

Fluid Mechanics

CHAPTER OUTLINE

- 14.1 Pressure
- 14.2 Variation of Pressure with Depth
- 14.3 Pressure Measurements
- 14.4 Buoyant Forces and Archimede's Principle
- 14.5 Fluid Dynamics
- 14.6 Bernoulli's Equation
- 14.7 Other Applications of Fluid Dynamics

ANSWERS TO QUESTIONS

- Q14.1** The weight depends upon the total volume of glass. The pressure depends only on the depth.
- Q14.2** Both must be built the same. The force on the back of each dam is the average pressure of the water times the area of the dam. If both reservoirs are equally deep, the force is the same.

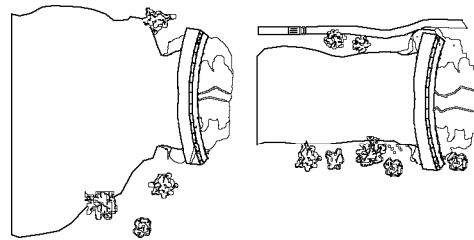


FIG. Q14.2

- Q14.3** If the tube were to fill up to the height of several stories of the building, the pressure at the bottom of the depth of the tube of fluid would be very large according to Equation 14.4. This pressure is much larger than that originally exerted by inward elastic forces of the rubber on the water. As a result, water is pushed into the bottle from the tube. As more water is added to the tube, more water continues to enter the bottle, stretching it thin. For a typical bottle, the pressure at the bottom of the tube can become greater than the pressure at which the rubber material will rupture, so the bottle will simply fill with water and expand until it bursts. Blaise Pascal splintered strong barrels by this method.
- Q14.4** About 1 000 N: that's about 250 pounds.
- Q14.5** The submarine would stop if the density of the surrounding water became the same as the average density of the submarine. Unfortunately, because the water is almost incompressible, this will be much deeper than the crush depth of the submarine.
- Q14.6** Yes. The propulsive force of the fish on the water causes the scale reading to fluctuate. Its average value will still be equal to the total weight of bucket, water, and fish.
- Q14.7** The boat floats higher in the ocean than in the inland lake. According to Archimedes's principle, the magnitude of buoyant force on the ship is equal to the weight of the water displaced by the ship. Because the density of salty ocean water is greater than fresh lake water, less ocean water needs to be displaced to enable the ship to float.

Q14.8 In the ocean, the ship floats due to the buoyant force from *salt water*. Salt water is denser than fresh water. As the ship is pulled up the river, the buoyant force from the fresh water in the river is not sufficient to support the weight of the ship, and it sinks.

Q14.9 Exactly the same. Buoyancy equals density of water times volume displaced.

Q14.10 At lower elevation the water pressure is greater because pressure increases with increasing depth below the water surface in the reservoir (or water tower). The penthouse apartment is not so far below the water surface. The pressure behind a closed faucet is weaker there and the flow weaker from an open faucet. Your fire department likely has a record of the precise elevation of every fire hydrant.

Q14.11 As the wind blows over the chimney, it creates a lower pressure at the top of the chimney. The smoke flows from the relatively higher pressure in front of the fireplace to the low pressure outside. Science doesn't suck; the smoke is pushed from below.

Q14.12 The rapidly moving air above the ball exerts less pressure than the atmospheric pressure below the ball. This can give substantial lift to balance the weight of the ball.

Q14.13 The ski-jumper gives her body the shape of an airfoil. She deflects downward the air stream as it rushes past and it deflects her upward by Newton's third law. The air exerts on her a lift force, giving her a higher and longer trajectory. To say it in different words, the pressure on her back is less than the pressure on her front.

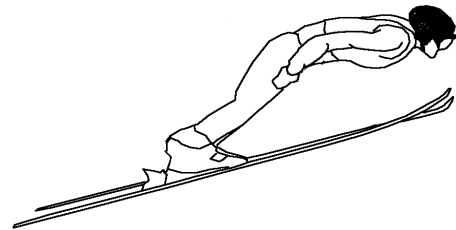


FIG. Q14.13

Q14.14 The horizontal force exerted by the outside fluid, on an area element of the object's side wall, has equal magnitude and opposite direction to the horizontal force the fluid exerts on another element diametrically opposite the first.

Q14.15 The glass may have higher density than the liquid, but the air inside has lower density. The total weight of the bottle can be less than the weight of an equal volume of the liquid.

Q14.16 Breathing in makes your volume greater and increases the buoyant force on you. You instinctively take a deep breath if you fall into the lake.

Q14.17 No. The somewhat lighter barge will float higher in the water.

Q14.18 The level of the pond falls. This is because the anchor displaces more water while in the boat. A floating object displaces a volume of water whose weight is equal to the weight of the object. A submerged object displaces a volume of water equal to the volume of the object. Because the density of the anchor is greater than that of water, a volume of water that weighs the same as the anchor will be greater than the volume of the anchor.

Q14.19 The metal is more dense than water. If the metal is sufficiently thin, it can float like a ship, with the lip of the dish above the water line. Most of the volume below the water line is filled with air. The mass of the dish divided by the volume of the part below the water line is just equal to the density of water. Placing a bar of soap into this space to replace the air raises the average density of the compound object and the density can become greater than that of water. The dish sinks with its cargo.

- Q14.20** The excess pressure is transmitted undiminished throughout the container. It will compress air inside the wood. The water driven into the wood raises its average density and makes it float lower in the water. Add some thumbtacks to reach neutral buoyancy and you can make the wood sink or rise at will by subtly squeezing a large clear-plastic soft-drink bottle. Bored with graph paper and proving his own existence, René Descartes invented this toy or trick.
- Q14.21** The plate must be horizontal. Since the pressure of a fluid increases with increasing depth, other orientations of the plate will give a non-uniform pressure on the flat faces.
- Q14.22** The air in your lungs, the blood in your arteries and veins, and the protoplasm in each cell exert nearly the same pressure, so that the wall of your chest can be in equilibrium.
- Q14.23** Use a balance to determine its mass. Then partially fill a graduated cylinder with water. Immerse the rock in the water and determine the volume of water displaced. Divide the mass by the volume and you have the density.
- Q14.24** When taking off into the wind, the increased airspeed over the wings gives a larger lifting force, enabling the pilot to take off in a shorter length of runway.
- Q14.25** Like the ball, the balloon will remain in front of you. It will not bob up to the ceiling. Air pressure will be no higher at the floor of the sealed car than at the ceiling. The balloon will experience no buoyant force. You might equally well switch off gravity.
- Q14.26** Styrofoam is a little more dense than air, so the first ship floats lower in the water.
- Q14.27** We suppose the compound object floats. In both orientations it displaces its own weight of water, so it displaces equal volumes of water. The water level in the tub will be unchanged when the object is turned over. Now the steel is underwater and the water exerts on the steel a buoyant force that was not present when the steel was on top surrounded by air. Thus, slightly less wood will be below the water line on the block. It will appear to float higher.
- Q14.28** A breeze from any direction speeds up to go over the mound and the air pressure drops. Air then flows through the burrow from the lower entrance to the upper entrance.
- Q14.29** Regular cola contains a considerable mass of dissolved sugar. Its density is higher than that of water. Diet cola contains a very small mass of artificial sweetener and has nearly the same density as water. The low-density air in the can has a bigger effect than the thin aluminum shell, so the can of diet cola floats.
- Q14.30** (a) Lowest density: oil; highest density: mercury
(b) The density must increase from top to bottom.
- Q14.31** (a) Since the velocity of the air in the right-hand section of the pipe is lower than that in the middle, the pressure is higher.
(b) The equation that predicts the same pressure in the far right and left-hand sections of the tube assumes laminar flow without viscosity. Internal friction will cause some loss of mechanical energy and turbulence will also progressively reduce the pressure. If the pressure at the left were not higher than at the right, the flow would stop.

- Q14.32** Clap your shoe or wallet over the hole, or a seat cushion, or your hand. Anything that can sustain a force on the order of 100 N is strong enough to cover the hole and greatly slow down the escape of the cabin air. You need not worry about the air rushing out instantly, or about your body being “sucked” through the hole, or about your blood boiling or your body exploding. If the cabin pressure drops a lot, your ears will pop and the saliva in your mouth may boil—at body temperature—but you will still have a couple of minutes to plug the hole and put on your emergency oxygen mask. Passengers who have been drinking carbonated beverages may find that the carbon dioxide suddenly comes out of solution in their stomachs, distending their vests, making them belch, and all but frothing from their ears; so you might warn them of this effect.

SOLUTIONS TO PROBLEMS

Section 14.1 Pressure

P14.1 $M = \rho_{\text{iron}} V = (7860 \text{ kg/m}^3) \left[\frac{4}{3} \pi (0.0150 \text{ m})^3 \right]$
 $M = \boxed{0.111 \text{ kg}}$

- P14.2** The density of the nucleus is of the same order of magnitude as that of one proton, according to the assumption of close packing:

$$\rho = \frac{m}{V} \sim \frac{1.67 \times 10^{-27} \text{ kg}}{\frac{4}{3} \pi (10^{-15} \text{ m})^3} \boxed{\sim 10^{18} \text{ kg/m}^3}.$$

With vastly smaller average density, a macroscopic chunk of matter or an atom must be mostly empty space.

P14.3 $P = \frac{F}{A} = \frac{50.0(9.80)}{\pi (0.500 \times 10^{-2})^2} = \boxed{6.24 \times 10^6 \text{ N/m}^2}$

- P14.4** Let F_g be its weight. Then each tire supports $\frac{F_g}{4}$,

so $P = \frac{F}{A} = \frac{F_g}{4A}$

yielding $F_g = 4AP = 4(0.0240 \text{ m}^2)(200 \times 10^3 \text{ N/m}^2) = \boxed{1.92 \times 10^4 \text{ N}}$

- P14.5** The Earth's surface area is $4\pi R^2$. The force pushing inward over this area amounts to

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

This force is the weight of the air:

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

so the mass of the air is

$$m = \frac{P_0 (4\pi R^2)}{g} = \frac{(1.013 \times 10^5 \text{ N/m}^2) \left[4\pi (6.37 \times 10^6 \text{ m})^2 \right]}{9.80 \text{ m/s}^2} = \boxed{5.27 \times 10^{18} \text{ kg}}.$$

Section 14.2 Variation of Pressure with Depth

P14.6 (a) $P = P_0 + \rho gh = 1.013 \times 10^5 \text{ Pa} + (1024 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(1000 \text{ m})$
 $P = \boxed{1.01 \times 10^7 \text{ Pa}}$

- (b) The gauge pressure is the difference in pressure between the water outside and the air inside the submarine, which we suppose is at 1.00 atmosphere.

$$P_{\text{gauge}} = P - P_0 = \rho gh = 1.00 \times 10^7 \text{ Pa}$$

The resultant inward force on the porthole is then

$$F = P_{\text{gauge}} A = 1.00 \times 10^7 \text{ Pa} [\pi (0.150 \text{ m})^2] = \boxed{7.09 \times 10^5 \text{ N}}.$$

P14.7 $F_{\text{el}} = F_{\text{fluid}}$ or $kx = \rho ghA$

and $h = \frac{kx}{\rho g A}$

$$h = \frac{(1000 \text{ N/m}^2)(5.00 \times 10^{-3} \text{ m})}{(10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2) [\pi (1.00 \times 10^{-2} \text{ m})^2]} = \boxed{1.62 \text{ m}}$$

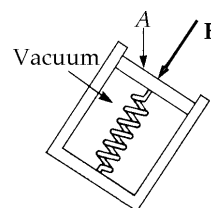


FIG. P14.7

P14.8 Since the pressure is the same on both sides, $\frac{F_1}{A_1} = \frac{F_2}{A_2}$

In this case, $\frac{15\,000}{200} = \frac{F_2}{3.00}$ or $F_2 = \boxed{225 \text{ N}}$

P14.9 $F_g = 80.0 \text{ kg}(9.80 \text{ m/s}^2) = 784 \text{ N}$

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

$$F_g = F = PA = (1.013 \times 10^5 \text{ Pa})A$$

$$A = \frac{F_g}{P} = \frac{784}{1.013 \times 10^5} = \boxed{7.74 \times 10^{-3} \text{ m}^2}$$

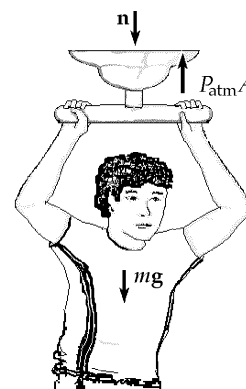


FIG. P14.9

- P14.10** (a) Suppose the “vacuum cleaner” functions as a high-vacuum pump. The air below the brick will exert on it a lifting force

$$F = PA = 1.013 \times 10^5 \text{ Pa} [\pi (1.43 \times 10^{-2} \text{ m})^2] = \boxed{65.1 \text{ N}}.$$

- (b) The octopus can pull the bottom away from the top shell with a force that could be no larger than

$$F = PA = (P_0 + \rho gh)A = [1.013 \times 10^5 \text{ Pa} + (1030 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(32.3 \text{ m})] [\pi (1.43 \times 10^{-2} \text{ m})^2]$$

$$F = \boxed{275 \text{ N}}$$

P14.11 The excess water pressure (over air pressure) halfway down is

$$P_{\text{gauge}} = \rho g h = (1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(1.20 \text{ m}) = 1.18 \times 10^4 \text{ Pa}.$$

The force on the wall due to the water is

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

horizontally toward the back of the hole.

P14.12 The pressure on the bottom due to the water is $P_b = \rho g z = 1.96 \times 10^4 \text{ Pa}$

So,

$$F_b = P_b A = \boxed{5.88 \times 10^6 \text{ N}}$$

On each end,

$$F = \bar{P} A = 9.80 \times 10^3 \text{ Pa}(20.0 \text{ m}^2) = \boxed{196 \text{ kN}}$$

On the side,

$$F = \bar{P} A = 9.80 \times 10^3 \text{ Pa}(60.0 \text{ m}^2) = \boxed{588 \text{ kN}}$$

P14.13 In the reference frame of the fluid, the cart's acceleration causes a fictitious force to act backward, as if the acceleration of gravity were $\sqrt{g^2 + a^2}$ directed downward and backward at $\theta = \tan^{-1}\left(\frac{a}{g}\right)$ from the vertical. The center of the spherical shell is at depth $\frac{d}{2}$ below the air bubble and the pressure there is

$$P = P_0 + \rho g_{\text{eff}} h = \boxed{P_0 + \frac{1}{2} \rho d \sqrt{g^2 + a^2}}.$$

P14.14 The air outside and water inside both exert atmospheric pressure, so only the excess water pressure $\rho g h$ counts for the net force. Take a strip of hatch between depth h and $h + dh$. It feels force

$$dF = PdA = \rho g h(2.00 \text{ m})dh.$$

(a) The total force is

$$\begin{aligned} F &= \int dF = \int_{h=1.00 \text{ m}}^{2.00 \text{ m}} \rho g h(2.00 \text{ m})dh \\ F &= \rho g(2.00 \text{ m}) \left[\frac{h^2}{2} \right]_{1.00 \text{ m}}^{2.00 \text{ m}} = (1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2) \frac{(2.00 \text{ m})}{2} [(2.00 \text{ m})^2 - (1.00 \text{ m})^2] \\ F &= \boxed{29.4 \text{ kN (to the right)}} \end{aligned}$$

(b) The lever arm of dF is the distance $(h - 1.00 \text{ m})$ from hinge to strip:

$$\begin{aligned} \tau &= \int d\tau = \int_{h=1.00 \text{ m}}^{2.00 \text{ m}} \rho g h(2.00 \text{ m})(h - 1.00 \text{ m})dh \\ \tau &= \rho g(2.00 \text{ m}) \left[\frac{h^3}{3} - (1.00 \text{ m}) \frac{h^2}{2} \right]_{1.00 \text{ m}}^{2.00 \text{ m}} \\ \tau &= (1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(2.00 \text{ m}) \left(\frac{7.00 \text{ m}^3}{3} - \frac{3.00 \text{ m}^3}{2} \right) \\ \tau &= \boxed{16.3 \text{ kN} \cdot \text{m counterclockwise}} \end{aligned}$$

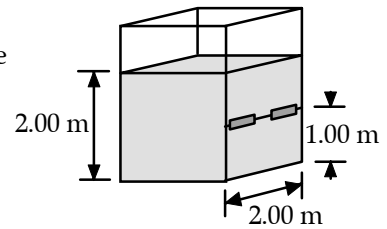


FIG. P14.14

P14.15 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:

$$\Delta V = \frac{-V\Delta P}{B} = -\frac{\rho_w ghV}{B} = -\frac{4\pi\rho_w gh r^3}{3B}, \text{ where } B \text{ is the Bulk Modulus.}$$

$$\Delta V = -\frac{4\pi(1030 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(10\,000 \text{ m})(1.50 \text{ m})^3}{(3)(14.0 \times 10^{10} \text{ Pa})} = -0.0102 \text{ m}^3$$

Therefore, the volume of the ball at the bottom of the ocean is

$$V - \Delta V = \frac{4}{3}\pi(1.50 \text{ m})^3 - 0.0102 \text{ m}^3 = 14.137 \text{ m}^3 - 0.0102 \text{ m}^3 = 14.127 \text{ m}^3.$$

This gives a radius of 1.49964 m and a new diameter of 2.9993 m. Therefore the diameter decreases by 0.722 mm.

Section 14.3 Pressure Measurements

P14.16 (a) We imagine the superhero to produce a perfect vacuum in the straw. Take point 1 at the water surface in the basin and point 2 at the water surface in the straw:

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

$$1.013 \times 10^5 \text{ N/m}^2 + 0 = 0 + (1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)y_2 \quad y_2 = \boxed{10.3 \text{ m}}$$

(b) No atmosphere can lift the water in the straw through zero height difference.

P14.17 $P_0 = \rho g h$

$$h = \frac{P_0}{\rho g} = \frac{10.13 \times 10^5 \text{ Pa}}{(0.984 \times 10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2)} = \boxed{10.5 \text{ m}}$$

No. Some alcohol and water will evaporate. The equilibrium vapor pressures of alcohol and water are higher than the vapor pressure of mercury.

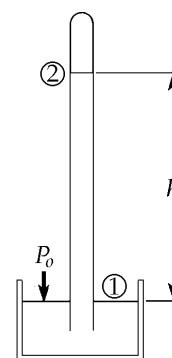


FIG. P14.17

P14.18 (a) Using the definition of density, we have

$$h_w = \frac{m_{\text{water}}}{A_2 \rho_{\text{water}}} = \frac{100 \text{ g}}{5.00 \text{ cm}^2 (1.00 \text{ g/cm}^3)} = \boxed{20.0 \text{ cm}}$$

(b) Sketch (b) at the right represents the situation after the water is added. A volume ($A_2 h_2$) of mercury has been displaced by water in the right tube. The additional volume of mercury now in the left tube is $A_1 h$. Since the total volume of mercury has not changed,

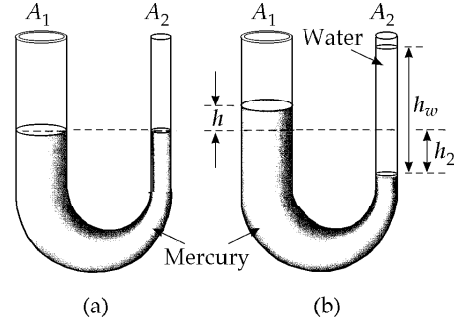


FIG. P14.18

$$A_2 h_2 = A_1 h \quad \text{or} \quad h_2 = \frac{A_1}{A_2} h \quad (1)$$

At the level of the mercury–water interface in the right tube, we may write the absolute pressure as:

$$P = P_0 + \rho_{\text{water}} g h_w$$

The pressure at this same level in the left tube is given by

$$P = P_0 + \rho_{\text{Hg}} g (h + h_2) = P_0 + \rho_{\text{water}} g h_w$$

which, using equation (1) above, reduces to

$$\rho_{\text{Hg}} h \left[1 + \frac{A_1}{A_2} \right] = \rho_{\text{water}} h_w$$

$$\text{or } h = \frac{\rho_{\text{water}} h_w}{\rho_{\text{Hg}} \left(1 + \frac{A_1}{A_2} \right)}$$

$$\text{Thus, the level of mercury has risen a distance of } h = \frac{(1.00 \text{ g/cm}^3)(20.0 \text{ cm})}{(13.6 \text{ g/cm}^3) \left(1 + \frac{10.0}{5.00} \right)} = \boxed{0.490 \text{ cm}}$$

above the original level.

P14.19 $\Delta P_0 = \rho g \Delta h = -2.66 \times 10^3 \text{ Pa}$: $P = P_0 + \Delta P_0 = (1.013 - 0.0266) \times 10^5 \text{ Pa} = \boxed{0.986 \times 10^5 \text{ Pa}}$

P14.20 Let h be the height of the water column added to the right side of the U-tube. Then when equilibrium is reached, the situation is as shown in the sketch at right. Now consider two points, A and B shown in the sketch, at the level of the water–mercury interface. By Pascal's Principle, the absolute pressure at B is the same as that at A . But,

$$P_A = P_0 + \rho_w g h + \rho_{\text{Hg}} g h_2 \quad \text{and}$$

$$P_B = P_0 + \rho_w g (h_1 + h + h_2).$$

Thus, from $P_A = P_B$, $\rho_w h_1 + \rho_w h + \rho_w h_2 = \rho_w h + \rho_{\text{Hg}} h_2$, or

$$h_1 = \left[\frac{\rho_{\text{Hg}}}{\rho_w} - 1 \right] h_2 = (13.6 - 1)(1.00 \text{ cm}) = \boxed{12.6 \text{ cm}}.$$

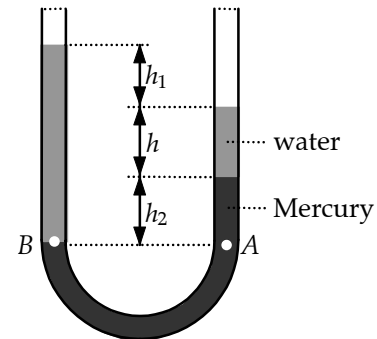


FIG. P14.20

***P14.21** (a) $P = P_0 + \rho gh$

The gauge pressure is

$$P - P_0 = \rho gh = 1000 \text{ kg} (9.8 \text{ m/s}^2) (0.160 \text{ m}) = \boxed{1.57 \text{ kPa}} = 1.57 \times 10^3 \text{ Pa} \left(\frac{1 \text{ atm}}{1.013 \times 10^5 \text{ Pa}} \right)$$

$$= \boxed{0.0155 \text{ atm}}.$$

It would lift a mercury column to height

$$h = \frac{P - P_0}{\rho g} = \frac{1568 \text{ Pa}}{(13600 \text{ kg/m}^3)(9.8 \text{ m/s}^2)} = \boxed{11.8 \text{ mm}}.$$

(b) Increased pressure of the cerebrospinal fluid will raise the level of the fluid in the spinal tap.

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

Section 14.4 Buoyant Forces and Archimede's Principle

P14.22 (a) The balloon is nearly in equilibrium:

$$\sum F_y = ma_y \Rightarrow B - (F_g)_{\text{helium}} - (F_g)_{\text{payload}} = 0$$

or $\rho_{\text{air}} g V - \rho_{\text{helium}} g V - m_{\text{payload}} g = 0$

This reduces to

$$m_{\text{payload}} = (\rho_{\text{air}} - \rho_{\text{helium}}) V = (1.29 \text{ kg/m}^3 - 0.179 \text{ kg/m}^3) (400 \text{ m}^3)$$

$$m_{\text{payload}} = \boxed{444 \text{ kg}}$$

(b) Similarly,

$$m_{\text{payload}} = (\rho_{\text{air}} - \rho_{\text{hydrogen}}) V = (1.29 \text{ kg/m}^3 - 0.0899 \text{ kg/m}^3) (400 \text{ m}^3)$$

$$m_{\text{payload}} = \boxed{480 \text{ kg}}$$

The air does the lifting, nearly the same for the two balloons.

P14.23 At equilibrium $\sum F = 0$ or $F_{\text{app}} + mg = B$

where B is the buoyant force.

The applied force, $F_{\text{app}} = B - mg$

where $B = \text{Vol}(\rho_{\text{water}})g$

and $m = (\text{Vol})\rho_{\text{ball}}$.

So, $F_{\text{app}} = (\text{Vol})g(\rho_{\text{water}} - \rho_{\text{ball}}) = \frac{4}{3}\pi r^3 g(\rho_{\text{water}} - \rho_{\text{ball}})$

$$F_{\text{app}} = \frac{4}{3}\pi (1.90 \times 10^{-2} \text{ m})^3 (9.80 \text{ m/s}^2) (10^3 \text{ kg/m}^3 - 84.0 \text{ kg/m}^3) = \boxed{0.258 \text{ N}}$$

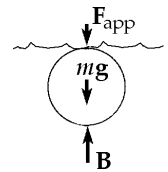


FIG. P14.23

P14.24 $F_g = (m + \rho_s V)g$ must be equal to $F_b = \rho_w Vg$

Since $V = Ah$, $m + \rho_s Ah = \rho_w Ah$

and $A = \boxed{\frac{m}{(\rho_w - \rho_s)h}}$

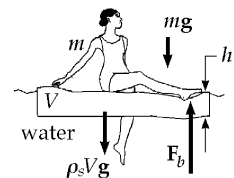


FIG. P14.24

P14.25 (a) Before the metal is immersed:

$$\sum F_y = T_1 - Mg = 0 \text{ or}$$

$$T_1 = Mg = (1.00 \text{ kg})(9.80 \text{ m/s}^2) = \boxed{9.80 \text{ N}}$$

(b) After the metal is immersed:

$$\sum F_y = T_2 + B - Mg = 0 \text{ or}$$

$$T_2 = Mg - B = Mg - (\rho_w V)g$$

$$V = \frac{M}{\rho} = \frac{1.00 \text{ kg}}{2700 \text{ kg/m}^3}$$

Thus,

$$T_2 = Mg - B = 9.80 \text{ N} - \left(1000 \text{ kg/m}^3\right) \left(\frac{1.00 \text{ kg}}{2700 \text{ kg/m}^3}\right) (9.80 \text{ m/s}^2) = \boxed{6.17 \text{ N}}.$$

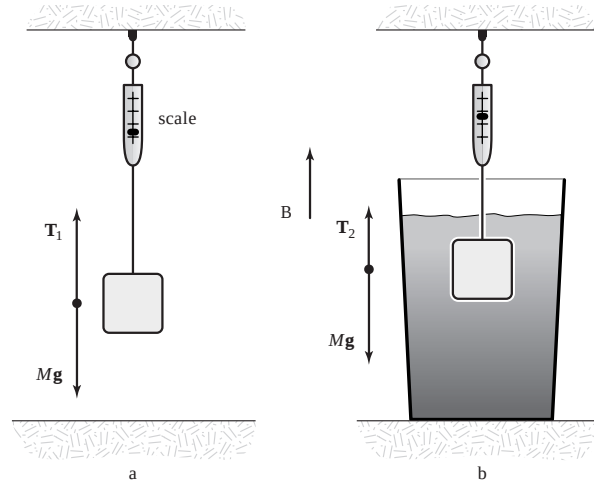
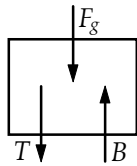


FIG. P14.25

***P14.26** (a)



(b) $\sum F_y = 0: -15 \text{ N} - 10 \text{ N} + B = 0$

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

(c) The oil pushes horizontally inward on each side of the block.

FIG. P14.26(a)

(d) String tension increases. The oil causes the water below to be under greater pressure, and the water pushes up more strongly on the bottom of the block.

(e) Consider the equilibrium just before the string breaks:

$$-15 \text{ N} - 60 \text{ N} + 25 \text{ N} + B_{\text{oil}} = 0$$

$$B_{\text{oil}} = 50 \text{ N}$$

For the buoyant force of the water we have

$$B = \rho V g \quad 25 \text{ N} = (1000 \text{ kg/m}^3)(0.25 V_{\text{block}}) 9.8 \text{ m/s}^2$$

$$V_{\text{block}} = 1.02 \times 10^{-2} \text{ m}^3$$

For the buoyant force of the oil

$$50 \text{ N} = (800 \text{ kg/m}^3) f_e (1.02 \times 10^{-2} \text{ m}^3) 9.8 \text{ m/s}^2$$

$$f_e = 0.625 = \boxed{62.5\%}$$

(f) $-15 \text{ N} + (800 \text{ kg/m}^3) f_f (1.02 \times 10^{-2} \text{ m}^3) 9.8 \text{ m/s}^2 = 0$

$$f_f = 0.187 = \boxed{18.7\%}$$

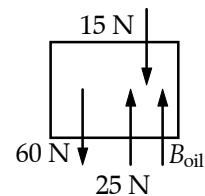


FIG. P14.26(e)

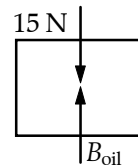


FIG. P14.26(f)

P14.27 (a) $P = P_0 + \rho gh$

Taking $P_0 = 1.013 \times 10^5 \text{ N/m}^2$ and $h = 5.00 \text{ cm}$

we find

$$P_{\text{top}} = 1.0179 \times 10^5 \text{ N/m}^2$$

For $h = 17.0 \text{ cm}$, we get

$$P_{\text{bot}} = 1.0297 \times 10^5 \text{ N/m}^2$$

Since the areas of the top and bottom are

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

we find

$$F_{\text{top}} = P_{\text{top}} A = \boxed{1.0179 \times 10^3 \text{ N}}$$

and

$$F_{\text{bot}} = \boxed{1.0297 \times 10^3 \text{ N}}$$

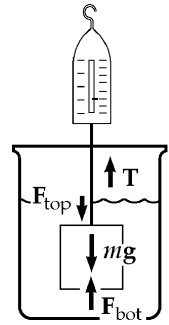


FIG. P14.27

(b) $T + B - Mg = 0$

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 $Mg = 10.0(9.80) = 98.0 \text{ N}$

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

(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).

P14.28 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

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

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

$$F_{\text{up}} = [(1.29 - 0.179) \text{ kg/m}^3] \left[\frac{4}{3} \pi (0.125 \text{ m})^3 \right] (9.80 \text{ m/s}^2) - 5.00 \times 10^{-3} \text{ kg} (9.80 \text{ m/s}^2) = 0.0401 \text{ N}$$

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: $\frac{686 \text{ N}}{0.0401 \text{ N}} = 17\,000 \sim 10^4$.

P14.29 (a) According to Archimedes, $B = \rho_{\text{water}} V_{\text{water}} g = (1.00 \text{ g/cm}^3) [20.0 \times 20.0 \times (20.0 - h)] g$

But $B = \text{Weight of block} = mg = \rho_{\text{wood}} V_{\text{wood}} g = (0.650 \text{ g/cm}^3) (20.0 \text{ cm})^3 g$

$$0.650(20.0)^3 g = 1.00(20.0)(20.0)(20.0 - h) g$$

$$20.0 - h = 20.0(0.650) \text{ so } h = 20.0(1 - 0.650) = \boxed{7.00 \text{ cm}}$$

(b) $B = F_g + Mg$ where $M = \text{mass of lead}$

$$1.00(20.0)^3 g = 0.650(20.0)^3 g + Mg$$

$$M = (1.00 - 0.650)(20.0)^3 = 0.350(20.0)^3 = 2\,800 \text{ g} = \boxed{2.80 \text{ kg}}$$

- *P14.30 (a) The weight of the ball must be equal to the buoyant force of the water:

$$1.26 \text{ kg}g = \rho_{\text{water}} \frac{4}{3} \pi r_{\text{outer}}^3 g$$

$$r_{\text{outer}} = \left(\frac{3 \times 1.26 \text{ kg}}{4\pi 1000 \text{ kg/m}^3} \right)^{1/3} = \boxed{6.70 \text{ cm}}$$

- (b) The mass of the ball is determined by the density of aluminum:

$$m = \rho_{\text{Al}} V = \rho_{\text{Al}} \left(\frac{4}{3} \pi r_0^3 - \frac{4}{3} \pi r_i^3 \right)$$

$$1.26 \text{ kg} = 2700 \text{ kg/m}^3 \left(\frac{4}{3} \pi \right) ((0.067 \text{ m})^3 - r_i^3)$$

$$1.11 \times 10^{-4} \text{ m}^3 = 3.01 \times 10^{-4} \text{ m}^3 - r_i^3$$

$$r_i = (1.89 \times 10^{-4} \text{ m}^3)^{1/3} = \boxed{5.74 \text{ cm}}$$

- *P14.31 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 $\rho = \frac{\rho_0 L}{L - h}$.

- *P14.32 We use the result of Problem 14.31. For the rod floating in a liquid of density 0.98 g/cm^3 ,

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

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

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

For floating in the dense liquid,

$$1.14 \text{ g/cm}^3 = \frac{\rho_0 L}{(L - 1.8 \text{ cm})}$$

$$1.14 \text{ g/cm}^3 - (1.14 \text{ g/cm}^3) 1.8 \text{ cm} = \rho_0 L$$

- (a) By substitution,

$$1.14L - 1.14(1.8 \text{ cm}) = 0.98L - 0.2(0.98)$$

$$0.16L = 1.856 \text{ cm}$$

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

- (b) Substituting back,

$$0.98 \text{ g/cm}^3 (11.6 \text{ cm} - 0.2 \text{ cm}) = \rho_0 11.6 \text{ cm}$$

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

- (c) The marks are not equally spaced. Because $\rho = \frac{\rho_0 L}{L - h}$ is not of the form $\rho = a + bh$, equal-size steps of ρ do not correspond to equal-size steps of h .

P14.33 The balloon stops rising when $(\rho_{\text{air}} - \rho_{\text{He}})gV = Mg$ and $(\rho_{\text{air}} - \rho_{\text{He}})V = M$,
 Therefore,
$$V = \frac{M}{\rho_{\text{air}} - \rho_{\text{He}}} = \frac{400}{1.25e^{-1} - 0.180} \quad V = \boxed{1\,430 \text{ m}^3}$$

P14.34 Since the frog floats, the buoyant force = the weight of the frog. Also, the weight of the displaced water = weight of the frog, so

$$\rho_{\text{ooze}} Vg = m_{\text{frog}} g$$

or
$$m_{\text{frog}} = \rho_{\text{ooze}} V = \rho_{\text{ooze}} \frac{1}{2} \left(\frac{4}{3} \pi r^3 \right) = (1.35 \times 10^3 \text{ kg/m}^3) \frac{2\pi}{3} (6.00 \times 10^{-2} \text{ m})^3$$

Hence, $m_{\text{frog}} = \boxed{0.611 \text{ kg}}$.

P14.35 $B = F_g$

$$\rho_{\text{H}_2\text{O}} g \frac{V}{2} = \rho_{\text{sphere}} g V$$

$$\rho_{\text{sphere}} = \frac{1}{2} \rho_{\text{H}_2\text{O}} = \boxed{500 \text{ kg/m}^3}$$

$$\rho_{\text{glycerin}} g \left(\frac{4}{10} V \right) - \rho_{\text{sphere}} g V = 0$$

$$\rho_{\text{glycerin}} = \frac{10}{4} (500 \text{ kg/m}^3) = \boxed{1\,250 \text{ kg/m}^3}$$

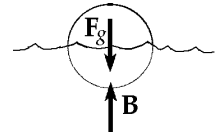


FIG. P14.35

P14.36 Constant velocity implies zero acceleration, which means that the submersible is in equilibrium under the gravitational force, the upward buoyant force, and the upward resistance force:

$$\sum F_y = ma_y = 0 \quad -(1.20 \times 10^4 \text{ kg} + m)g + \rho_w g V + 1\,100 \text{ N} = 0$$

where m is the mass of the added water and V is the sphere's volume.

$$1.20 \times 10^4 \text{ kg} + m = 1.03 \times 10^3 \left[\frac{4}{3} \pi (1.50)^3 \right] + \frac{1\,100 \text{ N}}{9.8 \text{ m/s}^2}$$

so
$$m = \boxed{2.67 \times 10^3 \text{ kg}}$$

P14.37 By Archimedes's principle, the weight of the fifty planes is equal to the weight of a horizontal slice of water 11.0 cm thick and circumscribed by the water line:

$$\Delta B = \rho_{\text{water}} g (\Delta V)$$

$$50(2.90 \times 10^4 \text{ kg})g = (1\,030 \text{ kg/m}^3)g(0.110 \text{ m})A$$

giving $A = \boxed{1.28 \times 10^4 \text{ m}^2}$. The acceleration of gravity does not affect the answer.

Section 14.5 Fluid Dynamics

Section 14.6 Bernoulli's Equation

P14.38 By Bernoulli's equation,

$$8.00 \times 10^4 \text{ N/m}^2 + \frac{1}{2}(1000)v^2 = 6.00 \times 10^4 \text{ N/m}^2 + \frac{1}{2}(1000)16v^2$$

$$2.00 \times 10^4 \text{ N/m}^2 = \frac{1}{2}(1000)15v^2$$

$$v = 1.63 \text{ m/s}$$

$$\frac{dm}{dt} = \rho A v = 1000 \pi (5.00 \times 10^{-2})^2 (1.63 \text{ m/s}) = \boxed{12.8 \text{ kg/s}}$$



FIG. P14.38

P14.39 Assuming the top is open to the atmosphere, then

$$P_1 = P_0.$$

Note $P_2 = P_0.$

$$\text{Flow rate} = 2.50 \times 10^{-3} \text{ m}^3/\text{min} = 4.17 \times 10^{-5} \text{ m}^3/\text{s}.$$

(a) $A_1 \gg A_2$ so $v_1 \ll v_2$

Assuming $v_1 = 0$,

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

$$v_2 = (2g y_1)^{1/2} = [2(9.80)(16.0)]^{1/2} = \boxed{17.7 \text{ m/s}}$$

(b) $\text{Flow rate} = A_2 v_2 = \left(\frac{\pi d^2}{4} \right) (17.7) = 4.17 \times 10^{-5} \text{ m}^3/\text{s}$

$$d = \boxed{1.73 \times 10^{-3} \text{ m}} = 1.73 \text{ mm}$$

***P14.40** Take point ① at the free surface of the water in the tank and ② inside the nozzle.

(a) With the cork in place $P_1 + \rho g y_1 + \frac{1}{2} \rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2} \rho v_2^2$ becomes
 $P_0 + 1000 \text{ kg/m}^3 9.8 \text{ m/s}^2 7.5 \text{ m} + 0 = P_2 + 0 + 0$; $P_2 - P_0 = 7.35 \times 10^4 \text{ Pa}.$

For the stopper $\sum F_x = 0$

$$F_{\text{water}} - F_{\text{air}} - f = 0$$

$$P_2 A - P_0 A = f$$

$$f = 7.35 \times 10^4 \text{ Pa} \pi (0.011 \text{ m})^2 = \boxed{27.9 \text{ N}}$$

(b) Now Bernoulli's equation gives

$$P_0 + 7.35 \times 10^4 \text{ Pa} + 0 = P_0 + 0 + \frac{1}{2} (1000 \text{ kg/m}^3) v_2^2$$

$$v_2 = 12.1 \text{ m/s}$$

The quantity leaving the nozzle in 2 h is

$$\rho V = \rho A v_2 t = (1000 \text{ kg/m}^3) \pi (0.011 \text{ m})^2 (12.1 \text{ m/s}) 7200 \text{ s} = \boxed{3.32 \times 10^4 \text{ kg}}.$$

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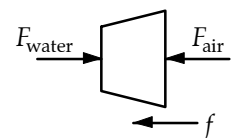


FIG. P14.40

(c) Take point 1 in the wide hose and 2 just outside the nozzle. Continuity:

$$\begin{aligned}
 A_1 v_1 &= A_2 v_2 \\
 \pi \left(\frac{6.6 \text{ cm}}{2} \right)^2 v_1 &= \pi \left(\frac{2.2 \text{ cm}}{2} \right)^2 12.1 \text{ m/s} \\
 v_1 &= \frac{12.1 \text{ m/s}}{9} = 1.35 \text{ m/s} \\
 P_1 + \rho g y_1 + \frac{1}{2} \rho v_1^2 &= P_2 + \rho g y_2 + \frac{1}{2} \rho v_2^2 \\
 P_1 + 0 + \frac{1}{2} (1000 \text{ kg/m}^3) (1.35 \text{ m/s})^2 &= P_0 + 0 + \frac{1}{2} (1000 \text{ kg/m}^3) (12.1 \text{ m/s})^2 \\
 P_1 - P_0 &= 7.35 \times 10^4 \text{ Pa} - 9.07 \times 10^2 \text{ Pa} = \boxed{7.26 \times 10^4 \text{ Pa}}
 \end{aligned}$$

P14.41 Flow rate $Q = 0.0120 \text{ m}^3/\text{s} = v_1 A_1 = v_2 A_2$

$$v_2 = \frac{Q}{A_2} = \frac{0.0120}{A_2} = \boxed{31.6 \text{ m/s}}$$

***P14.42** (a) $\mathcal{P} = \frac{\Delta E}{\Delta t} = \frac{\Delta m g h}{\Delta t} = \left(\frac{\Delta m}{\Delta t} \right) g h = R g h$

(b) $\mathcal{P}_{\text{EL}} = 0.85 (8.5 \times 10^5) (9.8) (87) = \boxed{616 \text{ MW}}$

***P14.43** The volume flow rate is

$$\frac{125 \text{ cm}^3}{16.3 \text{ s}} = A v_1 = \pi \left(\frac{0.96 \text{ cm}}{2} \right)^2 v_1.$$

The speed at the top of the falling column is

$$v_1 = \frac{7.67 \text{ cm}^3/\text{s}}{0.724 \text{ cm}^2} = 10.6 \text{ cm/s}.$$

Take point 2 at 13 cm below:

$$\begin{aligned}
 P_1 + \rho g y_1 + \frac{1}{2} \rho v_1^2 &= P_2 + \rho g y_2 + \frac{1}{2} \rho v_2^2 \\
 P_0 + (1000 \text{ kg/m}^3) (9.8 \text{ m/s}^2) 0.13 \text{ m} + \frac{1}{2} (1000 \text{ kg/m}^3) (0.106 \text{ m/s})^2 \\
 &= P_0 + 0 + \frac{1}{2} (1000 \text{ kg/m}^3) v_2^2 \\
 v_2 &= \sqrt{2(9.8 \text{ m/s}^2) 0.13 \text{ m} + (0.106 \text{ m/s})^2} = 1.60 \text{ m/s}
 \end{aligned}$$

The volume flow rate is constant:

$$\begin{aligned}
 7.67 \text{ cm}^3/\text{s} &= \pi \left(\frac{d}{2} \right)^2 160 \text{ cm/s} \\
 d &= \boxed{0.247 \text{ cm}}
 \end{aligned}$$

***P14.44** (a) Between sea surface and clogged hole: $P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$

$$1 \text{ atm} + 0 + (1030 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(2 \text{ m}) = P_2 + 0 + 0 \quad P_2 = 1 \text{ atm} + 20.2 \text{ kPa}$$

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

$$F = PA = (20.2 \times 10^3 \text{ N/m}^2) \left(\frac{\pi}{4} \right) (1.2 \times 10^{-2} \text{ m})^2 \quad F = \boxed{2.28 \text{ N}}$$

(b) Now, Bernoulli's theorem is

$$1 \text{ atm} + 0 + 20.2 \text{ kPa} = 1 \text{ atm} + \frac{1}{2}(1030 \text{ kg/m}^3)v_2^2 + 0 \quad v_2 = 6.26 \text{ m/s}$$

The volume rate of flow is $A_2 v_2 = \frac{\pi}{4} (1.2 \times 10^{-2} \text{ m})^2 (6.26 \text{ m/s}) = 7.08 \times 10^{-4} \text{ m}^3/\text{s}$

One acre-foot is $4047 \text{ m}^2 \times 0.3048 \text{ m} = 1234 \text{ m}^3$

Requiring $\frac{1234 \text{ m}^3}{7.08 \times 10^{-4} \text{ m}^3/\text{s}} = \boxed{1.74 \times 10^6 \text{ s}} = 20.2 \text{ days}$

P14.45 (a) Suppose the flow is very slow: $\left(P + \frac{1}{2}\rho v^2 + \rho g y \right)_{\text{river}} = \left(P + \frac{1}{2}\rho v^2 + \rho g y \right)_{\text{rim}}$

$$P + 0 + \rho g(564 \text{ m}) = 1 \text{ atm} + 0 + \rho g(2096 \text{ m})$$

$$P = 1 \text{ atm} + (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(1532 \text{ m}) = \boxed{1 \text{ atm} + 15.0 \text{ MPa}}$$

(b) The volume flow rate is $4500 \text{ m}^3/\text{d} = Av = \frac{\pi d^2 v}{4}$

$$v = (4500 \text{ m}^3/\text{d}) \left(\frac{1 \text{ d}}{86400 \text{ s}} \right) \left(\frac{4}{\pi (0.150 \text{ m})^2} \right) = \boxed{2.95 \text{ m/s}}$$

(c) Imagine the pressure as applied to stationary water at the bottom of the pipe:

$$\left(P + \frac{1}{2}\rho v^2 + \rho g y \right)_{\text{bottom}} = \left(P + \frac{1}{2}\rho v^2 + \rho g y \right)_{\text{top}}$$

$$P + 0 = 1 \text{ atm} + \frac{1}{2}(1000 \text{ kg/m}^3)(2.95 \text{ m/s})^2 + 1000 \text{ kg}(9.8 \text{ m/s}^2)(1532 \text{ m})$$

$$P = 1 \text{ atm} + 15.0 \text{ MPa} + 4.34 \text{ kPa}$$

The additional pressure is $\boxed{4.34 \text{ kPa}}$.

- P14.46** (a) For upward flight of a water-drop projectile from geyser vent to fountain-top,

$$v_{yf}^2 = v_{yi}^2 + 2a_y \Delta y$$

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

- (b) Between geyser vent and fountain-top: $P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$

$$\text{Air is so low in density that very nearly } P_1 = P_2 = 1 \text{ atm}$$

$$\text{Then, } \frac{1}{2}v_i^2 + 0 = 0 + (9.80 \text{ m/s}^2)(40.0 \text{ m})$$

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

- (c) Between the chamber and the fountain-top: $P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$

$$P_1 + 0 + (1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(-175 \text{ m}) = P_0 + 0 + (1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(+40.0 \text{ m})$$

$$P_1 - P_0 = (1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(215 \text{ m}) = \boxed{2.11 \text{ MPa}}$$

- P14.47** $P_1 + \frac{\rho v_1^2}{2} = P_2 + \frac{\rho v_2^2}{2}$ (Bernoulli equation), $v_1 A_1 = v_2 A_2$ where $\frac{A_1}{A_2} = 4$

$$\Delta P = P_1 - P_2 = \frac{\rho}{2}(v_2^2 - v_1^2) = \frac{\rho}{2}v_1^2\left(\frac{A_1^2}{A_2^2} - 1\right) \text{ and } \Delta P = \frac{\rho v_1^2}{2}15 = 21\,000 \text{ Pa}$$

$$v_1 = 2.00 \text{ m/s}; v_2 = 4v_1 = 8.00 \text{ m/s}:$$

$$\text{The volume flow rate is } v_1 A_1 = \boxed{2.51 \times 10^{-3} \text{ m}^3/\text{s}}$$

Section 14.7 Other Applications of Fluid Dynamics

- P14.48** $Mg = (P_1 - P_2)A$ for a balanced condition $\frac{16\,000(9.80)}{A} = 7.00 \times 10^4 - P_2$

$$\text{where } A = 80.0 \text{ m}^2 \quad \therefore P_2 = 7.0 \times 10^4 - 0.196 \times 10^4 = \boxed{6.80 \times 10^4 \text{ Pa}}$$

- P14.49** $\rho_{\text{air}} \frac{v^2}{2} = \Delta P = \rho_{\text{Hg}} g \Delta h$

$$v = \sqrt{\frac{2\rho_{\text{Hg}} g \Delta h}{\rho_{\text{air}}}} = \boxed{103 \text{ m/s}}$$

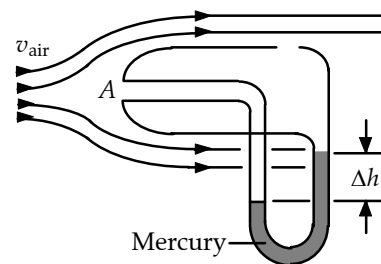


FIG. P14.49

P14.50 The assumption of incompressibility is surely unrealistic, but allows an estimate of the speed:

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

$$1.00 \text{ atm} + 0 + 0 = 0.287 \text{ atm} + 0 + \frac{1}{2} (1.20 \text{ kg/m}^3) v_2^2$$

$$v_2 = \sqrt{\frac{2(1.00 - 0.287)(1.013 \times 10^5 \text{ N/m}^2)}{1.20 \text{ kg/m}^3}} = \boxed{347 \text{ m/s}}$$

P14.51 (a) $P_0 + \rho g h + 0 = P_0 + 0 + \frac{1}{2} \rho v_3^2$

$$v_3 = \sqrt{2gh}$$

If $h = 1.00 \text{ m}$,

$$v_3 = \boxed{4.43 \text{ m/s}}$$

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

Since $v_2 = v_3$,

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

Since $P \geq 0$

$$y \leq \frac{P_0}{\rho g} = \frac{1.013 \times 10^5 \text{ Pa}}{(10^3 \text{ kg/m}^3)(9.8 \text{ m/s}^2)} = \boxed{10.3 \text{ m}}$$

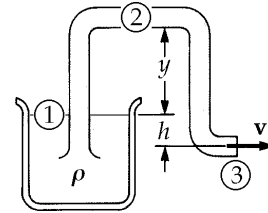


FIG. P14.51

***P14.52** Take points 1 and 2 in the air just inside and outside the window pane.

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

$$P_0 + 0 = P_2 + \frac{1}{2} (1.30 \text{ kg/m}^3) (11.2 \text{ m/s})^2$$

$$P_2 = P_0 - 81.5 \text{ Pa}$$

(a) The total force exerted by the air is outward,

$$P_1 A - P_2 A = P_0 A - P_0 A + (81.5 \text{ N/m}^2)(4 \text{ m})(1.5 \text{ m}) = \boxed{489 \text{ N outward}}$$

(b) $P_1 A - P_2 A = \frac{1}{2} \rho v_2^2 A = \frac{1}{2} (1.30 \text{ kg/m}^3) (22.4 \text{ m/s})^2 (4 \text{ m})(1.5 \text{ m}) = \boxed{1.96 \text{ kN outward}}$

P14.53 In the reservoir, the gauge pressure is

$$\Delta P = \frac{2.00 \text{ N}}{2.50 \times 10^{-5} \text{ m}^2} = 8.00 \times 10^4 \text{ Pa}$$

From the equation of continuity:

$$A_1 v_1 = A_2 v_2$$

$$(2.50 \times 10^{-5} \text{ m}^2) v_1 = (1.00 \times 10^{-8} \text{ m}^2) v_2 \quad v_1 = (4.00 \times 10^{-4}) v_2$$

Thus, v_1^2 is negligible in comparison to v_2^2 .

Then, from Bernoulli's equation:

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

$$8.00 \times 10^4 \text{ Pa} + 0 + 0 = 0 + \frac{1}{2} (1000 \text{ kg/m}^3) v_2^2$$

$$v_2 = \sqrt{\frac{2(8.00 \times 10^4 \text{ Pa})}{1000 \text{ kg/m}^3}} = \boxed{12.6 \text{ m/s}}$$

Additional Problems

- P14.54** Consider the diagram and apply Bernoulli's equation to points A and B, taking $y = 0$ at the level of point B, and recognizing that v_A is approximately zero. This gives:

$$\begin{aligned} P_A + \frac{1}{2} \rho_w (0)^2 + \rho_w g (h - L \sin \theta) \\ = P_B + \frac{1}{2} \rho_w v_B^2 + \rho_w g (0) \end{aligned}$$

Now, recognize that $P_A = P_B = P_{\text{atmosphere}}$ since both points are open to the atmosphere (neglecting variation of atmospheric pressure with altitude). Thus, we obtain

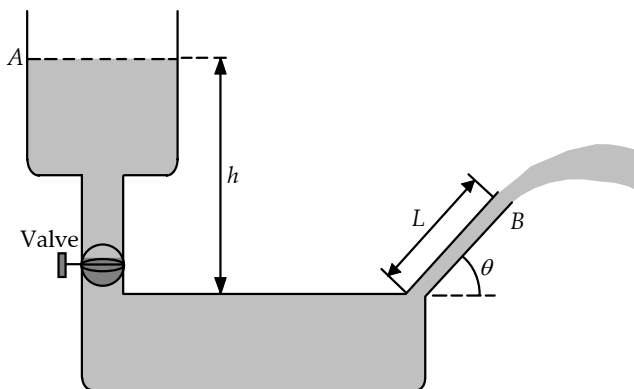


FIG. P14.54

$$\begin{aligned} v_B &= \sqrt{2g(h - L \sin \theta)} = \sqrt{2(9.80 \text{ m/s}^2)[10.0 \text{ m} - (2.00 \text{ m}) \sin 30.0^\circ]} \\ v_B &= 13.3 \text{ m/s} \end{aligned}$$

Now the problem reduces to one of projectile motion with $v_{yi} = v_B \sin 30.0^\circ = 6.64 \text{ m/s}$. Then, $v_{yf}^2 = v_{yi}^2 + 2a(\Delta y)$ gives at the top of the arc (where $y = y_{\text{max}}$ and $v_{yf} = 0$)

$$0 = (6.64 \text{ m/s})^2 + 2(-9.80 \text{ m/s}^2)(y_{\text{max}} - 0)$$

$$\text{or } y_{\text{max}} = \boxed{2.25 \text{ m (above the level where the water emerges)}}.$$

- P14.55** When the balloon comes into equilibrium, we must have

$$\sum F_y = B - F_{g, \text{balloon}} - F_{g, \text{He}} - F_{g, \text{string}} = 0$$

$F_{g, \text{string}}$ is the weight of the string above the ground, and B is the buoyant force. Now

$$F_{g, \text{balloon}} = m_{\text{balloon}} g$$

$$F_{g, \text{He}} = \rho_{\text{He}} V g$$

$$B = \rho_{\text{air}} V g$$

$$\text{and } F_{g, \text{string}} = m_{\text{string}} \frac{h}{L} g$$

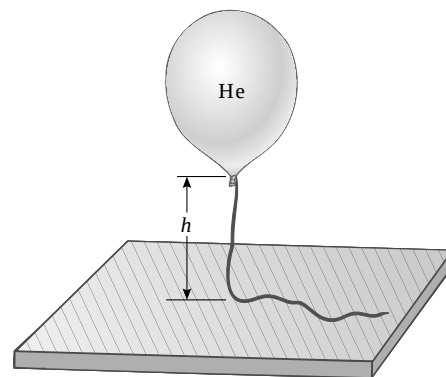


FIG. P14.55

Therefore, we have

$$\rho_{\text{air}} V g - m_{\text{balloon}} g - \rho_{\text{He}} V g - m_{\text{string}} \frac{h}{L} g = 0$$

$$\text{or } h = \frac{(\rho_{\text{air}} - \rho_{\text{He}})V - m_{\text{balloon}}}{m_{\text{string}}} L$$

giving,

$$h = \frac{(1.29 - 0.179)(\text{kg/m}^3) \left(\frac{4\pi(0.400 \text{ m})^3}{3} \right) - 0.250 \text{ kg}}{0.0500 \text{ kg}} (2.00 \text{ m}) = \boxed{1.91 \text{ m}}.$$

P14.56 Assume $v_{\text{inside}} \approx 0$

$$P + 0 + 0 = 1 \text{ atm} + \frac{1}{2}(1000)(30.0)^2 + 1000(9.80)(0.500)$$

$$P_{\text{gauge}} = P - 1 \text{ atm} = 4.50 \times 10^5 + 4.90 \times 10^3 = \boxed{455 \text{ kPa}}$$

P14.57 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, $F_g = F'_g + \left(V - \frac{F'_g}{\rho g}\right)\rho_{\text{air}}g$.

P14.58 The cross-sectional area above water is

$$\frac{2.46 \text{ rad}}{2\pi} \pi (0.600 \text{ cm})^2 - (0.200 \text{ cm})(0.566 \text{ cm}) = 0.330 \text{ cm}^2$$

$$A_{\text{all}} = \pi (0.600)^2 = 1.13 \text{ cm}^2$$

$$\rho_{\text{water}} g A_{\text{under}} = \rho_{\text{wood}} g A_{\text{all}}$$

$$\rho_{\text{wood}} = \frac{1.13 - 0.330}{1.13} = 0.709 \text{ g/cm}^3 = \boxed{709 \text{ kg/m}^3}$$

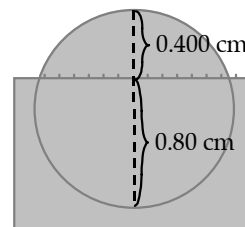


FIG. P14.58

P14.59 At equilibrium, $\sum F_y = 0$: $B - F_{\text{spring}} - F_{g, \text{He}} - F_{g, \text{balloon}} = 0$

giving $F_{\text{spring}} = kL = B - (m_{\text{He}} + m_{\text{balloon}})g$.

But $B = \text{weight of displaced air} = \rho_{\text{air}} Vg$

and $m_{\text{He}} = \rho_{\text{He}} V$.

Therefore, we have: $kL = \rho_{\text{air}} Vg - \rho_{\text{He}} Vg - m_{\text{balloon}}g$

or $L = \frac{(\rho_{\text{air}} - \rho_{\text{He}})V - m_{\text{balloon}}}{k}g$.

From the data given, $L = \frac{(1.29 \text{ kg/m}^3 - 0.180 \text{ kg/m}^3)5.00 \text{ m}^3 - 2.00 \times 10^{-3} \text{ kg}}{90.0 \text{ N/m}}(9.80 \text{ m/s}^2)$.

Thus, this gives $L = \boxed{0.604 \text{ m}}$.

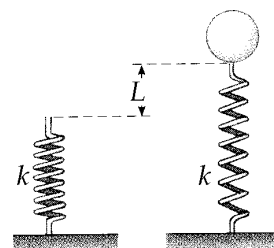


FIG. P14.59

P14.60 $P = \rho gh$

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

$$1.013 \times 10^5 = 1.29(9.80)h$$

For Mt. Everest, $29\,300 \text{ ft} = 8.88 \text{ km}$

Yes

P14.61 The torque is $\tau = \int d\tau = \int r dF$

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

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

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

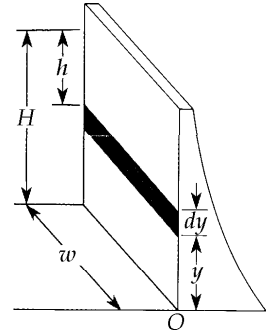


FIG. P14.61

P14.62 (a) The pressure on the surface of the two hemispheres is constant at all points, and the force on each element of surface area is directed along the radius of the hemispheres. The applied force along the axis must balance the force on the “effective” area, which is the projection of the actual surface onto a plane perpendicular to the x axis,

$$A = \pi R^2$$

Therefore,
$$F = \boxed{(P_0 - P) \pi R^2}$$

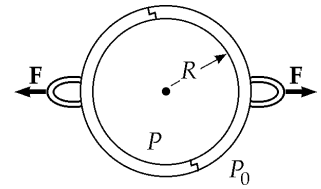


FIG. P14.62

(b) For the values given $F = (P_0 - 0.100 P_0) [\pi (0.300 \text{ m})^2] = 0.254 P_0 = \boxed{2.58 \times 10^4 \text{ N}}$

P14.63 Looking first at the top scale and the iron block, we have:

$$T_1 + B = F_{g, \text{iron}}$$

where T_1 is the tension in the spring scale, B is the buoyant force, and $F_{g, \text{iron}}$ is the weight of the iron block. Now if m_{iron} is the mass of the iron block, we have

$$m_{\text{iron}} = \rho_{\text{iron}} V \quad \text{so} \quad V = \frac{m_{\text{iron}}}{\rho_{\text{iron}}} = V_{\text{displaced oil}}$$

Then, $B = \rho_{\text{oil}} V_{\text{iron}} g$

Therefore, $T_1 = F_{g, \text{iron}} - \rho_{\text{oil}} V_{\text{iron}} g = m_{\text{iron}} g - \rho_{\text{oil}} \frac{m_{\text{iron}}}{\rho_{\text{iron}}} g$

or
$$T_1 = \left(1 - \frac{\rho_{\text{oil}}}{\rho_{\text{iron}}} \right) m_{\text{iron}} g = \left(1 - \frac{916}{7860} \right) (2.00)(9.80) = \boxed{17.3 \text{ N}}$$

Next, we look at the bottom scale which reads T_2 (i.e., exerts an upward force T_2 on the system). Consider the external vertical forces acting on the beaker–oil–iron combination.

$$\sum F_y = 0 \text{ gives}$$

$$T_1 + T_2 - F_{g, \text{beaker}} - F_{g, \text{oil}} - F_{g, \text{iron}} = 0$$

or
$$T_2 = (m_{\text{beaker}} + m_{\text{oil}} + m_{\text{iron}}) g - T_1 = (5.00 \text{ kg})(9.80 \text{ m/s}^2) - 17.3 \text{ N}$$

Thus, $T_2 = \boxed{31.7 \text{ N}}$ is the lower scale reading.

P14.64 Looking at the top scale and the iron block:

$$T_1 + B = F_{g, \text{Fe}} \quad \text{where} \quad B = \rho_0 V_{\text{Fe}} g = \rho_0 \left(\frac{m_{\text{Fe}}}{\rho_{\text{Fe}}} \right) g$$

is the buoyant force exerted on the iron block by the oil.

$$\text{Thus,} \quad T_1 = F_{g, \text{Fe}} - B = m_{\text{Fe}} g - \rho_0 \left(\frac{m_{\text{Fe}}}{\rho_{\text{Fe}}} \right) g$$

$$\text{or} \quad T_1 = \left[\left(1 - \frac{\rho_0}{\rho_{\text{Fe}}} \right) m_{\text{Fe}} g \right] \text{ is the reading on the top scale.}$$

Now, consider the bottom scale, which exerts an upward force of T_2 on the beaker-oil-iron combination.

$$\sum F_y = 0: \quad T_1 + T_2 - F_{g, \text{beaker}} - F_{g, \text{oil}} - F_{g, \text{Fe}} = 0$$

$$T_2 = F_{g, \text{beaker}} + F_{g, \text{oil}} + F_{g, \text{Fe}} - T_1 = (m_b + m_0 + m_{\text{Fe}})g - \left(1 - \frac{\rho_0}{\rho_{\text{Fe}}} \right) m_{\text{Fe}} g$$

$$\text{or} \quad T_2 = \left[\left[m_b + m_0 + \left(\frac{\rho_0}{\rho_{\text{Fe}}} \right) m_{\text{Fe}} \right] g \right] \text{ is the reading on the bottom scale.}$$

P14.65 $\rho_{\text{Cu}} V = 3.083 \text{ g}$

$$\rho_{\text{Zn}}(xV) + \rho_{\text{Cu}}(1-x)V = 2.517 \text{ g}$$

$$\rho_{\text{Zn}} \left(\frac{3.083}{\rho_{\text{Cu}}} \right) x + 3.083(1-x) = 2.517$$

$$\left(1 - \frac{7.133}{8.960} \right) x = \left(1 - \frac{2.517}{3.083} \right)$$

$$x = 0.9004$$

$$\% \text{Zn} = \boxed{90.04\%}$$

P14.66 (a) From $\sum F = ma$

$$B - m_{\text{shell}} g - m_{\text{He}} g = m_{\text{total}} a = (m_{\text{shell}} + m_{\text{He}}) a \quad (1)$$

$$\text{Where} \quad B = \rho_{\text{water}} V g \quad \text{and} \quad m_{\text{He}} = \rho_{\text{He}} V$$

$$\text{Also,} \quad V = \frac{4}{3} \pi r^3 = \frac{\pi d^3}{6}$$

Putting these into equation (1) above,

$$\left(m_{\text{shell}} + \rho_{\text{He}} \frac{\pi d^3}{6} \right) a = \left(\rho_{\text{water}} \frac{\pi d^3}{6} - m_{\text{shell}} - \rho_{\text{He}} \frac{\pi d^3}{6} \right) g$$

which gives

$$a = \frac{(\rho_{\text{water}} - \rho_{\text{He}}) \frac{\pi d^3}{6} - m_{\text{shell}}}{m_{\text{shell}} + \rho_{\text{He}} \frac{\pi d^3}{6}} g$$

$$\text{or} \quad a = \frac{(1000 - 0.180) \left(\frac{\text{kg}}{\text{m}^3} \right) \frac{\pi (0.200 \text{ m})^3}{6} - 4.00 \text{ kg}}{4.00 \text{ kg} + (0.180 \text{ kg/m}^3) \frac{\pi (0.200 \text{ m})^3}{6}} 9.80 \text{ m/s}^2 = \boxed{0.461 \text{ m/s}^2}$$

$$(b) \quad t = \sqrt{\frac{2x}{a}} = \sqrt{\frac{2(h-d)}{a}} = \sqrt{\frac{2(4.00 \text{ m} - 0.200 \text{ m})}{0.461 \text{ m/s}^2}} = \boxed{4.06 \text{ s}}$$

P14.67 Inertia of the disk: $I = \frac{1}{2}MR^2 = \frac{1}{2}(10.0 \text{ kg})(0.250 \text{ m})^2 = 0.312 \text{ kg} \cdot \text{m}^2$

Angular acceleration: $\omega_f = \omega_i + \alpha t$

$$\alpha = \left(\frac{0 - 300 \text{ rev/min}}{60.0 \text{ s}} \right) \left(\frac{2\pi \text{ rad}}{1 \text{ rev}} \right) \left(\frac{1 \text{ min}}{60.0 \text{ s}} \right) = -0.524 \text{ rad/s}^2$$

Braking torque: $\sum \tau = I\alpha \Rightarrow -fd = I\alpha$, so $f = \frac{-I\alpha}{d}$

Friction force: $f = \frac{(0.312 \text{ kg} \cdot \text{m}^2)(0.524 \text{ rad/s}^2)}{0.220 \text{ m}} = 0.744 \text{ N}$

Normal force: $f = \mu_k n \Rightarrow n = \frac{f}{\mu_k} = \frac{0.744 \text{ N}}{0.500} = 1.49 \text{ N}$

gauge pressure: $P = \frac{n}{A} = \frac{1.49 \text{ N}}{\pi(2.50 \times 10^{-2} \text{ m})^2} = \boxed{758 \text{ Pa}}$

P14.68 The incremental version of $P - P_0 = \rho gy$ is

$$dP = -\rho g dy$$

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

$$\frac{P}{\rho} = \frac{P_0}{\rho_0}$$

Combining these two equations we have

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

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

and integrating gives

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

so where $\alpha = \frac{\rho_0 g}{P_0}$,

$$P = P_0 e^{-\alpha h}$$

P14.69 Energy for the fluid-Earth system is conserved.

$$(K + U)_i + \Delta E_{\text{mech}} = (K + U)_f: \quad 0 + \frac{mgL}{2} + 0 = \frac{1}{2}mv^2 + 0$$

$$v = \sqrt{gL} = \sqrt{2.00 \text{ m}(9.8 \text{ m/s}^2)} = \boxed{4.43 \text{ m/s}}$$

P14.70 Let s stand for the edge of the cube, h for the depth of immersion, ρ_{ice} stand for the density of the ice, ρ_w stand for density of water, and ρ_a stand for density of the alcohol.

(a) According to Archimedes's principle, at equilibrium we have

$$\rho_{\text{ice}} g s^3 = \rho_w g h s^2 \Rightarrow h = s \frac{\rho_{\text{ice}}}{\rho_w}$$

With $\rho_{\text{ice}} = 0.917 \times 10^3 \text{ kg/m}^3$

$$\rho_w = 1.00 \times 10^3 \text{ kg/m}^3$$

and $s = 20.0 \text{ mm}$

we get $h = 20.0(0.917) = 18.34 \text{ mm} \approx \boxed{18.3 \text{ mm}}$

(b) We assume that the top of the cube is still above the alcohol surface. Letting h_a stand for the thickness of the alcohol layer, we have

$$\rho_a g s^2 h_a + \rho_w g s^2 h_w = \rho_{\text{ice}} g s^3 \quad \text{so} \quad h_w = \left(\frac{\rho_{\text{ice}}}{\rho_w} \right) s - \left(\frac{\rho_a}{\rho_w} \right) h_a$$

With $\rho_a = 0.806 \times 10^3 \text{ kg/m}^3$

and $h_a = 5.00 \text{ mm}$

we obtain $h_w = 18.34 - 0.806(5.00) = 14.31 \text{ mm} \approx \boxed{14.3 \text{ mm}}$

(c) Here $h'_w = s - h'_a$, so Archimedes's principle gives

$$\rho_a g s^2 h'_a + \rho_w g s^2 (s - h'_a) = \rho_{\text{ice}} g s^3 \Rightarrow \rho_a h'_a + \rho_w (s - h'_a) = \rho_{\text{ice}} s$$

$$h'_a = s \frac{(\rho_w - \rho_{\text{ice}})}{(\rho_w - \rho_a)} = 20.0 \frac{(1.000 - 0.917)}{(1.000 - 0.806)} = 8.557 \approx \boxed{8.56 \text{ mm}}$$

P14.71 **Note:** Variation of atmospheric pressure with altitude is included in this solution. Because of the small distances involved, this effect is unimportant in the final answers.

- (a) Consider the pressure at points A and B in part (b) of the figure:

Using the left tube: $P_A = P_{\text{atm}} + \rho_a g h + \rho_w g (L - h)$ where the second term is due to the variation of air pressure with altitude.

Using the right tube: $P_B = P_{\text{atm}} + \rho_0 g L$

But Pascal's principle says that $P_A = P_B$.

Therefore, $P_{\text{atm}} + \rho_0 g L = P_{\text{atm}} + \rho_a g h + \rho_w g (L - h)$

or $(\rho_w - \rho_a)h = (\rho_w - \rho_0)L$, giving

$$h = \left(\frac{\rho_w - \rho_0}{\rho_w - \rho_a} \right) L = \left(\frac{1000 - 750}{1000 - 1.29} \right) 5.00 \text{ cm} = \boxed{1.25 \text{ cm}}$$

- (b) Consider part (c) of the diagram showing the situation when the air flow over the left tube equalizes the fluid levels in the two tubes. First, apply Bernoulli's equation to points A and B ($y_A = y_B$, $v_A = v$, and $v_B = 0$)

$$\text{This gives: } P_A + \frac{1}{2} \rho_a v^2 + \rho_a g y_A = P_B + \frac{1}{2} \rho_a (0)^2 + \rho_a g y_B$$

$$\text{and since } y_A = y_B, \text{ this reduces to: } P_B - P_A = \frac{1}{2} \rho_a v^2 \quad (1)$$

Now consider points C and D, both at the level of the oil–water interface in the right tube. Using the variation of pressure with depth in static fluids, we have:

$$P_C = P_A + \rho_a g H + \rho_w g L \quad \text{and} \quad P_D = P_B + \rho_a g H + \rho_0 g L$$

But Pascal's principle says that $P_C = P_D$. Equating these two gives:

$$P_B + \rho_a g H + \rho_0 g L = P_A + \rho_a g H + \rho_w g L \quad \text{or} \quad P_B - P_A = (\rho_w - \rho_0) g L \quad (2)$$

$$\text{Substitute equation (1) for } P_B - P_A \text{ into (2) to obtain} \quad \frac{1}{2} \rho_a v^2 = (\rho_w - \rho_0) g L$$

$$\text{or} \quad v = \sqrt{\frac{2gL(\rho_w - \rho_0)}{\rho_a}} = \sqrt{2(9.80 \text{ m/s}^2)(0.0500 \text{ m})\left(\frac{1000 - 750}{1.29}\right)}$$

$$v = \boxed{13.8 \text{ m/s}}$$

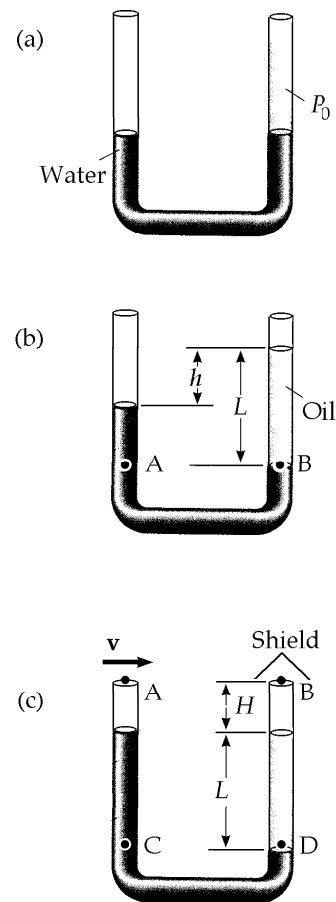


FIG. P14.71

P14.72 (a) The flow rate, Av , as given may be expressed as follows:

$$\frac{25.0 \text{ liters}}{30.0 \text{ s}} = 0.833 \text{ liters/s} = 833 \text{ cm}^3/\text{s}.$$

The area of the faucet tap is $\pi \text{ cm}^2$, so we can find the velocity as

$$v = \frac{\text{flow rate}}{A} = \frac{833 \text{ cm}^3/\text{s}}{\pi \text{ cm}^2} = 265 \text{ cm/s} = \boxed{2.65 \text{ m/s}}.$$

(b) We choose point 1 to be in the entrance pipe and point 2 to be at the faucet tap. $A_1 v_1 = A_2 v_2$ gives $v_1 = 0.295 \text{ m/s}$. Bernoulli's equation is:

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

and gives

$$P_1 - P_2 = \frac{1}{2} (10^3 \text{ kg/m}^3) \left[(2.65 \text{ m/s})^2 - (0.295 \text{ m/s})^2 \right] + (10^3 \text{ kg/m}^3) (9.80 \text{ m/s}^2) (2.00 \text{ m})$$

$$\text{or } P_{\text{gauge}} = P_1 - P_2 = \boxed{2.31 \times 10^4 \text{ Pa}}.$$

P14.73 (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, $\rho = 0.789 \text{ g/cm}^3$ at 20.0°C , and $R = 1.00 \text{ cm}$ so we find:

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

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

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

(c) When the first sphere is resting on the bottom of the tube,

$$n + B = F_{g1} = m_1 g, \text{ where } n \text{ is the normal force.}$$

Since $B = \rho' V g$

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

- *P14.74** (a) 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 $\frac{V}{t} = \frac{Ah}{t} = v_2 A'$. Then $t = \frac{Ah}{v_2 A'} = \frac{Ah}{A' \sqrt{2gd}}$.

$$(b) \quad t = \frac{(0.5 \text{ m})^2 0.5 \text{ m}}{2 \times 10^{-4} \text{ m}^2 \sqrt{2(9.8 \text{ m/s}^2) 10 \text{ m}}} = \boxed{44.6 \text{ s}}$$

- *P14.75** (a) For diverging stream lines 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 $y_t \approx y_b$

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

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

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.

$$(c) \quad v^2 (n^2 - 1)A\rho = 2Mg$$

$$A = \frac{2(800 \text{ kg})9.8 \text{ m/s}^2}{(9.5 \text{ m/s})^2 (1.05^2 - 1) 1000 \text{ kg/m}^3} = \boxed{1.70 \text{ m}^2}$$

ANSWERS TO EVEN PROBLEMS

- P14.2** $\sim 10^{18} \text{ kg/m}^3$; matter is mostly empty space
- P14.4** $1.92 \times 10^4 \text{ N}$
- P14.6** (a) $1.01 \times 10^7 \text{ Pa}$;
(b) $7.09 \times 10^5 \text{ N}$ outward
- P14.8** 255 N
- P14.10** (a) 65.1 N; (b) 275 N
- P14.12** $5.88 \times 10^6 \text{ N}$ down; 196 kN outward;
588 kN outward
- P14.14** (a) 29.4 kN to the right;
(b) 16.3 kN · m counterclockwise
- P14.16** (a) 10.3 m; (b) zero
- P14.18** (a) 20.0 cm; (b) 0.490 cm
- P14.20** 12.6 cm
- P14.22** (a) 444 kg; (b) 480 kg
- P14.24** $\frac{m}{(\rho_w - \rho_s)h}$
- P14.26** (a) see the solution; (b) 25.0 N up;
(c) horizontally inward;
(d) tension increases; see the solution;
(e) 62.5%; (f) 18.7%
- P14.28** $\sim 10^4$ balloons of 25-cm diameter
- P14.30** (a) 6.70 cm; (b) 5.74 cm
- P14.32** (a) 11.6 cm; (b) 0.963 g/cm^3 ;
(c) no; see the solution
- P14.34** 0.611 kg
- P14.36** $2.67 \times 10^3 \text{ kg}$
- P14.38** 12.8 kg/s
- P14.40** (a) 27.9 N; (b) $3.32 \times 10^4 \text{ kg}$;
(c) $7.26 \times 10^4 \text{ Pa}$
- P14.42** (a) see the solution; (b) 616 MW
- P14.44** (a) 2.28 N toward Holland; (b) $1.74 \times 10^6 \text{ s}$
- P14.46** (a), (b) 28.0 m/s; (c) 2.11 MPa
- P14.48** $6.80 \times 10^4 \text{ Pa}$
- P14.50** 347 m/s
- P14.52** (a) 489 N outward; (b) 1.96 kN outward
- P14.54** 2.25 m above the level where the water emerges
- P14.56** 455 kPa
- P14.58** 709 kg/m^3
- P14.60** 8.01 km; yes
- P14.62** (a) see the solution; (b) $2.58 \times 10^4 \text{ N}$
- P14.64** top scale: $\left(1 - \frac{\rho_0}{\rho_{\text{Fe}}}\right)m_{\text{Fe}}g$;
bottom scale: $\left(m_b + m_0 + \frac{\rho_0 m_{\text{Fe}}}{\rho_{\text{Fe}}}\right)g$
- P14.66** (a) 0.461 m/s^2 ; (b) 4.06 s
- P14.68** see the solution
- P14.70** (a) 18.3 mm; (b) 14.3 mm; (c) 8.56 mm
- P14.72** (a) 2.65 m/s; (b) $2.31 \times 10^4 \text{ Pa}$
- P14.74** (a) see the solution; (b) 44.6 s