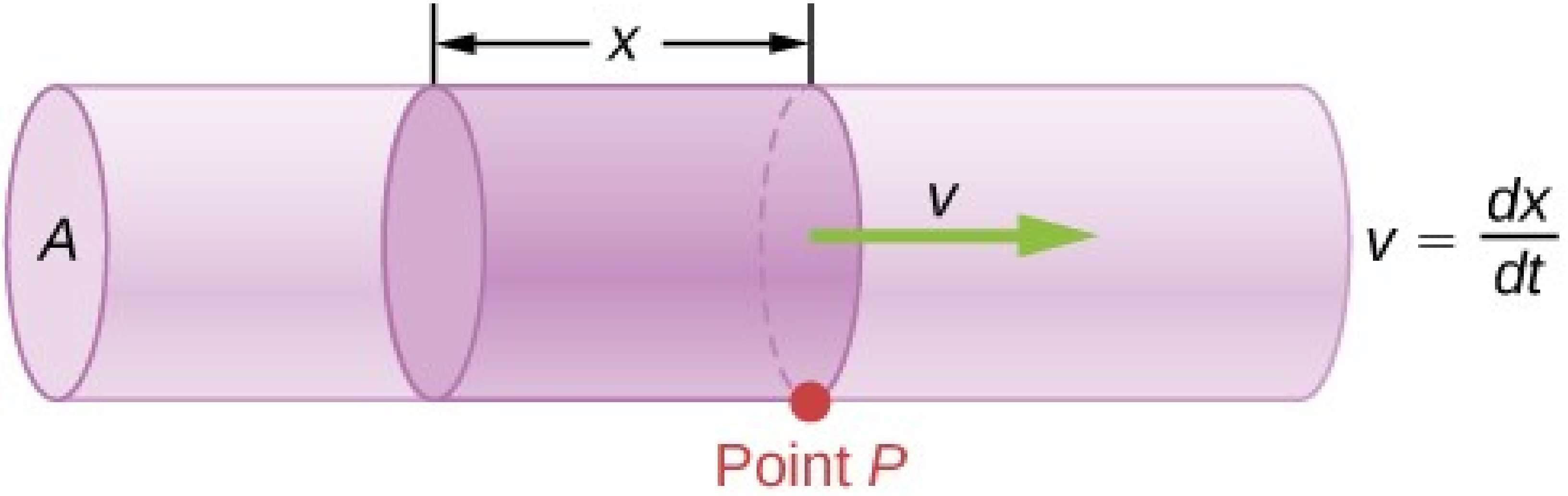
The velocity vectors show the flow of wind in Hurricane Arthur. Notice the circulation of the wind around the eye of the hurricane. Wind speeds are highest near the eye. The colors represent the relative vorticity, a measure of turning or spinning of the air.





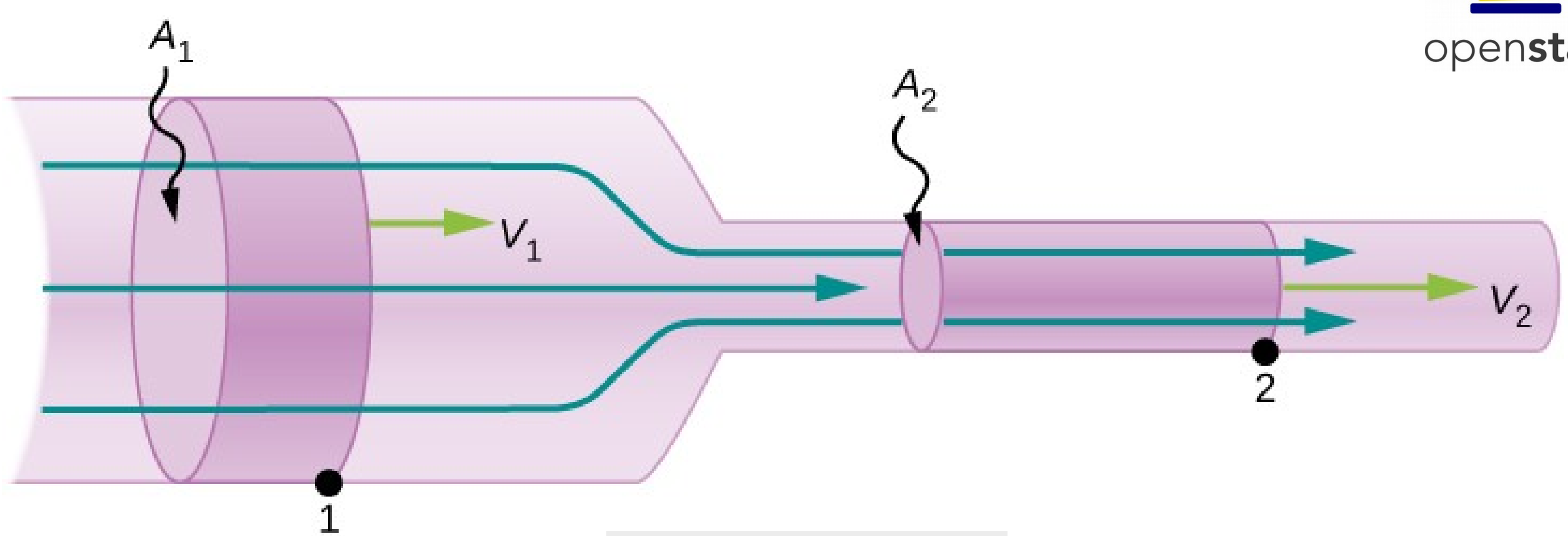
(a) Laminar flow can be thought of as layers of fluid moving in parallel, regular paths.

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



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

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*.

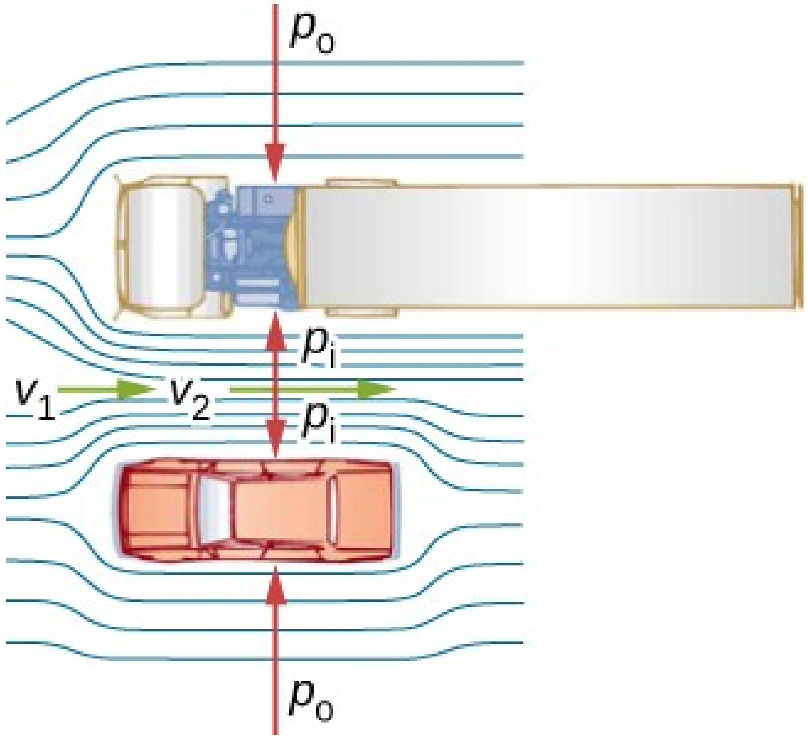


$$Q_1 = Q_2,$$
$$A_1 v_1 = A_2 v_2.$$

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.)

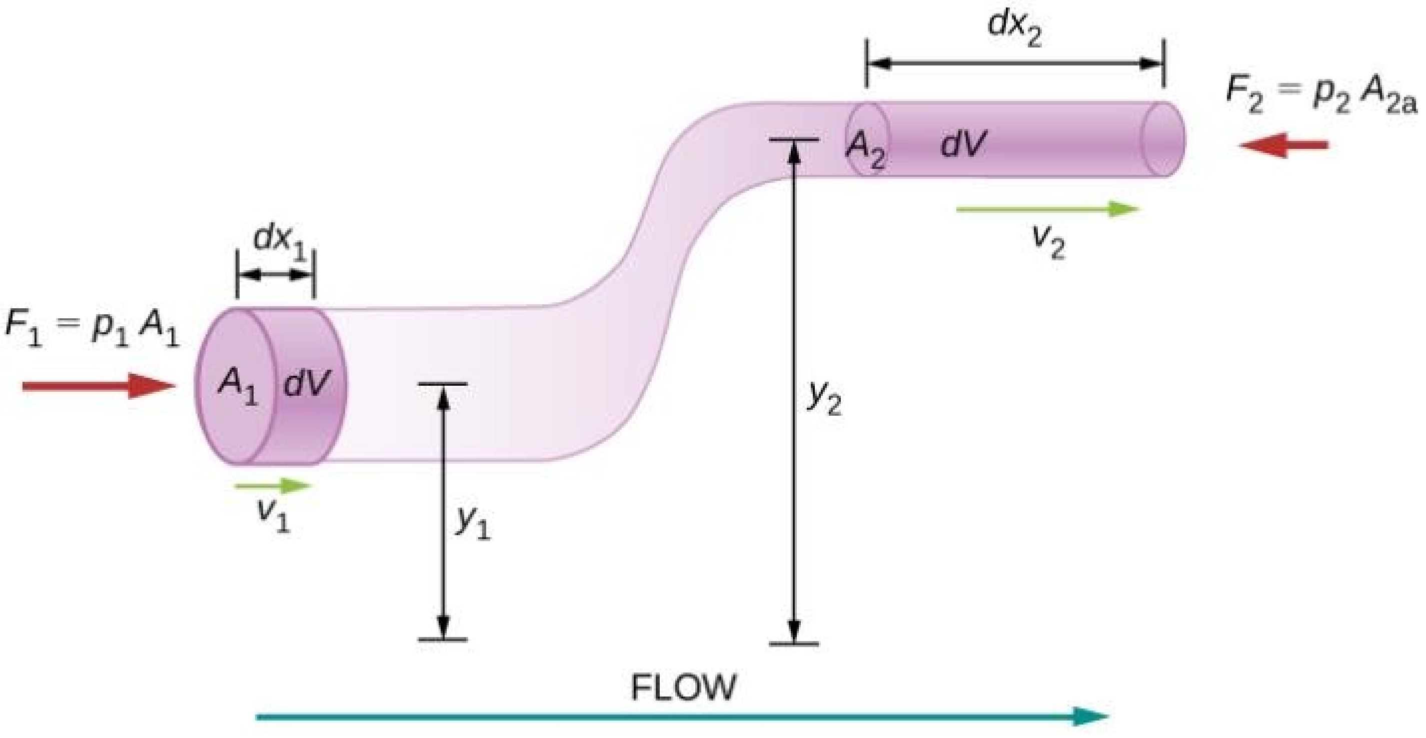
$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2.$$

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.

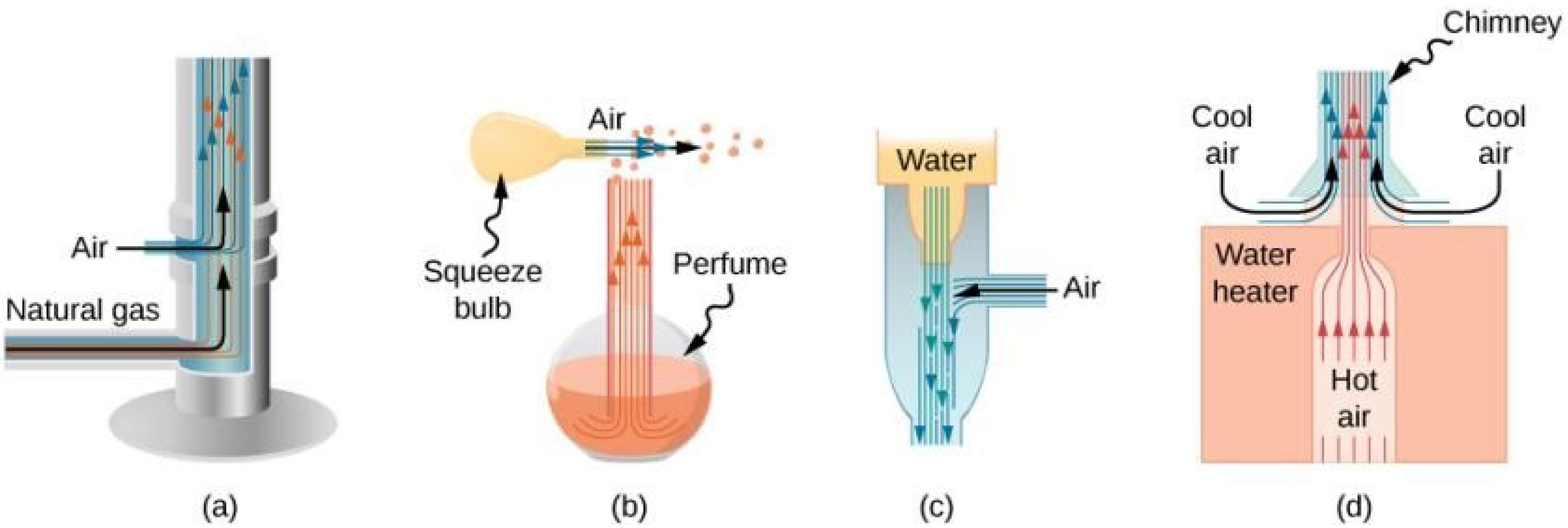
BERNOULLI EQUATION



BERNOULLI'S EQUATION

For an incompressible, frictionless fluid, the combination of pressure and the sum of kinetic and potential energy densities is constant not only over time, but also along a streamline:

$$p + \frac{1}{2}\rho v^2 + \rho g y = \text{constant} \quad (14.16)$$



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.

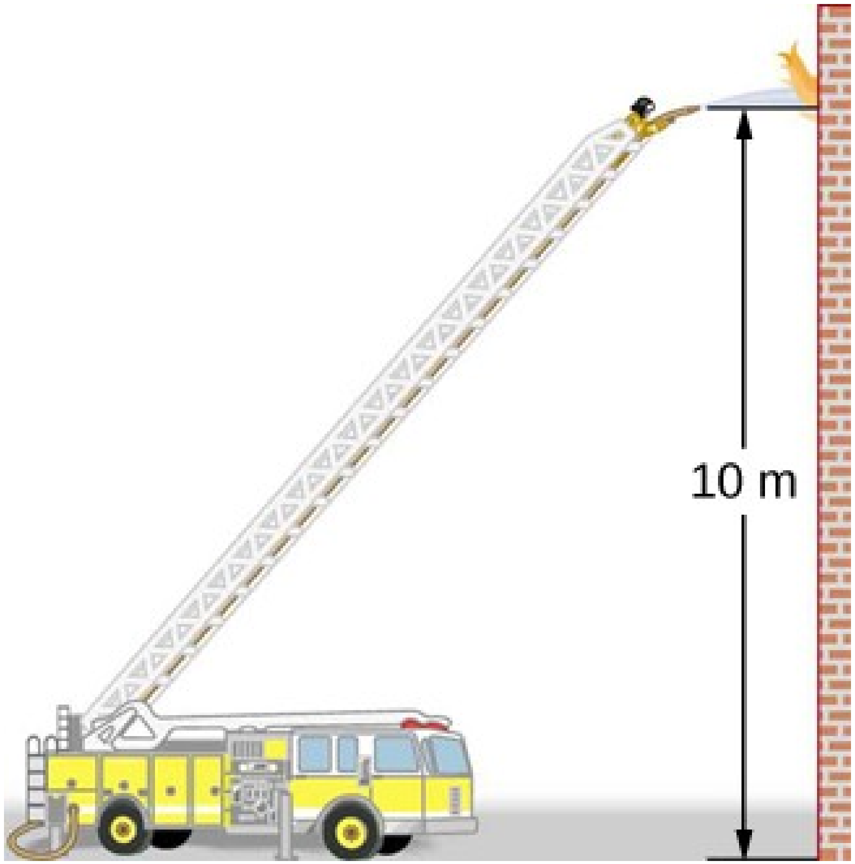
(b) An atomizer uses a squeeze bulb to create a jet of air that entrains drops of perfume. Paint sprayers and carburetors use very similar techniques to move their respective liquids.

(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.

Calculating Pressure: A Fire Hose Nozzle

Fire hoses used in major structural fires have an inside diameter of 6.40 cm (Figure 14.33). Suppose such a hose carries a flow of 40.0 L/s, starting at a gauge pressure of $1.62 \times 10^6 N/m^2$. The hose rises up 10.0 m along a ladder to a nozzle having an inside diameter of 3.00 cm. What is the pressure in the nozzle?



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.

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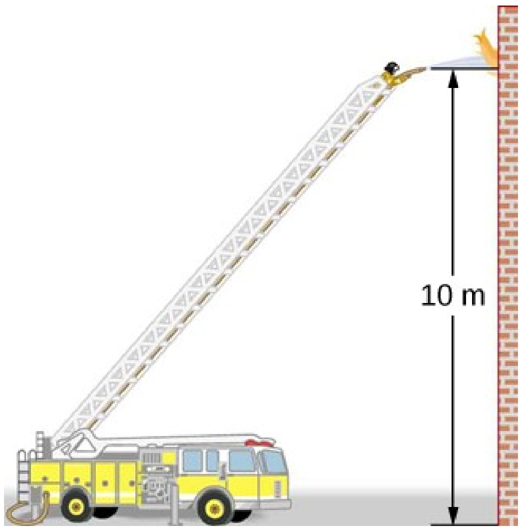


Bernoulli's equation is

$$p_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

where subscripts 1 and 2 refer to the initial conditions at ground level and the final conditions inside the nozzle, respectively. We must first find the speeds v_1 and v_2. Since $Q = A_1 v_1$, we get

$$v_1 = \frac{Q}{A_1} = \frac{40.0 \times 10^{-3} \text{m}^3/\text{s}}{\pi(3.20 \times 10^{-2} \text{m})^2} = 12.4 \text{m/s}.$$

Similarly, we find

$$v_2 = 56.6 \text{ m/s}.$$

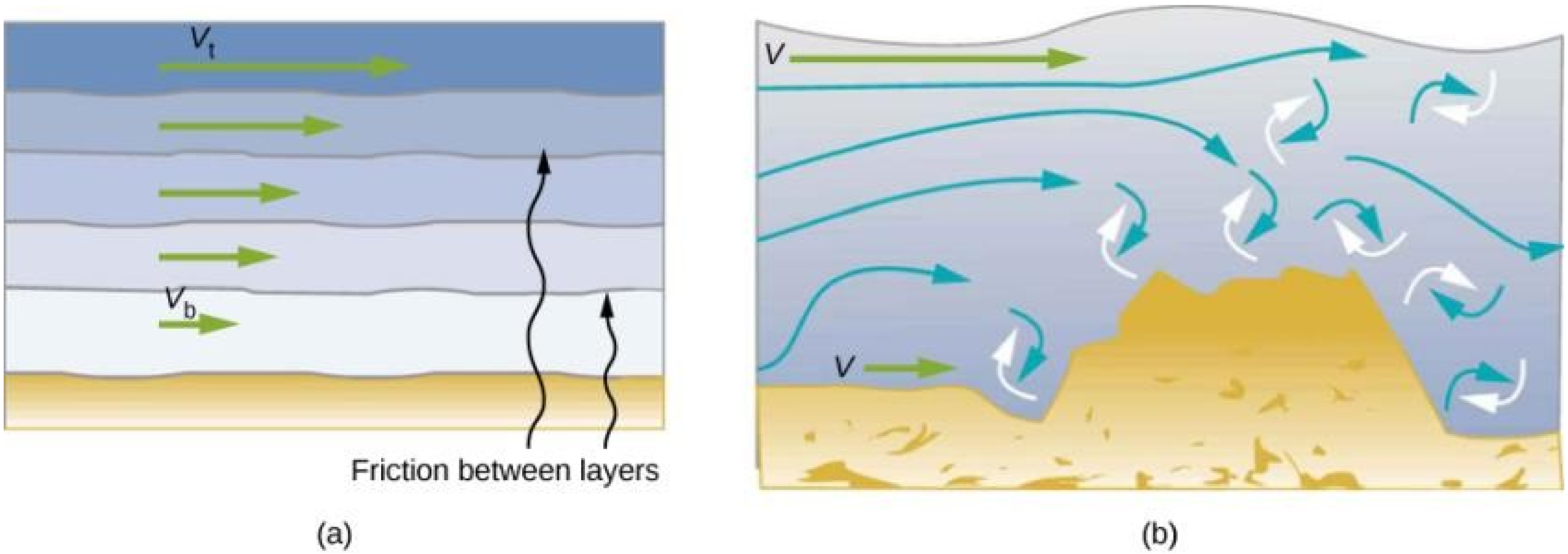
This rather large speed is helpful in reaching the fire. Now, taking h_1 to be zero, we solve Bernoulli's equation for p_2:

$$p_2 = p_1 + \frac{1}{2}\rho(v_1^2 - v_2^2) - \rho g h_2.$$

Substituting known values yields

$$\begin{aligned} p_2 &= 1.62 \times 10^6 \text{ N/m}^2 + \tfrac{1}{2}(1000 \text{ kg/m}^3)[(12.4 \text{ m/s})^2 - (56.6 \text{ m/s})^2] \\ &\quad - (1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(10.0 \text{ m}) \\ &= 0. \end{aligned}$$

VISCOSITY AND TURBULENCE



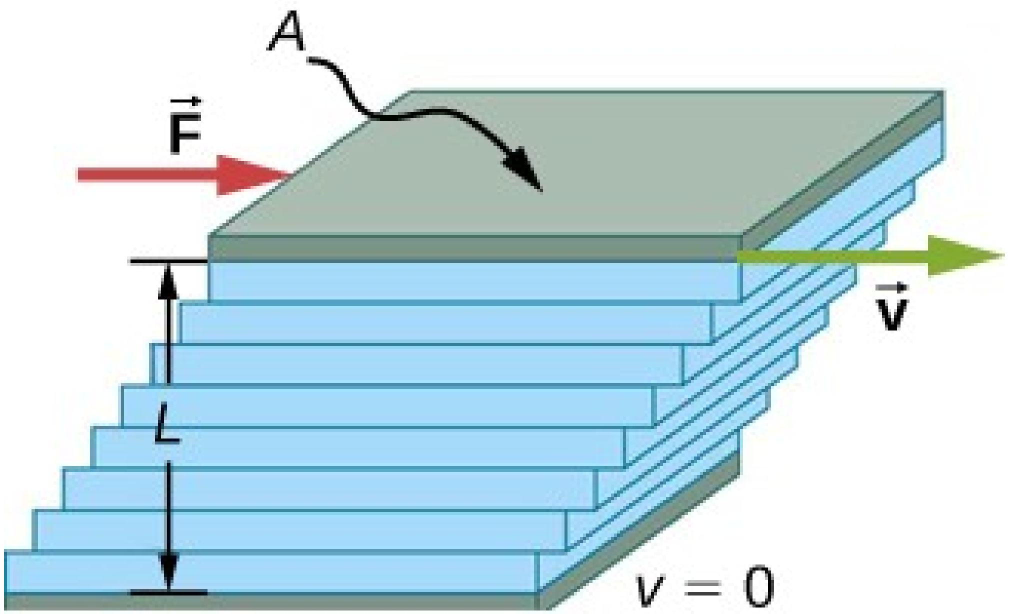
(a) Laminar flow occurs in layers without mixing. Notice that viscosity causes drag between layers as well as with the fixed surface. The speed near the bottom of the flow (v_b) is less than speed near the top (v_t) because in this case, the surface of the containing vessel is at the bottom.

(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 14.35

Smoke rises smoothly for a while and then begins to form swirls and eddies. The smooth flow is called laminar flow, whereas the swirls and eddies typify turbulent flow. Smoke rises more rapidly when flowing smoothly than after it becomes turbulent, suggesting that turbulence poses more resistance to flow. (credit: “Creativity103”/Flickr)

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.



$$F = \eta \frac{vA}{L}.$$

This equation gives us a working definition of fluid viscosity η. Solving for η gives

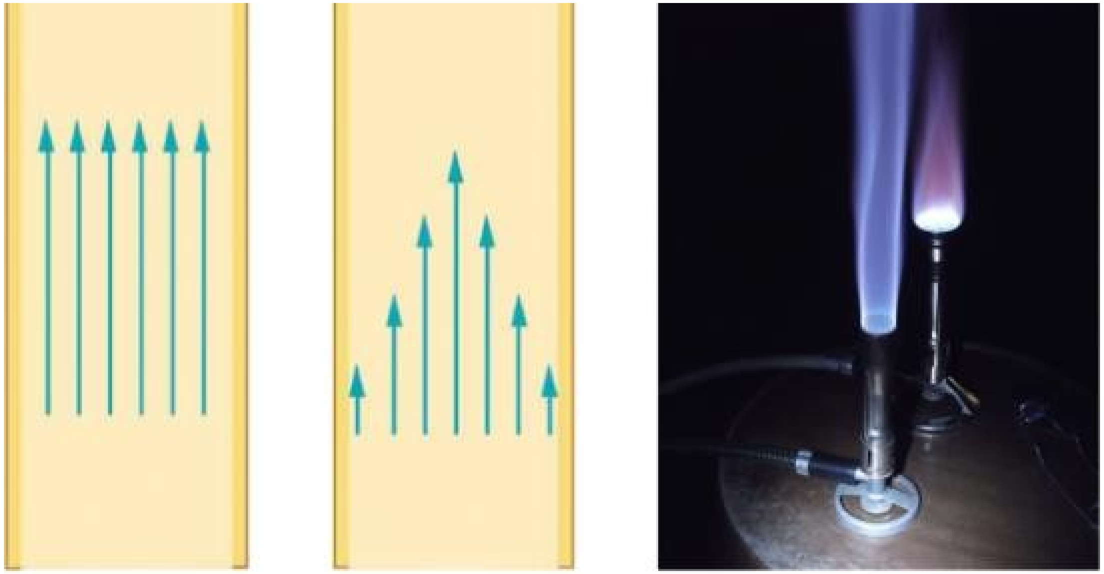
$$\eta = \frac{FL}{vA} \tag{14.17}$$

Laminar Flow Confined to Tubes: Poiseuille's Law

What causes flow? The answer, not surprisingly, is a pressure difference. In fact, there is a very simple relationship between horizontal flow and pressure. Flow rate *Q* is in the direction from high to low pressure. The greater the pressure differential between two points, the greater the flow rate. This relationship can be stated as

$$Q = \frac{p_2 - p_1}{R}$$

where p_1 and p_2 are the pressures at two points, such as at either end of a tube, and *R* is the resistance to flow. The resistance *R* includes everything, except pressure, that affects flow rate. For example, *R* is greater for a long tube than for a short one. The greater the viscosity of a fluid, the greater the value of *R*. Turbulence greatly increases *R*, whereas increasing the diameter of a tube decreases *R*.



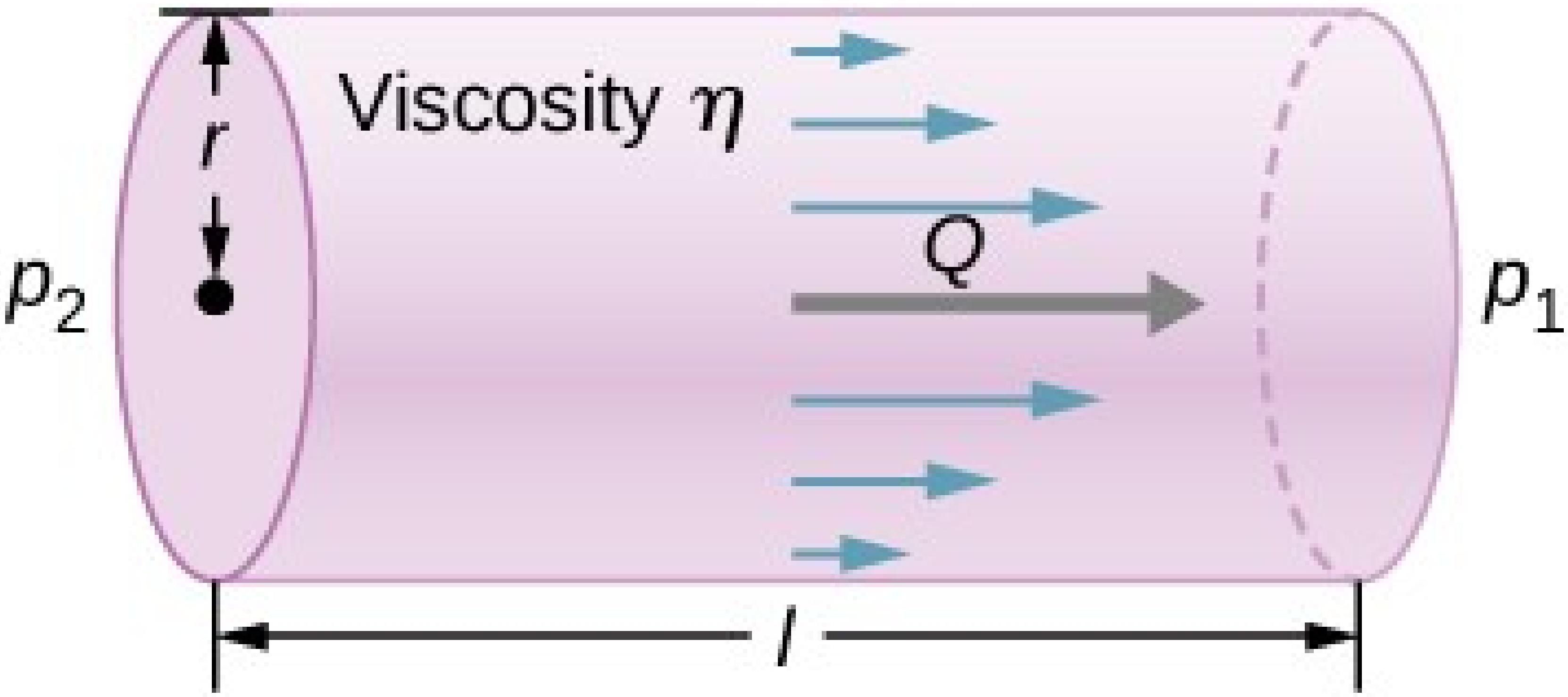
(a) (b) (c)

(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 η 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 η of the fluid. Flow rate increases with radius by a factor of r^4.

$$R = \frac{8\eta l}{\pi r^4}.$$

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

Measuring Turbulence

An indicator called the **Reynolds number** N_R can reveal whether flow is laminar or turbulent. For flow in a tube of uniform diameter, the Reynolds number is defined as

$$N_R = \frac{2\rho v r}{\eta} \text{(flow in tube)} \tag{14.20}$$

where ρ is the fluid density, v its speed, η its viscosity, and r the tube radius. The Reynolds number is a dimensionless quantity. Experiments have revealed that N_R is related to the onset of turbulence. For N_R below about 2000, flow is laminar. For N_R above about 3000, flow is turbulent.