14

Fluid Mechanics

CHAPTER OUTLINE

* An asterisk indicates a question or problem new to this edition.

SOLUTIONS TO THINK-PAIR-SHARE AND ACTIVITIES

***TP14.1.** Answers: (a) Regardless of the gas inside the football, as long as it is filled to the proper pressure, the football has the same volume. The buoyant force on the football from the air depends only on its volume, so the helium inside has no effect.

(b) The helium-filled football will be slightly less massive (about 1%) than the air-filled football, so the football with helium will be more subject to air resistance and wind. Both *Sports Illustrated* and *Mythbusters* have studied the helium-filled football and found that kicks and passes are *shorter* with the helium.

***TP14.2.** Let's look at the first proposed activity: the student has the mouthpiece in his mouth and sinks to the bottom while breathing. The process of breathing begins when the chest muscles expand to reduce the pressure in the lungs, causing air to be pushed into the lungs by the atmosphere. When surrounded by air, the chest muscles only have to push against the air pressure surrounding the student. When he is surrounded by water, there is both the atmospheric pressure and the pressure due to the water surrounding the student. His chest muscles must push against the force due to both pressures underwater. Because his body is used to only having to push against the force due to atmospheric pressure, it has difficulty moving the chest outward against a larger pressure. It turns out that only about 0.6 m of water is enough to provide a pressure against which one cannot expand the chest. Therefore, as he sinks to the bottom of the pool, he will find that he cannot expand his chest to take a breath, and the long snorkel is useless. He will notice this as he sinks and will hopefully abandon the snorkel and swim to the surface.

Now, let's address the *very dangerous* second activity, in which the student sinks to the bottom of the pool with the end of the snorkel closed and then puts it in your mouth. When he is surrounded by water at higher pressure than atmospheric pressure, his entire body is at a higher pressure. That includes the air in his lungs and his blood. The normal design of the lungs is that the higher air pressure in the lungs pushes oxygen into the lower pressure blood. When he puts the end of the snorkel in his mouth and releases the end, he suddenly has a connection to the atmosphere at the upper end, which is at a lower pressure than the air in his lungs. The high-pressure air in his lungs will suddenly rush up the PVC pipe, and his blood pressure will be higher than the air pressure in his lungs. The result is a *pneumothorax*: his lungs will collapse. If the pressure difference is large enough, blood will enter his lungs from the capillaries.

A related phenomenon occurs in scuba divers. If a scuba diver is rising from a deep dive, he or she *must* exhale as he or she rises. If not, the air pressure in the lungs stays fixed while the outer pressure on the body decreases. Because of this decreasing outside pressure, the diver's blood pressure also decreases. As a result, the high pressure in the lungs can force air into the blood vessels, creating an *air embolism*: bubbles in the bloodstream. These bubbles can travel throughout the body, including to the heart, possibly leading to cardiac arrest.

Answers: Answers will vary, but have to do with the effects of high pressure on the human lung system.

***TP14.3.** (a) The effective density of the diet soda is slightly less than that of water because of the artificial sweetener. Think about a packet of sugar and a packet of artificial sweetener with the same "sweetening power." The packet of artificial sweetener is lighter than the packet of sugar because the amount of the artificial sweetener needed to provide a certain "sweetening power" is lower than that for sugar. The amount of sugar needed to sweeten a soft drink is high enough that the effective density of the can–soda combination is slightly higher than that of water and the regular, sugar-sweetened soda sinks.

(b) Bubbles of carbon dioxide from the carbonation of the drink will adhere to the raisins. When enough bubbles adhere, the effective density of the raisin–bubble combination is less than that of the beverage, and the raisin rises to the surface. At the surface, the bubbles pop and the gas goes into the atmosphere. The now de-bubbled raisin sinks back to the bottom and begins gathering new bubbles, preparing to rise again.

Answers: (a) Diet soda floats; regular soda sinks. (b) Raisins alternately sink and float for several minutes after being added to the liquid.

SOLUTIONS TO END-OF-CHAPTER PROBLEMS

Section 14.1 Pressure

P14.1 We shall assume that each chair leg supports one-fourth of the total weight so the normal force each leg exerts on the floor is $n = mg/4$. The pressure of each leg on the floor is then

$$P_{\text{leg}} = \frac{n}{A_{\text{leg}}} = \frac{mg/4}{\pi r^2} = \frac{(95.0\text{ kg})(9.80\text{ m/s}^2)}{4\pi(0.500\times10^{-2}\text{ m})^2} = \boxed{2.96\times10^6\text{ Pa}}$$

P14.2 (a) If the particles in the nucleus are closely packed with negligible space between them, the average nuclear density should be approximately that of a proton or neutron. That is

$$\rho_{\text{nucleus}} \approx \frac{m_{\text{proton}}}{V_{\text{proton}}} = \frac{m_{\text{proton}}}{4\pi r^3/3} \sim \frac{3\left(1.67\times10^{-27}\ \text{kg}\right)}{4\pi\left(1\times10^{-15}\ \text{m}\right)^3}$$

$$\boxed{\sim 4\times10^{17}\ \text{kg/m}^3}$$

(b)

The density of an atom is about 10^{14} times greater than the density of iron and other common solids and liquids. This shows that an atom is mostly empty space. Liquids and solids, as well as gases, are mostly empty space.

P14.3 The Earth's surface area is $4\pi R^2$. The force pushing inward over this area amounts to

$$F = P_0 A = P_0\left(4\pi R^2\right)$$

This force is the weight of the air:

$$F_g = mg = P_0\left(4\pi R^2\right)$$

so, assuming g is everywhere the same, the mass of the air is

$$m = \frac{P_0\left(4\pi R^2\right)}{g}$$

$$= \frac{\left(1.013\times10^5\ \text{N/m}^2\right)\left[4\pi\left(6.37\times10^6\ \text{m}\right)^2\right]}{9.80\ \text{m/s}^2}$$

$$= \boxed{5.27\times10^{18}\ \text{kg}}$$

Section 14.2 Variation of Pressure with Depth

P14.4 We imagine Superman can produce a perfect vacuum in the straw.

Take point 1, at position $y_1 = 0$, to be at the water's surface and point 2, at position y_2 = length of straw, to be at the upper end of the straw. What is the greatest length of straw that will allow Superman to drink? Solve for y_2:

$$P_1 + \rho g y_1 = P_2 + \rho g y_2$$

$$1.013 \times 10^5 \text{ Pa} + 0 = 0 + (10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2)y_2$$

or $\quad y_2 = 10.3$ m.

The situation is impossible because the longest straw Superman can use and still get a drink is less than 12.0 m.

P14.5 $\quad F_g = (80.0 \text{ kg})(9.80 \text{ m/s}^2) = 784 \text{ N}$

When the cup barely supports the student, the normal force of the ceiling is zero and the cup is in equilibrium.

$$F_g = F = PA = (1.013 \times 10^5 \text{ Pa})A$$
$$A = \frac{F_g}{P} = \frac{784 \text{ N}}{1.013 \times 10^5 \text{ Pa}} = \boxed{7.74 \times 10^{-3} \text{ m}^2}$$

P14.6 $\quad$ The excess water pressure (over air pressure) halfway down is

$$P_{\text{gauge}} = \rho g h = (1\,000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(1.20 \text{ m})$$
$$= 1.18 \times 10^4 \text{ Pa}$$

The force on the wall due to the water is

$$F = P_{\text{gauge}} A = (1.18 \times 10^4 \text{ Pa})(2.40 \text{ m})(9.60 \text{ m})$$
$$= \boxed{2.71 \times 10^5 \text{ N}}$$

P14.7 $\quad$ The bell is uniformly compressed, so we can model it with any shape. We choose a sphere of diameter 3.00 m.

The pressure on the ball is given by $P = P_{\text{atm}} + \rho_w gh$, so the change in pressure on the ball from when it is on the surface of the ocean to when it is at the bottom of the ocean is $\Delta P = \rho_w gh$.

In addition,

$$\Delta V = \frac{-V\Delta P}{B} = \frac{-\rho_w ghV}{B} = -\frac{4\pi\rho_w ghr^3}{3B}$$

where B is the bulk modulus. Substituting,

$$\Delta V = -\frac{4\pi\left(1\ 030\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(1\ 000\ \text{m}\right)\left(1.50\ \text{m}\right)^3}{3\left(14.0\times 10^{10}\ \text{Pa}\right)}$$
$$\Delta V = -1.02\times 10^{-3}\ \text{m}^3$$

From $V = \frac{4}{3}\pi r^3 \to dV = 4\pi r^2 dr$, we use $r = 1.50$ m, set $dV = \Delta V$, and solve for dr:

$$dr = -3.60\times 10^{-5}\ \text{m}$$

Therefore, the diameter decreases by $\boxed{0.072\ 1\ \text{mm.}}$

Section 14.3 Pressure Measurements

P14.8 (a) $P = P_0 + \rho gh$ and the gauge pressure is

$$P - P_0 = \rho gh = \left(1\ 000\ \text{kg}\right)\left(9.8\ \text{m/s}^2\right)\left(0.160\ \text{m}\right)$$
$$= \boxed{1.57\ \text{kPa}} = \left(1.57\times 10^3\ \text{Pa}\right)\left(\frac{1\ \text{atm}}{1.013\times 10^5\ \text{Pa}}\right)$$
$$= \boxed{0.015\ 5\ \text{atm}}$$

It would lift a mercury column to height

$$h = \frac{P - P_0}{\rho g} = \frac{1\,568 \text{ Pa}}{\left(13\,600 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)} = \boxed{11.8 \text{ mm}}$$

(b)

Blockage of the fluid within the spinal column or between the skull and the spinal column would prevent the fluid level from rising.

P14.9 (a) To find the height of the column of wine, we use

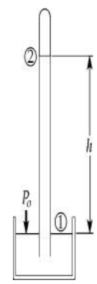
$$P_0 = \rho g h$$

then

$$h = \frac{P_0}{\rho g}$$

$$= \frac{1.013 \times 10^5 \text{ Pa}}{\left(0.984 \times 10^3 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)}$$

$$= \boxed{10.5 \text{ m}}$$



ANS. FIG. P14.9

(b) No. The vacuum is not as good because some alcohol and water will evaporate. The equilibrium vapor pressures of alcohol and water are higher than the vapor pressure of mercury.

P14.10 (a) We can directly write the bottom pressure as $P = P_0 + \rho g h$, or we can say that the bottom of the tank must support the weight of the water:

$$PA - P_0 A = m_{\text{water}} g = \rho V g = \rho A h g$$

which gives again

$$\boxed{P = P_0 + \rho g h}$$

(b) Now, the bottom of the tank must support the weight of the whole contents:

$$P_b A - P_0 A = m_{\text{water}} g + Mg = \rho V g + Mg = \rho A h g + Mg$$

and this gives

$$P_b = P_0 + \rho h g + Mg/A$$

Then

$$\Delta P = P_b - P = \boxed{\frac{Mg}{A}}$$

Section 14.4 Buoyant Forces and Archimedes's Principle

P14.11 Refer to Figure P14.11. We observe from the left-hand diagram,

$$\sum F_y = 0 \quad \rightarrow \quad T_1 = F_g = m_{\text{object}} g = \rho_{\text{object}} g V_{\text{object}}$$

and from the right-hand diagram,

$$\sum F_y = 0 \quad \rightarrow \quad T_2 + B = F_g \quad \rightarrow \quad T_2 + B = T_1$$

which gives

$$T_2 - T_1 = B$$

where the buoyant force is

$$B = m_{\text{water}} g = \rho_{\text{w}} V_{\text{object}} g$$

Now the density of the object is

$$\rho_{\text{object}} = \frac{m_{\text{object}}}{V_{\text{object}}} = \frac{T_1/g}{B/(\rho_w g)} = \frac{\rho_w T_1}{B}$$

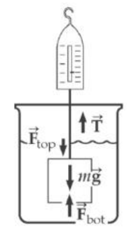
$$\rho_{\text{object}} = \frac{\rho_w T_1}{T_1 - T_2} = \frac{(1\ 000\ \text{kg/m}^3)(5.00\ \text{N})}{1.50\ \text{N}} = \boxed{3.33 \times 10^3\ \text{kg/m}^3}$$

P14.12 (a) We start with $P = P_0 + \rho g h.$

Taking $P_0 = 1.013 \times 10^5\ \text{N/m}^2$,

$\rho_{\text{water}} = 1\ 000\ \text{kg/m}^3$, and $h = 5.00$ cm,

we find $P_{\text{top}} = 1.017\ 9 \times 10^5\ \text{N/m}^2.$



ANS. FIG. P14.12

For $h = 17.0$ cm, we get

$$P_{\text{bot}} = 1.029\ 7 \times 10^5\ \text{N/m}^2$$

Since the areas of the top and bottom are

$$A = (0.100\ \text{m})^2 = 10^{-2}\ \text{m}^2$$

we find

$$F_{\text{top}} = P_{\text{top}} A = \boxed{1.017\ 9 \times 10^3\ \text{N}}$$

and $F_{\text{bot}} = \boxed{1.029\ 7 \times 10^3\ \text{N}}$.

(b) The tension in the string is the scale reading:

$$T = Mg - B$$

where

$$B = \rho_w V g = (10^3\ \text{kg/m}^3)(1.20 \times 10^{-3}\ \text{m}^3)(9.80\ \text{m/s}^2) = 11.8\ \text{N}$$

and

$$Mg = (10.0\ \text{kg})(9.80\ \text{m/s}^2) = 98.0\ \text{N}$$

Therefore,

$$T = Mg - B = 98.0\ \text{N} - 11.8\ \text{N} = \boxed{86.2\ \text{N}}$$

(c) $F_{\text{bot}} - F_{\text{top}} = (1.0297 - 1.0179) \times 10^3 \text{ N} = \boxed{11.8 \text{ N}}$

which is equal to B found in part (b).

P14.13 (a) The buoyant force of glycerin supports the weight of the sphere which is supported by the buoyant force of water.

$$B = \rho_{\text{glycerin}}(0.40V) = \rho_{\text{water}}\frac{V}{2}$$

$$\boxed{\rho_{\text{glycerin}} = \frac{\rho_{\text{water}}}{2(0.40)} = \frac{1\ 000 \text{ kg/m}^3}{0.80} = 1\ 250 \text{ kg/m}^3}$$

(b) The buoyant force from the water supports the weight of the sphere:

$$B = F_g$$

$$B = \rho_{\text{water}}\frac{V}{2} = \rho_{\text{sphere}}V$$

$$\boxed{\rho_{\text{sphere}} = \frac{\rho_{\text{water}}}{2} = 500 \text{ kg/m}^3}$$

P14.14 (a) $\sum F_y = 0$: $B - T - F_g = 0 \rightarrow B - 15.0 \text{ N} - 10.0 \text{ N} = 0$

$\boxed{B = 25.0 \text{ N}}$

(b) The oil pushes $\boxed{\text{horizontally inward}}$ on each side of the block.

(c) The string tension increases. The water under the block pushes up on the block more strongly than before because the water is under higher pressure due to the weight of the oil above it.

(d) The pressure of the oil's weight on the water is $P = \rho_{\text{oil}}gh$, where h is the height of the oil. This pressure is transmitted to the bottom of the block, so the extra upward force on the block is $F_{oil} = PA = \rho_{oil} ghA = \rho_{oil} g\Delta V$, where $\Delta V = hA$ is the volume of the block below the top surface of the oil.

The force from the oil and the buoyant force of water balance the tension and the weight of the block:

$$\begin{aligned}\sum F_y = 0:\quad & F_{oil} + B - T - F_g = 0\\ & F_{oil} + 25.0\text{ N} - 60.0\text{ N} - 15.0\text{ N} = 0\\ & F_{oil} = 50.0\text{ N}\end{aligned}$$

The ratio of F_{oil} and B are

$$\frac{F_{up}}{B} = \frac{\rho_{oil} g\Delta V}{\rho_{water} g\left(V/4\right)} \rightarrow \frac{\Delta V}{V} = \frac{F_{up}}{4B}\frac{\rho_{water}}{\rho_{oil}}$$

$$\frac{\Delta V}{V} = \frac{50.0\text{ N}}{4(25.0\text{ N})}\frac{1\ 000\text{ kg/m}^3}{800\text{ kg/m}^3} = 0.625$$

The additional fraction of the block's volume below the top surface of the oil is $\boxed{62.5\%.}$

P14.15 (a) While the system floats, $B = w_{total} = w_{block} + w_{steel}$, or

$$\rho_w \cancel{g} V_{submerged} = \rho_b \cancel{g} V_b + m_{steel} \cancel{g}$$

When $m_{steel} = 0.310$ kg, $V_{submerged} = V_b = 5.24 \times 10^{-4}\text{ m}^3$ giving

$$\begin{aligned}\rho_b &= \frac{\rho_w V_b - m_{steel}}{V_b} = \rho_w - \frac{m_{steel}}{V_b}\\ &= 1.00 \times 10^3\text{ kg/m}^3 - \frac{0.310\text{ kg}}{5.24 \times 10^{-4}\text{ m}^3}\\ &= \boxed{408\text{ kg/m}^3}\end{aligned}$$

(b) If the total weight of the block + steel system is reduced, by having $m_{\text{steel}} < 0.310$ kg, a smaller buoyant force is needed to allow the system to float in equilibrium. $\boxed{\text{Thus, the block will displace a smaller volume of water and will be only partially submerged in the water.}}$

(c) The block is fully submerged when $m_{\text{steel}} = 0.310$ kg. The mass of the steel object can increase slightly above this value without causing it and the block to sink to the bottom. As the mass of the steel object is gradually increased above 0.310 kg, the steel object begins to submerge, displacing additional water, and providing a slight increase in the buoyant force. With a density of about eight times that of water, the steel object will be able to displace approximately 0.310 kg/8 = 0.039 kg of additional water before it becomes fully submerged. At this point, the steel object will have a mass of about 0.349 kg and will be unable to displace any additional water. Any further increase in the mass of the object causes it and the block to sink to the bottom. In conclusion,

$$\boxed{\text{the block + steel system will sink if } m_{\text{stee}} \geq 0.350\text{ kg.}}$$

P14.16 Let A represent the horizontal cross-sectional area of the rod, which we presume to be constant. The rod is in equilibrium:

$$\sum F_y = 0: \quad -mg + B = 0 = -\rho_0 V_{\text{whole rod}} g + \rho_{\text{fluid}} V_{\text{immersed}} g$$

$$\rho_0 ALg = \rho A(L-h)g$$

The density of the liquid is $\rho = \dfrac{\rho_0 L}{L-h}$.

P14.17 We use the result of Problem 14.16. For the rod floating in a liquid of density 0.98 g/cm^3,

$$\rho = \rho_0 \frac{L}{L-h}$$

$$0.98\ \text{g/cm}^3 = \frac{\rho_0 L}{(L - 0.2\ \text{cm})}$$

$$\left(0.98\ \text{g/cm}^3\right)L - \left(0.98\ \text{g/cm}^3\right)0.2\ \text{cm} = \rho_0 L$$

For floating in the dense liquid,

$$1.14\ \text{g/cm}^3 = \frac{\rho_0 L}{(L - 1.80\ \text{cm})}$$

$$\left(1.14\ \text{g/cm}^3\right)L - \left(1.14\ \text{g/cm}^3\right)(1.80\ \text{cm}) = \rho_0 L$$

(a) By substitution, and suppressing units,

$$1.14L - 1.14(1.80) = 0.98L - 0.200(0.98)$$

$$0.16L = 1.856$$

$$L = \boxed{11.6\ \text{cm}}$$

(b) Substituting back,

$$\left(0.98\ \text{g/cm}^3\right)(11.6\ \text{cm} - 0.200\ \text{cm}) = \rho_0 (11.6\ \text{cm})$$

$$\rho_0 = \boxed{0.963\ \text{g/cm}^3}$$

(c) $\boxed{\text{No; the density } \rho \text{ is not linear in } h.}$

P14.18 (a) We can estimate the total buoyant force of the 600 toy balloons as

$$B_{\text{total}} = 600 \cdot B_{\substack{\text{single}\\\text{balloon}}} = 600\left(\rho_{\text{air}} g V_{\text{balloon}}\right)$$

$$= 600\left[\rho_{\text{air}} g \left(\frac{4\pi}{3} r^3\right)\right]$$

$$= 600\left[\left(1.20\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\frac{4\pi}{3}(0.50\ \text{m})^3\right]$$

$$= 3.7 \times 10^3\ \text{N} = \boxed{3.7\ \text{kN}}$$

(b) We estimate the net upward force by applying Newton's second law in the vertical direction:

$$\begin{aligned}\sum F_y &= B_{\text{total}} - m_{\text{total}} g \\ &= 3.7\times 10^3\ \text{N} - 600(0.30\ \text{kg})(9.8\ \text{m/s}^2) \\ &= 1.9\times 10^3\ \text{N} = \boxed{1.9\ \text{kN}}\end{aligned}$$

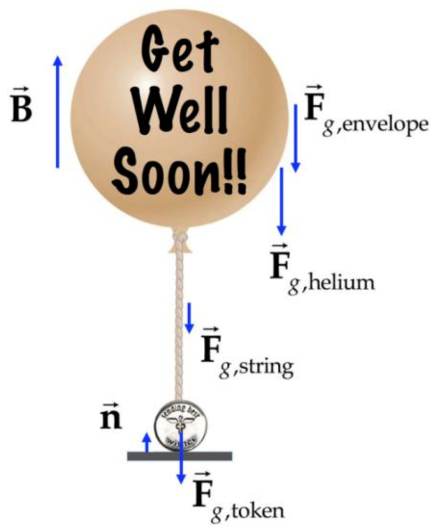
This net force was sufficient to lift Ashpole, his parachute, and other supplies.

(c) $\boxed{\text{Atmospheric pressure at this high altitude is much lower than at Earth's surface}}$, so the balloons expanded and eventually burst.

***P14.19** **Conceptualize** The diagram below shows the physical situation described in the problem, with the token resting on a flat surface and providing enough mass to keep the system from rising upward in the air. If the token is close to the minimum value required and the balloon is tied to the edge of the token, the force from the string can exert a torque on the token so that it stands upright as shown in the diagram.

Categorize Because the system of the balloon, string, and token does not move, we model it as a *particle in equilibrium.*

Analyze The diagram below shows the physical system with the forces acting on the system added: the weight of the balloon envelope and the enclosed helium, the weight of the string, and the weight of the token. The two upward forces on the system are the buoyant force on the balloon and the normal force from the flat surface on the token.



From the particle in equilibrium model, write the force equilibrium equation for the system:

$$\sum \vec{\mathbf{F}} = 0 \quad \rightarrow \quad \vec{\mathbf{B}} + \vec{\mathbf{n}} + \vec{\mathbf{F}}_{g,\text{envelope}} + \vec{\mathbf{F}}_{g,\text{helium}} + \vec{\mathbf{F}}_{g,\text{string}} + \vec{\mathbf{F}}_{g,\text{token}} = 0 \quad (1)$$

Substituting components in the y direction for each force in Equation (1) gives

$$B + n - F_{g,\text{envelope}} - F_{g,\text{helium}} - F_{g,\text{string}} - F_{g,\text{token}} = 0 \quad (2)$$

For each of the gravitational forces in Equation (2), substitute the product of the appropriate mass and g. In addition, to find the *minimum* required mass of the token, we imagine that the normal force $\vec{\mathbf{n}}$ on the token just goes to zero. Now we have

$$B - \left(m_{\text{envelope}} + m_{\text{helium}} + m_{\text{string}} + m_{\text{token}}\right) g = 0 \quad (3)$$

Solve Equation (3) for the mass of the token:

$$m_{\text{token}} = \frac{B}{g} - \left(m_{\text{envelope}} + m_{\text{helium}} + m_{\text{string}}\right) \qquad (4)$$

Substitute in Equation (4) for the buoyant force and the mass of the helium:

$$\begin{aligned} m_{\text{token}} &= \frac{\left(\rho_{\text{air}} g V_{\text{balloon}}\right)}{g} - \left(m_{\text{envelope}} + \rho_{\text{helium}} V_{\text{balloon}} + m_{\text{string}}\right) \\ &= \left(\rho_{\text{air}} - \rho_{\text{helium}}\right) V_{\text{balloon}} - \left(m_{\text{envelope}} + m_{\text{string}}\right) \qquad (5) \end{aligned}$$

Substitute numerical values:

$$\begin{aligned} m_{\text{token}} &= \left(1.20\text{ kg/ m}^3 - 0.179\text{ kg/ m}^3\right)\left(0.230\,0\text{ m}^3\right) - \left(0.150\text{ kg} + 0.070\,0\text{ kg}\right) \\ &= 0.014\,8\text{ kg} \end{aligned}$$

Finalize The 10.0-g token would not be sufficient to hold this balloon down, so you would need to select the 20.0-g token. In this case, there would be a small upward normal force on the token from the flat surface. (If the air temperature were to drop to 15°C, however, the density of air would increase to 1.225 kg/m^3, and a similar calculation yields m_{token} = 20.6 g. So, if there is a possible drop in temperature to 15°C, the 30 g token would be a better bet.

Answer: 20.0 g

Section 14.5 Fluid Dynamics

P14.20 (a) The cross-sectional area of the hose is

$$A = \pi r^2 = \pi d^2 / 4 = \pi (2.74\text{ cm})^2 / 4$$

and the volume flow rate (volume per unit time) is

$Av = 25.0 \text{ L}/1.50 \text{ min}$

Thus,

$$v = \frac{25.0 \text{ L}/1.50 \text{ min}}{A}$$
$$= \left(\frac{25.0 \cancel{\text{L}}}{1.50 \cancel{\text{min}}}\right)\left[\frac{4}{\pi \cdot (2.74)^2 \text{ cm}^2}\right]\left(\frac{1 \cancel{\text{min}}}{60 \text{ s}}\right)\left(\frac{10^3 \text{ cm}^3}{1 \cancel{\text{L}}}\right)$$
$$= (47.1 \text{ cm/s})\left(\frac{1 \text{ m}}{10^2 \text{ cm}}\right) = \boxed{0.471 \text{ m/s}}$$

(b) $$\frac{A_2}{A_1} = \left(\frac{\pi d_2^2}{4}\right)\left(\frac{4}{\pi d_1^2}\right) = \left(\frac{d_2}{d_1}\right)^2 = \left(\frac{1}{3}\right)^2 = \frac{1}{9} \quad \text{or} \quad A_2 = \frac{A_1}{9}$$

Then from the equation of continuity, $A_2 v_2 = A_1 v_1$, we find

$$v_2 = \left(\frac{A_1}{A_2}\right) v_1 = 9(0.471 \text{ m/s}) = \boxed{4.24 \text{ m/s}}$$

P14.21 (a) Power is the rate of energy flow as a function of time:

$$P = \frac{\Delta E}{\Delta t} = \frac{\Delta mgh}{\Delta t} = \left(\frac{\Delta m}{\Delta t}\right) gh = Rgh$$

(b) The power delivered by the Grand Coulee dam is

$$P_{\text{EL}} = 0.85(8.50 \times 10^5 \text{ kg/s})(9.80 \text{ m/s}^2)(87.0 \text{ m}) = \boxed{616 \text{ MW}}$$

Section 14.6 Bernoulli's Equation

P14.22 (a) Between sea surface and clogged hole:

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

$$1\text{ atm} + 0 + (1\ 030\text{ kg/m}^3)(9.80\text{ m/s}^2)(2.00\text{ m}) = P_2 + 0 + 0$$

$$P_2 = 1\text{ atm} + 20.2\text{ kPa}$$

The air on the back of his hand pushes opposite the water, so the net force on his hand is

$$F = PA = (20.2\times 10^3\text{ N/m}^2)\left(\frac{\pi}{4}\right)(1.2\times 10^{-2}\text{ m})^2$$

$$F = \boxed{2.28\text{ N}}\text{ toward Holland}$$

(b) Now, Bernoulli's equation gives

$$1\text{ atm} + 0 + 20.2\text{ kPa} = 1\text{ atm} + \frac{1}{2}(1\ 030\text{ kg/m}^3)v_2^2 + 0$$

$$v_2 = 6.26\text{ m/s}$$

The volume rate of flow is

$$A_2v_2 = \frac{\pi}{4}(1.2\times 10^{-2}\text{ m})^2(6.26\text{ m/s}) = 7.08\times 10^{-4}\text{ m}^3\text{/s}$$

One acre–foot is $4\ 047\text{ m}^2 \times 0.304\ 8\text{ m} = 1\ 234\text{ m}^3$.

Requiring $\dfrac{1\ 234\text{ m}^3}{7.08\times 10^{-4}\text{ m}^3\text{/s}} = \boxed{1.74\times 10^6\text{ s}} = 20.2$ days.

P14.23 (a) The cross-sectinal area is the same everywhere, so the speed is the same everywhere:

$$\left(P + \frac{1}{2}\rho v^2 + \rho gy\right)_{\text{river}} = \left(P + \frac{1}{2}\rho v^2 + \rho gy\right)_{\text{rim}}$$

$$P + 0 + \rho g(564\text{ m}) = 1\text{ atm} + 0 + \rho g(2\ 096\text{ m})$$
$$P = 1\text{ atm} + (1\ 000\text{ kg/m}^3)(9.80\text{ m/s}^2)(1\ 532\text{ m})$$
$$= \boxed{1\text{ atm} + 15.0\text{ MPa}}$$

(b) The volume flow rate is $4\ 500\ \text{m}^3/d = Av = \dfrac{\pi d^2 v}{4}$.

$$v = \left(4\ 500\ \text{m}^3/\text{d}\right)\left(\frac{1\ \text{d}}{86\ 400\ \text{s}}\right)\left(\frac{4}{\pi(0.150\ \text{m})^2}\right) = \boxed{2.95\ \text{m/s}}$$

P14.24 (a) The volume flow rate is the same at the two points: $A_1v_1 = A_2v_2$:

$$\pi(1\ \text{cm})^2 v_1 = \pi(0.5\ \text{cm})^2 v_2 \quad \rightarrow \quad v_2 = 4v_1$$

We assume the tubes are at the same elevation:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$
$$P_1 - P_2 = \Delta P = \frac{1}{2}\rho(4v_1)^2 + 0 - \frac{1}{2}\rho v_1^2$$
$$\Delta P = \frac{1}{2}(850\ \text{kg/m}^3)\ 15v_1^2$$
$$v_1 = (0.012\ 5\ \text{m/s})\sqrt{\Delta P}$$

where the pressure is in pascals.

The volume flow rate is

$$\pi(0.01\ \text{m})^2(0.0125\ \text{m/s})\sqrt{\Delta P}$$
$$= \boxed{\left(3.93\times10^{-6}\ \text{m}^3/\text{s}\right)\sqrt{\Delta P},\quad \text{where } \Delta P \text{ is in pascals}}$$

(b) For $\Delta P = 6.00\ \text{kPa}$,

$$\left(3.93\times10^{-6}\ \text{m}^3/\text{s}\right)\sqrt{6\ 000\ \text{Pa}} = \boxed{0.305\ \text{L/s}}$$

(c) With pressure difference 2 times larger, the flow rate is larger by the square root of 2:

$$\sqrt{2}(0.305\ \text{L/s}) = \boxed{0.431\ \text{L/s}}$$

P14.25 (a) For upward flight of a water-drop projectile from geyser vent to fountain–top, $v_{yf}^2 = v_{yi}^2 + 2a_y\Delta y$.

Then $0 = v_i^2 + 2\left(-9.80\ \text{m/s}^2\right)(+40.0\ \text{m})$ and $v_i = \boxed{28.0\ \text{m/s}}$.

(b) Between geyser vent and fountain-top:

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

Air is so low in density that very nearly $P_1 = P_2 = 1$ atm. Then,

$$\frac{1}{2}v_1^2 + 0 = 0 + \left(9.80\ \text{m/s}^2\right)(40.0\ \text{m})$$

$$v_1 = \boxed{28.0\ \text{m/s}}$$

(c) $\boxed{\text{The answers agree precisely. The models are consistent with each other.}}$

(d) Between the chamber and the fountain-top:

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

$$\begin{aligned} &P_1 + 0 + \left(1\,000\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)(-175\ \text{m}) \\ &\quad = P_0 + 0 + \left(1\,000\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)(+40.0\ \text{m}) \\ &P_1 - P_0 = \left(1\,000\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)(215\ \text{m}) = \boxed{2.11\ \text{MPa}} \end{aligned}$$

***P14.26** **Conceptualize** Consider the two plans shown, one with the buildings offset from each other and the other with the buildings right next to each other. In which case is there a narrower channel of air between the buildings?

Categorize As noted in the problem statement, we are concerned with the Bernoulli effect applied to moving air in this problem.

Analyze (a) You will have a difficult time formulating a defense for your client based on the last-minute substitution of the plans. Plan (ii) is more dangerous in terms of popping windows. There is a long, narrow channel of air between the buildings. According to the continuity equation for fluids, the wind will rush through this constricted channel at a very high speed. From Bernoulli's principle, this air will exert low pressure on the outer surfaces of the windows, causing them to possibly pop out due to the higher pressure of the interior air. In Plan (i), there is a narrow channel only between the corners of the buildings. Generally, there is structural material at the corners of buildings, rather than windows, so the possibility of window popping is reduced compared to Plan (ii).

(b) Let's apply Bernoulli's principle to this situation, defining point 1 as the inner surface of a window and point 2 as the outer surface in the wind:

$$P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g y_2 \qquad (1)$$

The inner and outer surfaces of the window are at the same height y, and the speed of the interior air is zero, so we can simplify the equation as follows:

$$P_1 + 0 + \rho g y = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g y \quad \rightarrow \quad P_2 = P_1 - \tfrac{1}{2}\rho v_2^2 \qquad (2)$$

The net force on the window is outward and given by

$$\square F = F_1 - F_2 = \left(P_1 - P_2\right)A = \left(\tfrac{1}{2}\rho v_2^2\right)A = \tfrac{1}{2}\rho A v_2^2 \qquad (3)$$

Substitute numerical values:

$$\square F = \tfrac{1}{2}\left(1.20\ \mathrm{kg/m^3}\right)\left(4.00\ \mathrm{m}\right)\left(1.50\ \mathrm{m}\right)\left(11.2\ \mathrm{m/s}\right)^2 = \boxed{452\ \mathrm{N}}$$

(c) Substitute modified numerical values into Equation (3):

$$\square F = \tfrac{1}{2}\left(1.20\ \mathrm{kg/m^3}\right)\left(4.00\ \mathrm{m}\right)\left(1.50\ \mathrm{m}\right)\left(22.4\ \mathrm{m/s}\right)^2 = \boxed{1.81 \square 10^3\ \mathrm{N}}$$

Finalize Note that the net force on a window is proportional to the *square* of the wind speed, so doubling the wind speed, as we did on part (c), causes the force to increase by a factor of *four*. The narrow channel in Plan (ii) in part (a) can easily double the wind speed, causing this plan to be very dangerous. So what can the owner do, now that the project is already built? All of the windows on the sides of both buildings facing each other need to be replaced with reinforced windows and mounts that can withstand the high pressure difference. Industry standards allow for a failure rate for windows, so ensuring that no window will ever pop out is impossible.

Answers: (a) Answers will vary, but will depend on the Bernoulli effect. (b) 452 N (c) 1.81×10^3

Section 14.7 Flow of Viscous Fluids in Pipes

***P14.27** Solution missing

***P14.28** Solution missing

***P14.29** Solution missing

메모 포함[AV1]: We did a quick search for the solution P14.27, P14.28, and P14.29 but couldn't find them.

Section 14.8 Other Applications of Fluid Dynamics

P14.30 (a) Force balance requires that

$$Mg = (P_1 - P_2)A$$

$$\frac{(16\,000 \text{ kg})(9.80 \text{ m/s}^2)}{2(40.0 \text{ m}^2)} = 7.00 \times 10^4 \text{ Pa} - P_2$$

$$\therefore P_2 = 7.0\times10^4\ \text{Pa} - 0.196\times10^4\ \text{Pa} = \boxed{6.80\times10^4\ \text{Pa}}$$

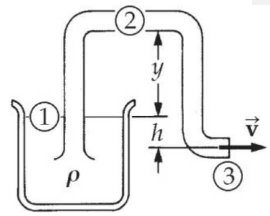
(b) Higher. With the inclusion of another upward force due to deflection of air downward, the pressure difference does not need to be as great to keep the airplane in flight.

P14.31 (a) We use Bernoulli's equation,

$$P_0 + \rho g h + 0 = P_0 + 0 + \frac{1}{2}\rho v_3^2$$

which gives $v_3 = \sqrt{2gh}$.

If $h = 1.00$ m, then $v_3 = \boxed{4.43\ \text{m/s}}$.



ANS. FIG. P14.31

(b) Again, from Bernoulli's equation,

$$P + \rho g y + \frac{1}{2}\rho v_2^2 = P_0 + 0 + \frac{1}{2}\rho v_3^2$$

Since $v_2 = v_3$,

$$P = P_0 - \rho g y$$

Since $P \geq 2.3$ kPa, the greatest possible siphon height is given by

$$y \leq \frac{P_0 - P}{\rho g} = \frac{1.013\times10^5\ \text{Pa} - 2.30\times10^3\ \text{Pa}}{(10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)} = \boxed{10.1\ \text{m}}$$

Additional Problems

P14.32 The water exerts a buoyant force on the air, given by

$$B = \rho_{\text{fluid}} g V = (1\,000\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(10.0\ \text{L})\left(\frac{1\ \text{m}^3}{10^3\ \text{L}}\right)$$
$$= 98.0\ \text{N up}$$

The weight of the air is

$$F_g = \rho g V = (2.40\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(10.0\times10^{-3}\ \text{m}^3)$$
$$= 0.235\ \text{N down}$$

To transport the air down at constant speed requires a downward force D in $+98.0\ \text{N} - 0.235\ \text{N} - D = 0$, $D = 97.8\ \text{N}$, and work

$$W = \vec{\mathbf{D}}\cdot\vec{\mathbf{d}} = (97.8\ \text{N})(10.3\ \text{m})\cos 0° = \boxed{1.01\ \text{kJ}}$$

P14.33 (a) $\boxed{\text{A particle in equilibrium model}}$

(b) When the balloon comes into equilibrium, we must have

$$\boxed{\sum F_y = B - F_b - F_{\text{He}} - F_s = 0}$$

where B is the buoyant force, F_b the weight of the balloon, F_{He} the weight of the helium, and F_s the weight of the segment of string above the ground.

(c) Write expressions for each of the terms in the force equation:

$$B = \rho_{\text{air}} V g = \rho_{\text{air}}\frac{4}{3}\pi r^3 g$$
$$F_b = m_b g$$
$$F_{\text{He}} = \rho_{\text{He}} V g = \rho_{\text{He}}\frac{4}{3}\pi r^3 g$$

and $F_s = m_s g$; where $m_s = m\dfrac{h}{\ell}$

Therefore, we have

$$\rho_{\text{air}} V\cancel{g} - m_b\cancel{g} - \rho_{\text{He}} V\cancel{g} - m_s\cancel{g} = 0$$

or $\quad m_s = (\rho_{\text{air}} - \rho_{\text{He}})V - m_b \rightarrow \boxed{m_s = (\rho_{\text{air}} - \rho_{\text{He}})\frac{4}{3}\pi r^2 - m_b}$

(d) $m_s = \left[(1.20 - 0.179)\ \text{kg/m}^3\right]\left[\frac{4}{3}\pi(0.400\ \text{m})^3\right] - 0.250\ \text{kg}$

$= \boxed{0.023\ 7\ \text{kg}}$

(e) $m_s = m\frac{h}{\ell} \;\rightarrow\; h = \ell\frac{m_s}{m} = (2.00\ \text{m})\frac{0.023\ 7\ \text{kg}}{0.050\ 0\ \text{kg}} = \boxed{0.948\ \text{m}}$

P14.34 The "balanced" condition is one in which the apparent weight of the body equals the apparent weight of the weights. This condition can be written as

$$F_g - B = F_g' - B'$$

where B and B' are the buoyant forces on the body and weights, respectively. The buoyant force experienced by an object of volume V in air equals

$$\text{Buoyant force} = (\text{Volume of object})\rho_{\text{air}}g$$

so we have $B = V\rho_{\text{air}}g$ and

$$B' = \left(\frac{F_g'}{\rho g}\right)\rho_{\text{air}}g$$

Therefore, $F_g = F_g' + \left(V - \frac{F_g'}{\rho g}\right)\rho_{\text{air}}g$.

P14.35 Consider spherical balloons of radius 12.5 cm containing helium at STP and immersed in air at 0°C and 1 atm. If the rubber envelope has mass 5.00 g, the upward force on each is

$$F_{up} = B - F_{g,\text{He}} - F_{g,\text{env}} = \rho_{\text{air}} Vg - \rho_{\text{He}} Vg - m_{\text{env}} g$$

$$F_{up} = (\rho_{\text{air}} - \rho_{\text{He}})\left(\frac{4}{3}\pi r^3\right) g - m_{\text{env}} g$$

$$F_{up} = \left[(1.29 - 0.179)\ \text{kg/m}^3\right]\left[\frac{4}{3}\pi (0.125\ \text{m})^3\right](9.80\ \text{m/s}^2) - (5.00 \times 10^{-3}\ \text{kg})(9.80\ \text{m/s}^2) = 0.040\,1\ \text{N}$$

If your weight (including harness, strings, and submarine sandwich) is

$$70.0\ \text{kg}(9.80\ \text{m/s}^2) = 686\ \text{N}$$

you need this many balloons:

$$\frac{686\ \text{N}}{0.040\,1\ \text{N}} = 17\ 000 \boxed{\sim 10^4}$$

P14.36 Let the ball be released at point 1, enter the liquid at point 2, attain maximum depth at point 3, and pop through the surface on the way up at point 4.

(a) Energy conservation for the fall through the air:

$$K_i + U_i = K_f + U_f$$

$$0 + mgy_1 = \frac{1}{2} m v_2^2$$

$$v_2 = \sqrt{2gy_1} = \sqrt{2(9.80\ \text{m/s}^2)(3.30\ \text{m})} = \boxed{8.04\ \text{m/s}}$$

(b) $\boxed{\text{The gravitational force and the buoyant force.}}$

The gravitational force is

mg = (2.10 kg)(9.80 N/kg) = 20.6 N down

and the buoyant force is

$$m_{\text{fluid}}g = \rho_{\text{fluid}}V_{\text{object}}g = \rho_{\text{fluid}}(4/3)\pi r^3 g$$
$$= (1\ 230\ \text{kg/m}^3)(4\pi/3)(0.090\ 0\ \text{m})^3(9.80\ \text{m/s}^2)$$
$$= 36.8\ \text{N up}$$

(c) The buoyant force is greater than the gravitational force.

$\boxed{\text{The net upward force on the ball brings its downward motion to a stop.}}$

We choose to use the work-kinetic energy theorem.

$$\frac{1}{2}mv_2^2 + F_{net}\cdot\Delta y = \frac{1}{2}mv_3^2$$

$$\frac{1}{2}(2.10\ \text{kg})(8.04\ \text{m/s})^2 + (36.8\ \text{N} - 20.6\ \text{N})(-\Delta y) = 0$$

$$\Delta y = 67.9\ \text{J}/16.2\ \text{N} = \boxed{4.18\ \text{m}}$$

P14.37 (a) $P = \rho gh$ gives $1.013\times 10^5\ \text{Pa} = (1.29\ \text{kg/m}^3)(9.80\ \text{m/s}^2)h.$

$h = \boxed{8.01\ \text{km}}$

(b) For Mt. Everest, $29\ 300\ \text{ft} = 8.88\ \text{km}$, $\boxed{\text{Yes}}$.

P14.38 (a) The blood flowing through the artery is similar to water flowing through a pipe. We substitute numerical values into the equation for the Reynolds number:

$$\text{Re} = \frac{(1.06\times 10^3\ \text{kg/m}^3)(6.70\times 10^{-2}\ \text{m/s})(3.00\times 10^{-2}\ \text{m})}{3.00\times 10^{-3}\ \text{Pa}\cdot\text{s}}$$
$$= 710$$

Because this result is less than 2 300, the flow is laminar.

(b) Denote the situation in part (a) using subscripts 1. In the expression for the Reynolds number for the capillary, which we denote as situation 2, incorporate the continuity equation for fluids as the blood flows into the smaller blood vessel:

$$\text{Re}_2 = \frac{\rho v_2 d_2}{\mu} = \frac{\rho v_1\left(\frac{A_1}{A_2}\right)(2r_2)}{\mu} = \frac{\rho v_1\left(\frac{\pi r_1^2}{\pi r_2^2}\right)(2r_2)}{\mu} = \frac{2\rho v_1 r_1^2}{\mu r_2}$$

Solve the resulting equation for the radius of the capillary:

$$r_2 = \frac{2\rho v_1 r_1^2}{\mu(\text{Re}_2)}$$

Substitute numerical values, including a Reynolds number representing turbulent flow:

$$r_2 = \frac{2\left(1.06 \times 10^3 \text{ kg/m}^3\right)\left(6.70 \times 10^{-2} \text{ m/s}\right)\left(1.50 \times 10^{-2} \text{ m}\right)^2}{\left(3.00 \times 10^{-3} \text{ Pa}\cdot\text{s}\right)(4\ 000)}$$

$$= \boxed{2.66 \times 10^{-3} \text{ m}}$$

(c) The situation in the human body is not represented by a large artery feeding into a single capillary as in part (b). The artery branches into smaller vessels and eventually into approximately 10 billion capillaries. Even though the radius of each capillary is very small, the overall area through which the blood flows in all the capillaries is larger than the area of the artery in part (a). Consequently, in the expression for the Reynolds number, both the speed of the blood and the diameter is very small for each capillary, representing a very low value for the Reynolds number and, consequently, laminar flow.

P14.39 Let f represent the fraction of the volume V occupied by zinc in the new coin. We have $m = \rho V$ for both coins:

$$3.083 \text{ g} = (8.920 \text{ g/cm}^3)V$$

and $$2.517 \text{ g} = \left(7.133 \text{ g/cm}^3\right)(fV) + \left(8.920 \text{ g/cm}^3\right)(1-f)V$$

By substitution,

$$2.517 \text{ g} = (7.133 \text{ g/cm}^3) fV + 3.083 \text{ g} - (8.920 \text{ g/cm}^3) fV$$

$$fV = \frac{3.083 \text{ g} - 2.517 \text{ g}}{8.920 \text{ g/cm}^3 - 7.133 \text{ g/cm}^3}$$

and again substituting to eliminate the volume,

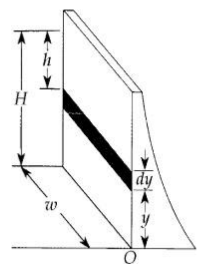
$$f = \frac{0.566 \text{ g}}{1.787 \text{ g/cm}^3}\left(\frac{8.920 \text{ g/cm}^3}{3.083 \text{ g}}\right) = 0.916\,4 = \boxed{91.64\%}$$

P14.40 (a) The torque is

$$\tau = \int d\tau = \int r dF$$

From ANS. FIG. P14.40,

$$\tau = \int_0^H y\left[\rho g (H - y) w dy\right] = \boxed{\frac{1}{6}\rho g w H^3}$$



ANS. FIG. P14.40

(b) The total force is given as $\frac{1}{2}\rho g w H^2$.

If this were applied at a height y_{eff} such that the torque remains unchanged, we have

$$\frac{1}{6}\rho g w H^3 = y_{eff}\left[\frac{1}{2}\rho g w H^2\right] \quad \text{and} \quad y_{eff} = \boxed{\frac{1}{3}H}$$

(d) The same net force acts on the ball over the same distance as it moves down and as it moves up, to produce the same speed change. Thus v_4 = $\boxed{8.04 \text{ m/s}}$.

(e) $\boxed{\text{The time intervals are equal}}$, because the ball moves with the same range of speeds over equal distance intervals.

(f)

$\boxed{\text{With friction present, } \Delta t_{\text{down}} \text{ is less than } \Delta t_{\text{up}}\text{. The magnitude of the ball's acceleration on the way down is greater than its acceleration on the way up. The two motions cover equal distances and both have zero speed at one end point, so the downward trip with larger-magnitude acceleration must take less time.}}$

P14.41 (a) Since the upward buoyant force is balanced by the weight of the sphere,

$$m_1 g = \rho V g = \rho\left(\frac{4}{3}\pi R^3\right) g$$

In this problem, $\rho = 0.789\,45 \text{ g/cm}^3$ at 20.0°C, and $R = 1.00$ cm, so we find

$$m_1 = \rho\left(\frac{4}{3}\pi R^3\right) = \left(0.789\,45 \text{ g/cm}^3\right)\left[\frac{4}{3}\pi(1.00 \text{ cm})^3\right] = \boxed{3.307 \text{ g}}$$

(b) Following the same procedure as in part (a), with $\rho' = 0.780\,97 \text{ g/cm}^3$ at 30.0°C, we find

$$m_2 = \rho'\left(\frac{4}{3}\pi R^3\right) = \left(0.780\,97 \text{ g/cm}^3\right)\left[\frac{4}{3}\pi(1.00 \text{ cm})^3\right] = \boxed{3.271 \text{ g}}$$

(c) When the first sphere is resting on the bottom of the tube, $n + B = F_{g1} = m_1 g$, where n is the normal force.

Since $B = \rho' V g$,

$$n = m_1 g - \rho' V g$$
$$= \left[3.307 \text{ g} - \left(0.780\,97 \text{ g/cm}^3\right)\frac{4}{3}\pi(1.00 \text{ cm})^3\right]\left(980 \text{ cm/s}^2\right)$$
$$n = 34.8 \text{ g}\cdot\text{cm/s}^2 = \boxed{3.48 \times 10^{-4} \text{ N}}$$

P14.42 Take point ① at the free water surface in the tank and point ② at the bottom end of the tube:

$$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$$
$$P_0 + \rho g d + 0 = P_0 + 0 + \frac{1}{2}\rho v_2^2$$
$$v_2 = \sqrt{2gd}$$

The volume flow rate is $\dfrac{V}{t} = \dfrac{Ah}{t} = v_2 A'$. Then $t = \dfrac{Ah}{v_2 A'} = \dfrac{Ah}{A'\sqrt{2gd}}$.

***P14.43** **Conceptualize** The force from the water pressure will act outward on the hatch, which will tend to open it. The latch must supply sufficient force inward at the bottom of the hatch to counter this effect.

Categorize We wish the hatch not to rotate around the hinges, so we model it as a *rigid object in equilibrium.*

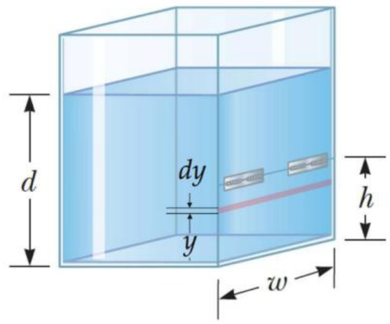
Analyze In Figure P14.43, the force from the water pressure will create a positive torque on the hatch about the hinges, while the latch will provide a negative torque. From the rigid object in equilibrium model applied to the hatch,

$$\sum \tau_{\text{ext}} = 0 \quad \rightarrow \quad \tau_{\text{water}} - \tau_{\text{latch}} = 0 \quad \rightarrow \quad \tau_{\text{water}} = \tau_{\text{latch}} \qquad (1)$$

Substitute for the torque applied by the latch:

$$\tau_{\text{water}} = \left(F_{\text{latch}}\right)\left(h\right) \quad \rightarrow \quad F_{\text{latch}} = \frac{\tau_{\text{water}}}{h} \qquad (2)$$

To evaluate the torque applied by the water, we need to add some geometry to Figure P14.43. Identify a horizontal strip on the hatch and add a variable y to represent the height of the strip above the bottom of the tank:



Now, the torque applied by the force due to the pressure of the water on the strip about the hinges is expressed as follows:

$$\begin{aligned} d\tau_{\text{water}} &= F_{\text{water}}(h-y) = P_{\text{water}}(h-y)\,dA \\ &= \left[\rho_{\text{water}} g(d-y)\right](h-y)(w\,dy) \\ &= \rho_{\text{water}} gw\left[(d-y)(h-y)\right]dy \\ &= \rho_{\text{water}} gw\left(hd - yd - hy + y^2\right)dy \qquad (3) \end{aligned}$$

Integrate this expression over the range from $y = 0$ to $y = h$:

$$\begin{aligned} \tau_{\text{water}} &= \int_h^0 \rho_{\text{water}} gw\left(hd - yd - hy + y^2\right)dy \\ &= \rho_{\text{water}} gw\left(hdy - d\frac{y^2}{2} - h\frac{y^2}{2} + \frac{y^3}{3}\right)\Bigg|_0^h \\ &= \rho_{\text{water}} gw\left(h^2 d - \tfrac{1}{2}h^2 d - \tfrac{1}{2}h^3 + \tfrac{1}{3}h^3\right) \\ &= \rho_{\text{water}} gwh^2\left(\tfrac{1}{2}d - \tfrac{1}{6}h\right) \qquad (4) \end{aligned}$$

Substitute Equation (4) into Equation (2):

$$F_{\text{latch}} = \frac{\rho_{\text{water}} gwh^2\left(\frac{1}{2}d - \frac{1}{6}h\right)}{h} = \rho_{\text{water}} gwh\left(\tfrac{1}{2}d - \tfrac{1}{6}h\right) \qquad (5)$$

Substitute numerical values:

$$F_{\text{latch}} = \left(1\,000\text{ kg/ m}^3\right)\left(9.80\text{ m/ s}^2\right)\left(0.150\text{ m}\right)\left(0.100\text{ m}\right)\left(\frac{0.280\text{ m}}{2} - \frac{0.100\text{ m}}{6}\right)$$
$$= \boxed{18.1\text{ N}}$$

Finalize This value will guide you as to which type of latch to purchase. Notice that we did not include the effect of air pressure on the hatch. That is due to the fact that a force due to air pressure pushes inward on the outer surface of the hatch, but the pressure at various depths on the inner surface is increased by the air pressure above the water. Therefore, the effects of the air on the inner and outer surfaces cancel and we only need to consider the force on the hatch due to the water.

Answer: 18.1 N

***P14.44** **Conceptualize** The force from the water pressure will act outward on the hatch, which will tend to open it. The latch must supply sufficient force inward at the bottom of the hatch to counter this effect.

Categorize We wish the hatch not to rotate around the hinges, so we model it as a *rigid object in equilibrium.*

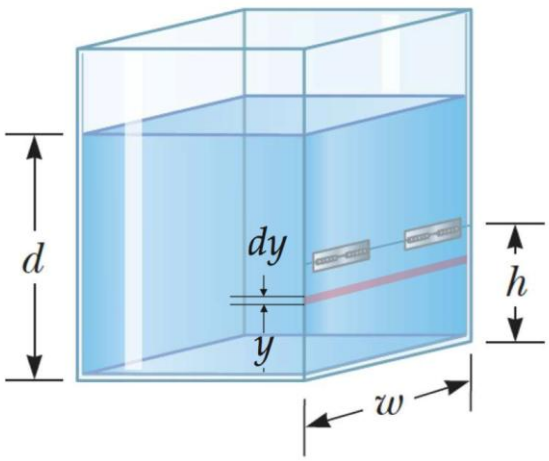
Analyze In Figure P14.43, the force from the water pressure will create a positive torque on the hatch about the hinges, while the latch will provide a negative torque. From the rigid object in equilibrium model applied to the hatch,

$$\sum \tau_{\text{ext}} = 0 \quad \rightarrow \quad \tau_{\text{water}} - \tau_{\text{latch}} = 0 \quad \rightarrow \quad \tau_{\text{water}} = \tau_{\text{latch}} \qquad (1)$$

Substitute for the torque applied by the latch:

$$\tau_{\text{water}} = \left(F_{\text{latch}}\right)\left(h\right) \quad \rightarrow \quad F_{\text{latch}} = \frac{\tau_{\text{water}}}{h} \qquad (2)$$

To evaluate the torque applied by the water, we need to add some geometry to Figure P14.43. Identify a horizontal strip on the hatch and add a variable y to represent the height of the strip above the bottom of the tank:



Now, the torque applied by the force due to the pressure of the water on the strip about the hinges is expressed as follows:

$$\begin{aligned} d\tau_{\text{water}} &= F_{\text{water}}\left(h-y\right) = P_{\text{water}}\left(h-y\right)dA \\ &= \left[\rho_{\text{water}}g\left(d-y\right)\right]\left(h-y\right)\left(w\,dy\right) \\ &= \rho_{\text{water}}gw\left[\left(d-y\right)\left(h-y\right)\right]dy \\ &= \rho_{\text{water}}gw\left(hd-yd-hy+y^2\right)dy \qquad (3) \end{aligned}$$

Integrate this expression over the range from $y = 0$ to $y = h$:

$$\tau_{\text{water}} = \int_h^0 \rho_{\text{water}} g w \left(hd - yd - hy + y^2\right) dy$$
$$= \rho_{\text{water}} g w \left(hdy - d\frac{y^2}{2} - h\frac{y^2}{2} + \frac{y^3}{3} \right)\Bigg|_0^h$$
$$= \rho_{\text{water}} g w \left(h^2 d - \tfrac{1}{2} h^2 d - \tfrac{1}{2} h^3 + \tfrac{1}{3} h^3 \right)$$
$$= \rho_{\text{water}} g w h^2 \left(\tfrac{1}{2} d - \tfrac{1}{6} h \right) \qquad (4)$$

Substitute Equation (4) into Equation (2):

$$F_{\text{latch}} = \frac{\rho_{\text{water}} g w h^2 \left(\tfrac{1}{2} d - \tfrac{1}{6} h \right)}{h} = \boxed{\rho_{\text{water}} g w h \left(\tfrac{1}{2} d - \tfrac{1}{6} h \right)} \qquad (5)$$

Finalize This value will guide you as to which type of latch to purchase. Notice that we did not include the effect of air pressure on the hatch. That is due to the fact that a force due to air pressure pushes inward on the outer surface of the hatch, but the pressure at various depths on the inner surface is increased by the air pressure above the water. Therefore, the effects of the air on the inner and outer surfaces cancel and we only need to consider the force on the hatch due to the water.

Answer: $F_{\text{latch}} = \rho_{\text{water}} g w h \left(\tfrac{1}{2} d - \tfrac{1}{6} h \right)$

P14.45 The disk (mass $M = 10.0$ kg, radius $R = 0.250$ m) has moment of inertia $I = \dfrac{1}{2} MR^2$. The disk slows from $\omega_i = 300$ rev/min to $\omega_f = 0$ in time interval $\Delta t = 60.0$ s. Its angular acceleration is

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{\omega_f - \omega_i}{\Delta t} = \frac{-\omega_i}{\Delta t}$$

Frictional torque from the brake pad slows the wheel. Friction has moment arm $d = 0.220$ m. The relation between friction and angular acceleration is

$$\sum \tau = I\alpha: \quad -fd = I\alpha \quad \rightarrow \quad f = -\frac{I}{d}\alpha = -\frac{\frac{1}{2}MR^2}{d}\left(\frac{-\omega_i}{\Delta t}\right)$$

$$\rightarrow f = \frac{MR^2\omega_i}{2d\Delta t}$$

The normal force and coefficient of friction $(\mu_k = 0.500)$ between the brake pad and the disk determine the amount of friction. We can write an expression for the normal force:

$$f = \mu_k n \quad \rightarrow \quad n = \frac{f}{\mu_k} = \frac{MR^2\omega_i}{2\mu_k d\Delta t}$$

The pressure of the brake fluid acting on a piston of area A (diameter $D = 5.00$ cm, radius $r = D/2 = 0.0250$ m) produces the normal force that the brake pad exerts on the disk. The pressure in the brake fluid is

$$P = \frac{n}{\pi r^2} = \frac{MR^2\omega_i}{\left(2\mu_k d\Delta t\right)\pi r^2}$$

$$P = \frac{(10.0 \text{ kg})(0.250 \text{ m})^2\left[\left(\frac{300 \text{ rev}}{\text{min}}\right)\left(\frac{2\pi \text{ rad}}{1 \text{ rev}}\right)\left(\frac{1 \text{ min}}{60.0 \text{ s}}\right)\right]}{2(0.500)(0.220 \text{ m})(60.0 \text{ s})\pi(0.0250 \text{ m})^2}$$

$$= \boxed{758 \text{ Pa}}$$

P14.46 (a) Since the pistol is fired horizontally, the emerging water stream has initial velocity components of $(v_{0x} = v_{\text{nozzle}}, v_{0y} = 0)$. Then, $\Delta y = v_{0y}t + \frac{1}{2}a_y t^2$, with $a_y = -g$, gives the time of flight as

$$t = \sqrt{\frac{2(\Delta y)}{a_y}} = \sqrt{\frac{2(-1.50 \text{ m})}{-9.80 \text{ m/s}^2}} = \boxed{0.553 \text{ s}}$$

(b) With $a_x = 0$, and $v_{0x} = v_{\text{nozzle}}$, the horizontal range of the emergent stream is $\Delta x = v_{\text{nozzle}} t$, where t is the time of flight from above. Thus, the speed of the water emerging from the nozzle is

$$v_{\text{nozzle}} = \frac{\Delta x}{t} = \frac{8.00 \text{ m}}{0.553 \text{ s}} = \boxed{14.5 \text{ m/s}}$$

(c) From the equation of continuity, $A_1v_1 = A_2v_2$, the speed of the water in the larger cylinder is $v_1 = (A_2/A_1)v_2 = (A_2/A_1)v_{\text{nozzle}}$, or

$$v_1 = \left(\frac{\pi r_2^2}{\pi r_1^2}\right) v_{\text{nozzle}} = \left(\frac{r_2}{r_1}\right)^2 v_{\text{nozzle}} = \left(\frac{1.00 \text{ mm}}{10.0 \text{ mm}}\right)^2 (14.5 \text{ m/s})$$
$$= \boxed{0.145 \text{ m/s}}$$

(d) The pressure at the nozzle is atmospheric pressure, or

$\boxed{P_2 = 1.013 \times 10^5 \text{ Pa}}$.

(e) With the two cylinders horizontal, $y_1 = y_2$ and gravity terms from Bernoulli's equation can be neglected, leaving

$$P_1 + \frac{1}{2}\rho_w v_1^2 = P_2 + \frac{1}{2}\rho_w v_2^2$$

so the needed pressure in the larger cylinder is

$$P_1 = P_2 + \frac{\rho_w}{2}\left(v_2^2 - v_1^2\right)$$
$$= 1.013 \times 10^5 \text{ Pa}$$
$$+ \frac{1.00 \times 10^3 \text{ kg/m}^3}{2}\left[(14.5 \text{ m/s})^2 - (0.145 \text{ m/s})^2\right]$$

or

$P_1 = \boxed{2.06 \times 10^5 \text{ Pa}}$

(f) To create an overpressure of $\Delta P = 2.06 \times 10^5 \text{ Pa} = 1.05 \times 10^5 \text{ Pa}$ in the larger cylinder, the force that must be exerted on the piston is

$$F_1 = (\Delta P) A_1 = (\Delta P)(\pi r_1^2)$$
$$= (1.05 \times 10^5 \text{ Pa}) \pi (1.00 \times 10^{-2} \text{ m})^2$$
$$= \boxed{33.0 \text{ N}}$$

P14.47 Energy for the fluid-Earth system is conserved.

$$(K + U)_i = (K + U)_f$$
$$0 + \frac{mgL}{2} + 0 = \frac{1}{2} mv^2 + 0$$
$$v = \sqrt{gL} = \sqrt{(2.00 \text{ m})(9.80 \text{ m/s}^2)} = \boxed{4.43 \text{ m/s}}$$

P14.48 (a) For diverging streamlines that pass just above and just below the hydrofoil, we have

$$P_t + \rho g y_t + \frac{1}{2} \rho v_t^2 = P_b + \rho g y_b + \frac{1}{2} \rho v_b^2$$

Ignoring the buoyant force means taking $y_t \approx y_b$:

$$P_t + \frac{1}{2} \rho (n v_b)^2 = P_b + \frac{1}{2} \rho v_b^2$$
$$P_b - P_t = \frac{1}{2} \rho v_b^2 (n^2 - 1)$$

The lift force is $(P_b - P_t) A = \frac{1}{2} \rho v_b^2 (n^2 - 1) A$.

(b) For liftoff,

$$\frac{1}{2} \rho v_b^2 (n^2 - 1) A = Mg$$
$$v_b = \left(\frac{2Mg}{\rho (n^2 - 1) A} \right)^{1/2}$$

The speed of the boat relative to the shore must be nearly equal to this speed of the water below the hydrofoil relative to the boat.

Challenge Problems

P14.49 The incremental version of $P - P_0 = \rho g y$ is $dP = -\rho g dy$.

We assume that the density of air is proportional to pressure,

or $\dfrac{P}{\rho} = \dfrac{P_0}{\rho_0}$. Combining these two equations we have

$$dP = -P\frac{\rho_0}{P_0}g dy$$

Integrating both sides,

$$\int_{P_0}^{P}\frac{dP}{P} = -g\frac{\rho_0}{P_0}\int_0^y dy$$

gives $$\ln\left(\frac{P}{P_0}\right) = -\frac{\rho_0 g y}{P_0}$$

Defining $\alpha = \dfrac{\rho_0 g}{P_0}$ then gives $P = P_0 e^{-\alpha y}$.

P14.50 Assume the top of the barge without the pile of iron has height H_0 above the surface of the water. When a mass of iron M_{Fe} is added to the barge, the barge sinks a distance ΔH until the buoyant force from the water equals the additional weight of the iron. The barge is a square with sides of length L, so the volume of displaced water is $L^2 \Delta H$, and the buoyant force supporting the extra weight is

$$B = \left(\rho_{\text{w}} L^2 \Delta H\right) g = M_{\text{Fe}} g$$

where ρ_{w} is the density of water.

The scrap iron pile has the shape of a cone, and the volume of a cone of base radius R and central height h is $V_{\text{cone}} = \pi R^2 h/3$; therefore, the mass of the iron is $M_{\text{Fe}} = \rho_{\text{Fe}} \pi R^2 h / 3$, where ρ_{Fe} is the density of iron. We find the distance the barge sinks with a pile of iron:

$$B = \left(\rho_{\text{w}} L^2 \Delta H\right) g = M_{\text{Fe}} g$$

$$\left(\rho_{\text{w}} L^2 \Delta H\right) g = \left(\rho_{\text{Fe}} \pi R^2 h / 3\right) g \rightarrow \Delta H = \left(\frac{\rho_{\text{Fe}}}{\rho_{\text{w}}}\right)\left(\frac{\pi}{3}\right)\left(\frac{R^2}{L^2}\right) h$$

If the iron is piled to a height h, the barge will sink by the distance ΔH, so the distance from the water level to the top of the iron pile is $D_{\text{top}} = H_0 - \Delta H + h.$

For the situation of the problem, side $L = 2r$, and the initial conical pile of scrap iron has radius $R = r$ and height is $h = r$. The distance the barge sinks is

$$\Delta H = \left(\frac{\rho_{\text{Fe}}}{\rho_{\text{w}}}\right)\left(\frac{\pi}{3}\right)\left(\frac{R^2}{L^2}\right) h$$

$$\Delta H = \left(\frac{\rho_{\text{Fe}}}{\rho_{\text{w}}}\right)\left(\frac{\pi}{3}\right)\left(\frac{r^2}{(2r)^2}\right) r = \left(\frac{\rho_{\text{Fe}}}{\rho_{\text{w}}}\right)\left(\frac{\pi}{3}\right)\left(\frac{r^2}{4r^2}\right) r = \left(\frac{\rho_{\text{Fe}}}{\rho_{\text{w}}}\right)\left(\frac{\pi}{12}\right) r$$

and the height of the top of the pile above the water is

$$D_{\text{top}} = H_0 - \Delta H + h = H_0 - \left(\frac{\rho_{\text{Fe}}}{\rho_{\text{w}}}\right)\left(\frac{\pi}{12}\right) r + r$$

For $\rho_{\text{w}} = 1.00 \times 10^3 \text{ kg/m}^3$ and $\rho_{\text{Fe}} = 7.86 \times 10^3 \text{ kg/m}^3$, this expression becomes

$$D_{\text{top}} = H_0 - \left(\frac{7.86 \times 10^3}{1.00 \times 10^3}\right)\left(\frac{\pi}{12}\right) r + r = H_0 - 2.06r + r$$

$$D_{\text{top}} = H_0 - 1.06r$$

This distance is too large to allow the barge to go under the bridge:

$$D_{\text{top}} = H_0 - 1.06r \geq D_{\text{bridge}}$$

When the pile is reduced to a height h', but still with the same base radius $R = r$, the distance the barge sinks is

$$\Delta H = \left(\frac{\rho_{\text{Fe}}}{\rho_{\text{w}}}\right)\left(\frac{\pi}{12}\right)h' = 2.06h'$$

The height of the top of the pile above the water is now

$$D'_{\text{top}} = H_0 - \Delta H + h' = H_0 - 2.06h' + h' = H_0 - 1.06h'$$

but this means the top of the pile is now higher! To check this, recall that the height of the pile is reduced, so $h' < r$:

$$D'_{\text{top}} > D_{\text{top}}$$

$$H_0 - 1.06h' > H_0 - 1.06r \quad \rightarrow \quad -1.06h' > -1.06r \quad \rightarrow \quad h' < r$$

which is true.

$$\boxed{\text{The situation is impossible because lowering the height of the iron pile on the barge while keeping the base radius the same results in the top of the pile rising higher above the water level.}}$$

ANSWERS TO QUICK-QUIZZES

1. (a)

2. (a)

3. (c)

4. (b) or (c)

5. (a)

ANSWERS TO EVEN-NUMBERED PROBLEMS

P14.2 (a) ~4×10^{17} kg/m^3; (b) See P14.2 for the full description.

P14.4 The situation is impossible because the longest straw Superman can use and still get a drink is less than 12.0 m.

P14.6 2.71×10^5 N

P14.8 (a) 14.7 kPa, 0.015 5 atm, 11.8 m; (b) Blockage of the fluid within the spinal column or between the skull and the spinal column would prevent the fluid level from rising.

P14.10 (a) $P = P_0 + \rho g h$; (b) Mg/A

P14.12 (a) 4.9 N down, 16.7 N up (b) 86.2 N (c) By either method of evaluation, the buoyant force is 11.8 N up.

P14.14 (a) B = 25.0 N; (b) horizontally inward; (c) The string tension increases. The water under the block pushes up on the block more strongly than before because the water is under higher pressure due to the weight of the oil above it; (d) 62.5%

P14.16 See P14.16 for the full derivation.

P14.18 (a) 3.7 kN; (b) 1.9 kN; (c) Atmospheric pressure at this high altitude is much lower than at the Earth's surface

P14.20 (a) 0.471 m/s; (b) 4.24 m/s

P14.22 (a) 2.28 N toward Holland (b) 1.74×10^6 s

P14.24 (a) $\left(3.93 \times 10^{-6}\ \text{m}^3/\text{s}\right)\sqrt{\Delta P}$ where ΔP is in pascal; (b) 0.305 L/s;

(c) 0.431 L/s

P14.26 (a) Answers will vary, but will depend on the Bernoulli effect. (b) 452 N (c) 1.81×10^3 N

P14.28 [Solution missing]

P14.30 (a) 6.80×10^4 Pa; (b) Higher. With the inclusion of another upward force due to deflection of air downward, the pressure difference does not need to be as great to keep the airplane in flight.

P14.32 1.01 kJ

P14.34 See P14.34 for full description.

P14.36 (a) 8.04 m/s; (b) The gravitational force and the buoyant force; (c) The net upward force on the ball brings it downward motion to a stop, 4.18 m; (d) 8.04 m/s; (e) The time intervals are equal; (f) See P14.36(f) for a full conceptual argument.

P14.38 (a) See P14.38(a) for full description; (b) 2.66×10^{-3} m; (c) The situation in the human body is not represented by a large artery feeding into a single capillary as in part (b). See P14.38(c) for full explanation.

P14.40 (a) $\frac{1}{6}\rho g w H^3$; (b) $\frac{1}{3}H$

P14.42 See P14.42 for the full answer.

P14.44 $F_{\text{latch}} = \rho_{\text{water}} g w h\left(\frac{1}{2}d - \frac{1}{6}h\right)$

P14.46 (a) 0.553 s; (b) 14.5 m/s; (c) 0.145 m/s; (d) $P_2 = 1.013 \times 10^5$ Pa; (e) 2.06×10^5 Pa; (f) 33.0 N

P14.48 (a) The lift force is $\left(P_b - P_t\right)A = \frac{1}{2}\rho v_b^2\left(n^2 - 1\right)A.$ (b) The speed of the boat relative to the shore must be nearly equal to this speed of the water below the hydrofoil relative to the boat.

P14.50 The situation is impossible because lowering the height of the iron pile on the barge while keeping the base radius the same results in the top of the pile rising higher above the water level.