14

Fluid Mechanics

CHAPTER OUTLINE

ANSWERS TO QUESTIONS

***Q14.1** Answer (c). 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.

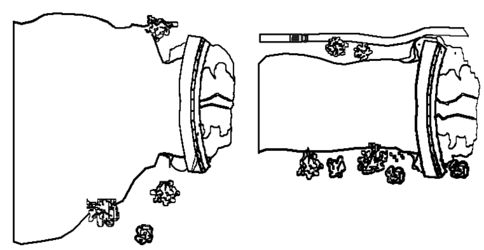

FIG. Q14.1

Q14.2 The weight depends upon the total volume of water in the glass. The pressure at the bottom depends only on the depth. With a cylindrical glass, the water pushes only horizontally on the side walls and does not contribute to an extra downward force above that felt by the base. On the other hand, if the glass is wide at the top with a conical shape, the water pushes outward and downward on each bit of side wall. The downward components add up to an extra downward force, more than that exerted on the small base area.

Q14.3 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.

Q14.4 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.

Q14.5 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.

Q14.6 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.

***Q14.7** Answer (b). The apple does not change volume appreciably in a dunking bucket, and the water also keeps constant density. Then the buoyant force is constant at all depths.

Q14.8 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.

Q14.9 No. The somewhat lighter barge will float higher in the water.

Q14.10 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.

***Q14.11** Answer (c). The water keeps nearly constant density as it increases in pressure with depth. The beach ball is compressed to smaller volume as you take it deeper, so the buoyant force decreases.

Q14.12 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.

Q14.13 (i) b (ii) c. In both orientations the compound floating object 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 wooden block. It will appear to float higher.

***Q14.14** 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. It may be more precise to hang the rock from a string, measure the force required to support it under water, and subtract to find the buoyant force. The buoyant force can be thought of as the weight of so many grams of water, which is that number of cubic centimeters of water, which is the volume of the submerged rock. This volume with the actual rock mass tells you its density.

***Q14.15** Objects a and c float, and e barely floats. On them the buoyant forces are equal to the gravitational forces exerted on them, so the ranking is e greater than a by perhaps 1.5 times and e greater than c by perhaps 500 times. Objects b and d sink, and have volumes equal to e, so they feel equal-size buoyant forces: $e = b = d$. Now f has smaller volume than e and g still smaller volume, so they feel smaller buoyant forces: e is greater than f by 2.7 times and e is greater than g by 7.9 times. We have altogether $e = b = d > a > f > g > c$.

***Q14.16** Answer (b). 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.

***Q14.17** The buoyant force is a conservative force. It does positive work on an object moving upward in a fluid and an equal amount of negative work on the object moving down between the same two elevations. Potential energy is not associated with the object on which the buoyant force acts, but with the set of objects interacting by the buoyant force. This system (set) is the immersed object and the fluid. The potential energy then is the gravitational potential energy we have already studied. The higher potential energy associated with a basketball at the bottom of a swimming pool is equally well or more clearly associated with the extra basketball-volume of water that is at the top of the pool, displaced there by the ball.

Q14.18 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.

***Q14.19** The excess pressure is transmitted undiminished throughout the container. It will compress air inside the wood. The water driven into the pores of the wood raises the block's average density and makes if float lower in the water. The answer is (b). 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, called a Cartesian diver.

Q14.20 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.

Q14.21 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.

Q14.22 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.

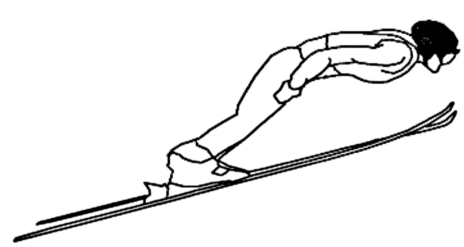

FIG. Q14.22

Q14.23 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.

***Q14.24** You want a water drop to have four times the gravitational energy as it turns around at the top of the fountain. You want it to start out with four times the kinetic energy, which means with twice the speed at the nozzles. Given the constant volume flow rate Av, you want the area to be two times smaller, answer (d). If the nozzle has a circular opening, you need decrease its radius only by the square root of two times.

Q14.25 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.

Q14.26 (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.

***Q14.27** (i) Answer (c). The water level stays the same. The solid ice displaced its own mass of liquid water. The meltwater does the same. You can accurately measure the quantity of H_2O going into a recipe, even if some of it is frozen, either by using a kitchen scale or by letting the ice float in liquid water in a measuring cup and looking at the liquid water level.

(ii) Answer (b). Ice on the continent of Antarctica is above sea level.

SOLUTIONS TO PROBLEMS

Section 14.1 **Pressure**

P14.1 $M = \rho_{\text{iron}} V = \left(7\,860 \text{ kg/m}^3\right)\left[\frac{4}{3}\pi\left(0.015\,0 \text{ m}\right)^3\right]$

$M = \boxed{0.111 \text{ kg}}$

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:

$$\rho = \frac{m}{V} \sim \frac{1.67\times10^{-27} \text{ kg}}{\frac{4}{3}\pi\left(10^{-15} \text{ m}\right)^3} \boxed{\sim 10^{18} \text{ kg/m}^3}$$

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

P14.3 $P = \frac{F}{A} = \frac{50.0(9.80)}{\pi\left(0.500\times10^{-2}\right)^2} = \boxed{6.24\times10^6 \text{ N/m}^2}$

P14.4 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 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**

P14.5 $F_{el} = F_{\text{fluid}}$ or $kx = \rho g h A$

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

$$h = \frac{(1\,000\ \text{N/m}^2)(5.00 \times 10^{-3}\ \text{m})}{(10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)\left[\pi(1.00 \times 10^{-2}\ \text{m})^2\right]} = \boxed{1.62\ \text{m}}$$

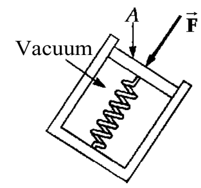

FIG. P14.5

P14.6 (a) $P = P_0 + \rho g h = 1.013 \times 10^5\ \text{Pa} + (1\,024\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(1\,000\ \text{m})$

$P = \boxed{1.01 \times 10^7\ \text{Pa}}$

(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.

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

The resultant inward force on the porthole is then

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

P14.7 $F_g = 80.0\ \text{kg}(9.80\ \text{m/s}^2) = 784\ \text{N}$

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

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

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

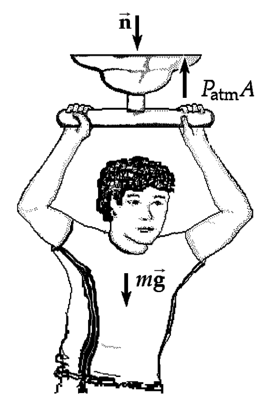

FIG. P14.7

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

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

P14.9 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

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

$\boxed{\text{horizontally toward the back of the hole}}$. Russell Shadle suggested the idea for this problem.

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

$$F = PA = 1.013\times10^5 \text{ Pa}\left[\pi\left(1.43\times10^{-2} \text{ m}\right)^2\right] = \boxed{65.1 \text{ N}}$$

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

$$F = PA = \left(P_0 + \rho g h\right)A$$

$$= \left[1.013\times10^5 \text{ Pa} + \left(1\,030 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)(32.3 \text{ m})\right]\left[\pi\left(1.43\times10^{-2} \text{ m}\right)^2\right]$$

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

P14.11 The pressure on the bottom due to the water is $P_b = \rho g z = 1.96\times10^4 \text{ Pa}$

So, $$F_b = P_b A = \boxed{5.88\times10^6 \text{ N down}}$$

On each end, $$F = P_{average}A = 9.80\times10^3 \text{ Pa}\left(20.0 \text{ m}^2\right) = \boxed{196 \text{ kN outward}}$$

On the side, $$F = P_{average}A = 9.80\times10^3 \text{ Pa}\left(60.0 \text{ m}^2\right) = \boxed{588 \text{ kN outward}}$$

P14.12 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

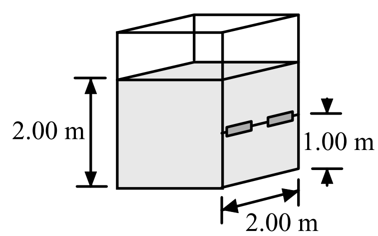

FIG. P14.12

$$dF = P\,dA = \rho g h(2.00 \text{ m})\,dh$$

(a) The total force is

$$F = \int dF = \int_{h=1.00 \text{ m}}^{2.00 \text{ m}} \rho g h(2.00 \text{ m})\,dh$$

$$F = \rho g(2.00 \text{ m})\left.\frac{h^2}{2}\right|_{1.00 \text{ m}}^{2.00 \text{ m}} = \left(1\,000 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)\frac{(2.00 \text{ m})}{2}\left[(2.00 \text{ m})^2 - (1.00 \text{ m})^2\right]$$

$$F = \boxed{29.4 \text{ kN (to the right)}}$$

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

$$\tau = \int d\tau = \int_{h=1.00 \text{ m}}^{2.00 \text{ m}} \rho g h(2.00 \text{ m})(h - 1.00 \text{ m})\,dh$$

$$\tau = \rho g(2.00 \text{ m})\left[\frac{h^3}{3} - (1.00 \text{ m})\frac{h^2}{2}\right]_{1.00 \text{ m}}^{2.00 \text{ m}}$$

$$\tau = \left(1\,000 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)(2.00 \text{ m})\left(\frac{7.00 \text{ m}^3}{3} - \frac{3.00 \text{ m}^3}{2}\right)$$

$$\tau = \boxed{16.3 \text{ kN}\cdot\text{m counterclockwise}}$$

P14.13 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:

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

$$\Delta V = -\frac{4\pi\left(1\,030 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)\left(10\,000 \text{ m}\right)\left(1.50 \text{ m}\right)^3}{(3)\left(14.0\times10^{10} \text{ Pa}\right)} = -0.010\,2 \text{ m}^3$$

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

$$V - \Delta V = \frac{4}{3}\pi(1.50 \text{ m})^3 - 0.010\,2 \text{ m}^3 = 14.137 \text{ m}^3 - 0.010\,2 \text{ m}^3 = 14.127 \text{ m}^3$$

This gives a radius of 1.499 64 m and a new diameter of 2.999 3 m. Therefore the diameter decreases by $\boxed{0.722 \text{ mm}}$.

Section 14.3 **Pressure Measurements**

P14.14 (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:

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

$$1.013\times10^5 \text{ N/m}^2 + 0 = 0 + \left(1\,000 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)y_2 \qquad y_2 = \boxed{10.3 \text{ m}}$$

(b) No atmosphere can lift the water in the straw through $\boxed{\text{zero}}$ height difference.

P14.15 $P_0 = \rho gh$

$$h = \frac{P_0}{\rho g} = \frac{1.013\times10^5 \text{ Pa}}{\left(0.984\times10^3 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)} = \boxed{10.5 \text{ m}}$$

No. The "Torricellian vacuum" is not so good. Some alcohol and water will evaporate.

The equilibrium vapor pressures of alcohol and water are higher than the vapor pressure of mercury.

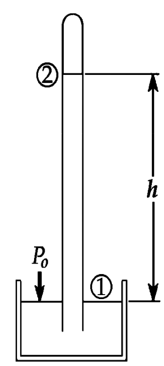

FIG. P14.15

P14.16 (a) Using the definition of density, we have

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

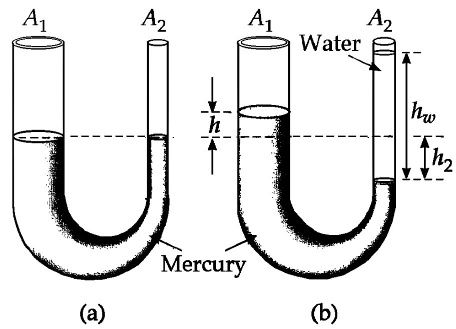

FIG. P14.16

(b) Sketch (b) at the right represents the situation after the water is added. A volume (A_2h_2) of mercury has been displaced by water in the right tube. The additional volume of mercury now in the left tube is A_1h. Since the total volume of mercury has not changed,

$$A_2h_2 = A_1h \qquad \text{or} \qquad h_2 = \frac{A_1}{A_2}h \tag{1}$$

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

$$P = P_0 + \rho_{\text{water}}gh_w$$

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

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

which, using equation (1) above, reduces to

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

or

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

Thus, the level of mercury has risen a distance of

$$h = \frac{\left(1.00\text{ g/cm}^3\right)(20.0\text{ cm})}{\left(13.6\text{ g/cm}^3\right)(1+10.0/50.0)} = \boxed{0.490\text{ cm}} \quad \text{above the original level.}$$

P14.17 $\Delta P_0 = \rho g\Delta h = -2.66\times10^3\text{ Pa}$: $\quad P = P_0 + \Delta P_0 = (1.013 - 0.026\,6)\times10^5\text{ Pa} = \boxed{0.986\times10^5\text{ Pa}}$

***P14.18** (a) We can directly write the bottom pressure as $P = P_0 + \rho gh$, or we can say that the bottom of the tank must support the weight of the water:

$PA - P_0A = m_{\text{water}}g = \rho Vg = \rho Ahg$ which gives again

$P = P_0 + \rho gh = 101.3\text{ kPa} + (1000\text{ kg/m}^3)(9.8\text{ m/s}^2)h = \boxed{101.3\text{ kPa} + (9.8\text{ kPa/m})h}$

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

$P_bA - P_0A = m_{\text{water}}g + Mg = \rho Vg + Mg = \rho Ahg + Mg$ so

$P_b = P_0 + \rho hg + Mg/A$ Then $\Delta P = P_b - P = \boxed{Mg/A}$

(c) Before the people enter, $P = 101.3\text{ kPa} + (9.8\text{ kPa/m})(1.5\text{ m}) = \boxed{116\text{ kPa}}$

afterwards, $\Delta P = Mg/A = (150\text{ kg})(9.8\text{ m/s}^2)/\pi(3\text{ m})^2 = \boxed{52.0\text{ Pa}}$

P14.19 (a) $P = P_0 + \rho g h$

The gauge pressure is

$$P - P_0 = \rho g h = 1\,000\ \text{kg}\left(9.8\ \text{m/s}^2\right)\left(0.160\ \text{m}\right) = \boxed{1.57\ \text{kPa}}$$

$$= 1.57\times 10^3\ \text{Pa}\left(\frac{1\ \text{atm}}{1.013\times 10^5\ \text{Pa}}\right)$$

$$= \boxed{0.015\,5\ \text{atm}}$$

It would lift a mercury column to height

$$h = \frac{P - P_0}{\rho g} = \frac{1\,568\ \text{Pa}}{\left(13\,600\ \text{kg/m}^3\right)\left(9.8\ \text{m/s}^2\right)} = \boxed{11.8\ \text{mm}}$$

(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 Archimedes's Principle**

P14.20 (a) The balloon is nearly in equilibrium:

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

or

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

This reduces to

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

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

(b) Similarly,

$$m_{\text{payload}} = \left(\rho_{\text{air}} - \rho_{\text{hydrogen}}\right)V = \left(1.29\ \text{kg/m}^3 - 0.089\,9\ \text{kg/m}^3\right)\left(400\ \text{m}^3\right)$$

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

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

P14.21 At equilibrium $\sum F = 0$ or $F_{app} + mg = B$

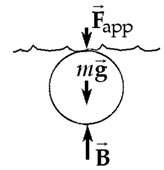

FIG. P14.21

where B is the buoyant force.

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

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

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

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

$$F_{app} = \frac{4}{3}\pi\left(1.90\times10^{-2}\ \text{m}\right)^3\left(9.80\ \text{m/s}^2\right)\left(10^3\ \text{kg/m}^3 - 84.0\ \text{kg/m}^3\right) = \boxed{0.258\ \text{N down}}$$

***P14.22** For the submerged object $\Sigma F_y = 0$ $\quad +B - F_g + T = 0 \quad +B = F_g - T = 5\ \text{N} - 3.5\ \text{N} = 1.5\ \text{N}$

This is the weight of the water displaced. Its volume is the same as the volume V of the object:

$B = m_{\text{water}}g = \rho_{\text{w}}V_{\text{object}}g = 1.5\ \text{N}$: $\quad V_{\text{object}} = 1.5\ \text{N}/\rho_{\text{w}}g$

Now the density of the object is

$$\rho_{\text{object}} = m_{\text{object}}/V_{\text{object}} = \frac{m_{object}\rho_w g}{1.5\ \text{N}} = \frac{F_g\rho_w}{1.5\ \text{N}} = \frac{5\ \text{N}\ (1000\ \text{kg/m}^3)}{1.5\ \text{N}} = \boxed{3.33\times10^3\ \text{kg/m}^3}$$

P14.23 (a) $P = P_0 + \rho g h$

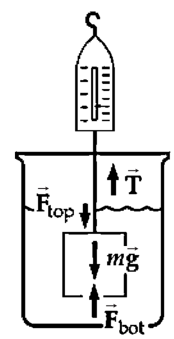

FIG. P14.23

Taking $P_0 = 1.013\times10^5\ \text{N/m}^2$ and $h = 5.00$ cm

we find $P_{\text{top}} = 1.017\,9\times10^5\ \text{N/m}^2$

For $h = 17.0$ cm, we get $P_{\text{bot}} = 1.029\,7\times10^5\ \text{N/m}^2$

Since the areas of the top and bottom are $A = (0.100\ \text{m})^2 = 10^{-2}\ \text{m}^2$

we find $F_{\text{top}} = P_{\text{top}}A = \boxed{1.017\,9\times10^3\ \text{N}}$

and $F_{\text{bot}} = \boxed{1.029\,7\times10^3\ \text{N}}$

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

where $B = \rho_w V g = \left(10^3\ \text{kg/m}^3\right)\left(1.20\times10^{-3}\ \text{m}^3\right)\left(9.80\ \text{m/s}^2\right) = 11.8\ \text{N}$

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

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

(c) $F_{\text{bot}} - F_{\text{top}} = (1.029\,7 - 1.017\,9)\times10^3\ \text{N} = \boxed{11.8\ \text{N}}$

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

P14.24 (a)

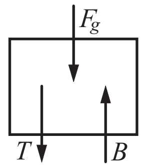

FIG. P14.24(a)

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

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

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

(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:

$$-15\text{ N} - 60\text{ N} + 25\text{ N} + B_{\text{oil}} = 0$$
$$B_{\text{oil}} = 50\text{ N}$$

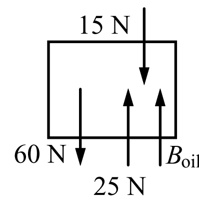

FIG. P14.24(e)

For the buoyant force of the water we have

$$B = \rho V g \qquad 25\text{ N} = \left(1\,000\text{ kg/m}^3\right)\left(0.25V_{\text{block}}\right)9.8\text{ m/s}^2$$
$$V_{\text{block}} = 1.02 \times 10^{-2}\text{ m}^3$$

For the buoyant force of the oil

$$50\text{ N} = \left(800\text{ kg/m}^3\right) f_e \left(1.02 \times 10^{-2}\text{ m}^3\right)9.8\text{ m/s}^2$$
$$f_e = 0.625 = \boxed{62.5\%}$$

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

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

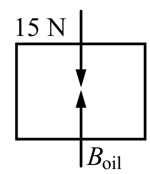

FIG. P14.24(f)

***P14.25** (a) Let P represent the pressure at the center of one face, of edge ℓ. $\quad P = P_0 + \rho g h$

The force on the face is $F = PA = P_0 A + \rho g \ell^2 h$

It increases in time at the rate
$dF/dt = 0 + \rho g \ell^2\, dh/dt = (1030\text{ kg/m}^3)(9.8\text{ m/s}^2)(0.25\text{ m})^2(1.9\text{ m/s}) = \boxed{1.20 \times 10^3\text{ N/s}}$

(b) $B = \rho V g$ is constant as both the force on the top and the bottom of the block increase together. The rate of change is $\boxed{\text{zero}}$.

P14.26 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

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

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

$$F_{up} = \left[(1.29 - 0.179)\ \mathrm{kg/m^3}\right]\left[\frac{4}{3}\pi(0.125\ \mathrm{m})^3\right](9.80\ \mathrm{m/s^2}) - 5.00\times10^{-3}\ \mathrm{kg}(9.80\ \mathrm{m/s^2})$$

$$= 0.040\,1\ \mathrm{N}$$

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

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

you need this many balloons: $\dfrac{686\ \mathrm{N}}{0.040\,1\ \mathrm{N}} = 17\,000\ \boxed{\sim 10^4}$

P14.27 (a) According to Archimedes, $B = \rho_{\mathrm{water}} V_{\mathrm{water}} g = (1.00\ \mathrm{g/cm^3})[20.0\times20.0\times(20.0-h)]g$

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

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

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

(b) $B = F_g + Mg$ where M = mass of lead

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

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

P14.28 (a) The weight of the ball must be equal to the buoyant force of the water:

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

$$r_{\mathrm{outer}} = \left(\frac{3\times1.26\ \mathrm{kg}}{4\pi\ 1\,000\ \mathrm{kg/m^3}}\right)^{1/3} = \boxed{6.70\ \mathrm{cm}}$$

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

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

$$1.26\ \mathrm{kg} = 2\,700\ \mathrm{kg/m^3}\left(\frac{4}{3}\pi\right)\left((0.067\ \mathrm{m})^3 - r_i^3\right)$$

$$1.11\times10^{-4}\ \mathrm{m^3} = 3.01\times10^{-4}\ \mathrm{m^3} - r_i^3$$

$$r_i = \left(1.89\times10^{-4}\ \mathrm{m^3}\right)^{1/3} = \boxed{5.74\ \mathrm{cm}}$$

P14.29 Let A represent the horizontal cross-sectional area of the rod, which we presume to be constant. The rod is in equilibrium:

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

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

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

P14.30 We use the result of Problem 14.29. For the rod floating in a liquid of density $0.98\ \text{g/cm}^3$,

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

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

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

For floating in the dense liquid,

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

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

(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 $\rho = \dfrac{\rho_0 L}{L-h}$ is not of the form $\rho = a + bh$, equal-size steps of ρ do not correspond to equal-size steps of h. The number 1.06 is halfway between 0.98 and 1.14 but the mark for that density is 0.0604 cm below the geometric halfway point between the ends of the scale. The marks get closer together as you go down.

P14.31 The balloon stops rising when $\left(\rho_{\text{air}} - \rho_{\text{He}}\right)gV = Mg$ and $\left(\rho_{\text{air}} - \rho_{\text{He}}\right)V = M$

Therefore,

$$V = \frac{M}{\rho_{\text{air}} - \rho_{\text{He}}} = \frac{400}{1.25e^{-1} - 0.180} \qquad V = \boxed{1\,430\ \text{m}^3}$$

P14.32 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:

$$\sum F_y = ma_y = 0 \qquad -\left(1.20\times10^4\ \text{kg}+m\right)g+\rho_w gV+1\,100\ \text{N}=0$$

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

$$1.20\times10^4\ \text{kg}+m=1.03\times10^3\left[\frac{4}{3}\pi(1.50)^3\right]+\frac{1\,100\ \text{N}}{9.8\ \text{m/s}^2}$$

so

$$m=\boxed{2.67\times10^3\ \text{kg}}$$

P14.33 $B=F_g$

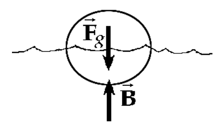

FIG. P14.33

$$\rho_{H_2O}g\frac{V}{2}=\rho_{\text{sphere}}gV$$

$$\rho_{\text{sphere}}=\frac{1}{2}\rho_{H_2O}=\boxed{500\ \text{kg/m}^3}$$

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

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

P14.34 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:

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

$$50\left(2.90\times10^4\ \text{kg}\right)g=\left(1\,030\ \text{kg/m}^3\right)g(0.110\ \text{m})A$$

giving $A=\boxed{1.28\times10^4\ \text{m}^2}$. The acceleration of gravity does not affect the answer.

Section 14.5 **Fluid Dynamics**

Section 14.6 **Bernoulli's Equation**

P14.35 Assuming the top is open to the atmosphere, then

$$P_1=P_0$$

Note $P_2=P_0$. The water pushes on the air just as hard as the air pushes on the water.

Flow rate $=2.50\times10^{-3}\ \text{m}^3/\text{min}=4.17\times10^{-5}\ \text{m}^3/\text{s}$.

(a) $A_1 >> A_2$ so $v_1 << v_2$

Assuming $v_1=0$,

$$P_1+\frac{\rho v_1^2}{2}+\rho gy_1=P_2+\frac{\rho v_2^2}{2}+\rho gy_2$$

$$v_2=\left(2gy_1\right)^{1/2}=\left[2(9.80)(16.0)\right]^{1/2}=\boxed{17.7\ \text{m/s}}$$

(b) $$\text{Flow rate}=A_2v_2=\left(\frac{\pi d^2}{4}\right)(17.7)=4.17\times10^{-5}\ \text{m}^3/\text{s}$$

$$d=\boxed{1.73\times10^{-3}\ \text{m}}=1.73\ \text{mm}$$

P14.36 Take point ① at the free surface of the water in the tank and ② inside the nozzle.

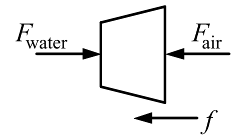

FIG. P14.36

(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

$$P_0 + 1\,000 \text{ kg/m}^3\ 9.8 \text{ m/s}^2\ 7.5 \text{ m} + 0 = P_2 + 0 + 0\,;\ P_2 - P_0 = 7.35 \times 10^4 \text{ Pa}$$

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

$$P_0 + 7.35 \times 10^4 \text{ Pa} + 0 = P_0 + 0 + \frac{1}{2}\left(1\,000 \text{ kg/m}^3\right) v_2^2$$
$$v_2 = 12.1 \text{ m/s}$$

The quantity leaving the nozzle in 2 h is

$$\rho V = \rho A v_2 t = \left(1\,000 \text{ kg/m}^3\right)\pi (0.011 \text{ m})^2 (12.1 \text{ m/s})\,7\,200 \text{ s} = \boxed{3.32 \times 10^4 \text{ kg}}$$

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

$$A_1 v_1 = A_2 v_2$$
$$\pi \left(\frac{6.6 \text{ cm}}{2}\right)^2 v_1 = \pi \left(\frac{2.2 \text{ cm}}{2}\right)^2 12.1 \text{ m/s}$$
$$v_1 = \frac{12.1 \text{ m/s}}{9} = 1.35 \text{ m/s}$$
$$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$$
$$P_1 + 0 + \frac{1}{2}\left(1\,000 \text{ kg/m}^3\right)(1.35 \text{ m/s})^2 = P_0 + 0 + \frac{1}{2}\left(1\,000 \text{ kg/m}^3\right)(12.1 \text{ m/s})^2$$
$$P_1 - P_0 = 7.35 \times 10^4 \text{ Pa} - 9.07 \times 10^2 \text{ Pa} = \boxed{7.26 \times 10^4 \text{ Pa}}$$

P14.37 Flow rate $Q = 0.012\,0 \text{ m}^3/\text{s} = v_2 A_2$

$$v_2 = \frac{Q}{A_2} = \frac{0.012\,0 \text{ m}^3/\text{s}}{\pi (0.011 \text{ m})^2} = \boxed{31.6 \text{ m/s}}$$

***P14.38** (a) The mass flow rate and the volume flow rate are constant:

$$\rho A_1 v_1 = \rho A_2 v_2 \qquad \pi r_1^2 v_1 = \pi r_2^2 v_2 \qquad (4\text{ cm})^2 v_1 = (2\text{ cm})^2 v_2 \qquad v_2 = 4v_1$$

For ideal flow

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

$$2.5\times10^4\ \text{Pa} + 0 + \frac{1}{2}\left(1\,000\ \text{kg/m}^3\right)\left(v_1\right)^2$$

$$= 1.5\times10^4\ \text{Pa} + (1000)(9.8)(0.5)\ \text{Pa} + \frac{1}{2}\left(1\,000\ \text{kg/m}^3\right)(4v_1)^2$$

$$v_1 = \sqrt{\frac{5100\ \text{Pa}}{7500\ \text{kg/m}^3}} = \boxed{0.825\ \text{m/s}}$$

(b) $v_2 = 4v_1 = \boxed{3.30\ \text{m/s}}$

(c) $\pi r_1^2 v_1 = \pi(0.04\text{ m})^2(0.825\text{ m/s}) = \boxed{4.14\times10^{-3}\ \text{m}^3/\text{s}}$

P14.39 The volume flow rate is

$$\frac{125\ \text{cm}^3}{16.3\ \text{s}} = Av_1 = \pi\left(\frac{0.96\ \text{cm}}{2}\right)^2 v_1$$

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:

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

$$P_0 + \left(1\,000\ \text{kg/m}^3\right)\left(9.8\ \text{m/s}^2\right)0.13\ \text{m} + \frac{1}{2}\left(1\,000\ \text{kg/m}^3\right)\left(0.106\ \text{m/s}\right)^2$$

$$= P_0 + 0 + \frac{1}{2}\left(1\,000\ \text{kg/m}^3\right)v_2^2$$

$$v_2 = \sqrt{2\left(9.8\ \text{m/s}^2\right)0.13\ \text{m} + \left(0.106\ \text{m/s}\right)^2} = 1.60\ \text{m/s}$$

The volume flow rate is constant:

$$7.67\ \text{cm}^3/\text{s} = \pi\left(\frac{d}{2}\right)^2 160\ \text{cm/s}$$

$$d = \boxed{0.247\ \text{cm}}$$

P14.40 (a) $\mathcal{P} = \dfrac{\Delta E}{\Delta t} = \dfrac{\Delta mgh}{\Delta t} = \left(\dfrac{\Delta m}{\Delta t}\right)gh = Rgh$

(b) $\mathcal{P}_{\text{EL}} = 0.85\left(8.5\times10^5\right)(9.8)(87) = \boxed{616\ \text{MW}}$

P14.41 (a) Between sea surface and clogged hole: $P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$

$$1\text{ atm} + 0 + \left(1\,030\text{ kg/m}^3\right)\left(9.8\text{ m/s}^2\right)(2\text{ m}) = P_2 + 0 + 0 \qquad P_2 = 1\text{ atm} + 20.2\text{ kPa}$$

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

$$F = PA = \left(20.2\times10^3\text{ N/m}^2\right)\left(\frac{\pi}{4}\right)\left(1.2\times10^{-2}\text{ m}\right)^2 \qquad F = \boxed{2.28\text{ N}}\text{ toward Holland}$$

(b) Now, Bernoulli's theorem is

$$1\text{ atm} + 0 + 20.2\text{ kPa} = 1\text{ atm} + \frac{1}{2}\left(1\,030\text{ kg/m}^3\right)v_2^2 + 0 \qquad v_2 = 6.26\text{ m/s}$$

The volume rate of flow is $A_2 v_2 = \frac{\pi}{4}\left(1.2\times10^{-2}\text{ m}\right)^2(6.26\text{ m/s}) = 7.08\times10^{-4}\text{ m}^3/\text{s}$

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

Requiring $\frac{1\,234\text{ m}^3}{7.08\times10^{-4}\text{ m}^3/\text{s}} = \boxed{1.74\times10^6\text{ s}} = 20.2\text{ days}$

***P14.42** (a) The volume flow rate is the same at the two points: $A_1 v_1 = A_2 v_2$

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

We assume the tubes are at the same elevation:

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

$$P_1 - P_2 = \Delta P = \frac{1}{2}\rho(4v_1)^2 + 0 - \frac{1}{2}\rho v_1^2$$

$$\Delta P = \frac{1}{2}(850\text{ kg/m}^3)\,15v_1^2$$

$v_1 = (0.0125\text{ m/s})\sqrt{\Delta P}$ 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) $\left(3.93\times10^{-6}\text{ m}^3/\text{s}\right)\sqrt{6000} = \boxed{0.305\text{ L/s}}$

(c) With pressure difference 2 times larger, the flow rate is larger by the square root of 2 times: $(2)^{1/2}(0.305\text{ L/s}) = \boxed{0.431\text{ L/s}}$

(d) The flow rate is proportional to the square root of the pressure difference.

P14.43 (a) Suppose the flow is very slow: $\left(P+\frac{1}{2}\rho v^2+\rho g y\right)_{\text{river}}=\left(P+\frac{1}{2}\rho v^2+\rho g y\right)_{\text{rim}}$

$$P+0+\rho g(564\text{ m})=1\text{ atm}+0+\rho g(2\,096\text{ m})$$

$$P=1\text{ atm}+\left(1\,000\text{ kg/m}^3\right)\left(9.8\text{ m/s}^2\right)(1\,532\text{ m})=\boxed{1\text{ atm}+15.0\text{ MPa}}$$

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

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

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

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

$$P+0=1\text{ atm}+\frac{1}{2}\left(1\,000\text{ kg/m}^3\right)(2.95\text{ m/s})^2+1\,000\text{ kg}\left(9.8\text{ m/s}^2\right)(1\,532\text{ m})$$

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

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

***P14.44** (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 $P_1=P_2=1\text{ atm}$

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

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

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

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

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

P14.45 $P_1+\frac{\rho v_1^2}{2}=P_2+\frac{\rho_2^2}{2}$ (Bernoulli equation), $v_1A_1=v_2A_2$ where $\frac{A_1}{A_2}=4$

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

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

The volume flow rate is $v_1A_1=\boxed{2.51\times10^{-3}\text{ m}^3/\text{s}}$

Section 14.7 **Other Applications of Fluid Dynamics**

P14.46 $Mg = (P_1 - P_2)A$ for a balanced condition $\dfrac{16\,000(9.80)}{A} = 7.00\times10^4 - P_2$

where $A = 80.0\text{ m}^2$ $\therefore P_2 = 7.0\times10^4 - 0.196\times10^4 = \boxed{6.80\times10^4\text{ Pa}}$

P14.47 (a) $P_0 + \rho gh + 0 = P_0 + 0 + \dfrac{1}{2}\rho v_3^2$ $v_3 = \sqrt{2gh}$

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

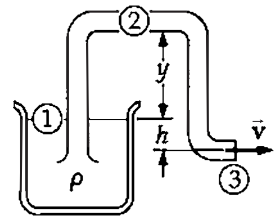

FIG. P14.47

(b) $P + \rho gy + \dfrac{1}{2}\rho v_2^2 = P_0 + 0 + \dfrac{1}{2}\rho v_3^2$

Since $v_2 = v_3$ $P = P_0 - \rho gy$

Since $P \ge 0$, the greatest possible siphon height is given by

$$y \le \frac{P_0}{\rho g} = \frac{1.013\times10^5\text{ Pa}}{(10^3\text{ kg/m}^3)(9.8\text{ m/s}^2)} = \boxed{10.3\text{ m}}$$

P14.48 The assumption of incompressibility is surely unrealistic, but allows an estimate of the speed:

$$P_1 + \rho gy_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho gy_2 + \frac{1}{2}\rho v_2^2$$

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

$$v_2 = \sqrt{\frac{2(1.00-0.287)(1.013\times10^5\text{ N/m}^2)}{1.20\text{ kg/m}^3}} = \boxed{347\text{ m/s}}$$

P14.49 In the reservoir, the gauge pressure is $\Delta P = \dfrac{2.00\text{ N}}{2.50\times10^{-5}\text{ m}^2} = 8.00\times10^4\text{ Pa}$

From the equation of continuity: $A_1v_1 = A_2v_2$

$(2.50\times10^{-5}\text{ m}^2)v_1 = (1.00\times10^{-8}\text{ m}^2)v_2$ $v_1 = (4.00\times10^{-4})v_2$

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

Then, from Bernoulli's equation: $(P_1 - P_2) + \dfrac{1}{2}\rho v_1^2 + \rho gy_1 = \dfrac{1}{2}\rho v_2^2 + \rho gy_2$

$$8.00\times10^4\text{ Pa} + 0 + 0 = 0 + \frac{1}{2}(1\,000\text{ kg/m}^3)v_2^2$$

$$v_2 = \sqrt{\frac{2(8.00\times10^4\text{ Pa})}{1\,000\text{ kg/m}^3}} = \boxed{12.6\text{ m/s}}$$

P14.50 Take points 1 and 2 in the air just inside and outside the window pane.

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

$$P_0 + 0 = P_2 + \frac{1}{2}\left(1.30\ \text{kg/m}^3\right)\left(11.2\ \text{m/s}\right)^2 \qquad P_2 = P_0 - 81.5\ \text{Pa}$$

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

$$P_1A - P_2A = P_0A - P_0A + \left(81.5\ \text{N/m}^2\right)(4\ \text{m})(1.5\ \text{m}) = \boxed{489\ \text{N outward}}$$

(b) $$P_1A - P_2A = \frac{1}{2}\rho v_2^2 A = \frac{1}{2}\left(1.30\ \text{kg/m}^3\right)\left(22.4\ \text{m/s}\right)^2 (4\ \text{m})(1.5\ \text{m}) = \boxed{1.96\ \text{kN outward}}$$

Additional Problems

P14.51 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

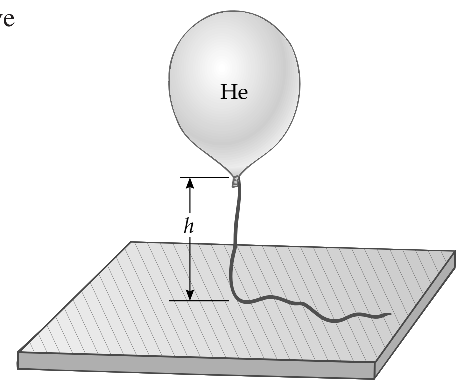

FIG. P14.51

$$F_{g,\text{ balloon}} = m_{\text{balloon}}g$$
$$F_{g,\text{ He}} = \rho_{\text{He}}Vg$$
$$B = \rho_{\text{air}}Vg$$

and

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

Therefore, we have

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

or

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

giving

$$h = \frac{(1.29 - 0.179)\left(\text{kg/m}^3\right)\left(4\pi(0.400\ \text{m})^3/3\right) - 0.250\ \text{kg}}{0.050\,0\ \text{kg}}(2.00\ \text{m}) = \boxed{1.91\ \text{m}}$$

P14.52 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:

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

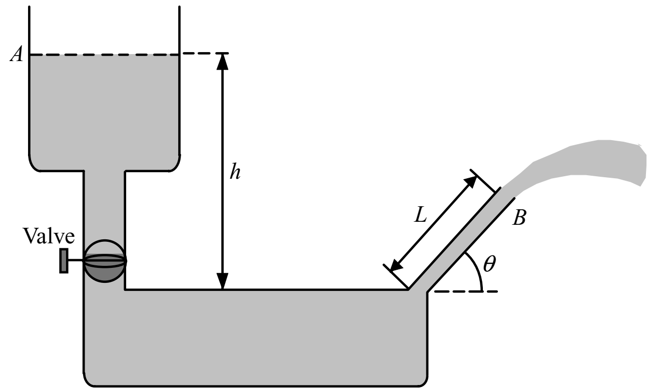

FIG. P14.52

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

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

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

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

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

P14.53 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:

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

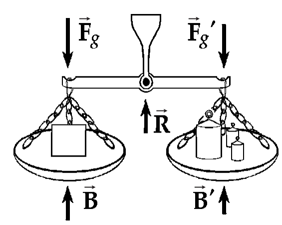

FIG. P14.53

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

Therefore,

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

P14.54 Assume $v_{\text{inside}} \approx 0$ From Bernoulli's equation,

$$P + 0 + 0 = 1\ \text{atm} + \frac{1}{2}(1\,000)(30.0)^2 + 1\,000(9.80)(0.500)$$
$$P_{\text{gauge}} = P - 1\ \text{atm} = 4.50\times10^5 + 4.90\times10^3 = \boxed{455\ \text{kPa}}$$

P14.55 At equilibrium, $\sum F_y = 0$: $B - F_{\text{spring}} - F_{g,\text{ He}} - F_{g,\text{ balloon}} = 0$

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

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

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

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

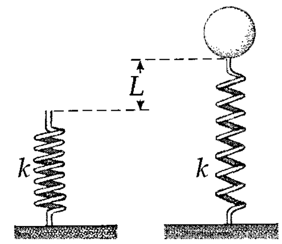

FIG. P14.55

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

From the data given, $$L = \frac{\left(1.29\ \text{kg/m}^3 - 0.180\ \text{kg/m}^3\right)5.00\ \text{m}^3 - 2.00\times10^{-3}\ \text{kg}}{90.0\ \text{N/m}}\left(9.80\ \text{m/s}^2\right)$$

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

***P14.56** 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:

$0 + mgy_1 = (1/2)mv_2^2$
$v_2 = (2gy_1)^{1/2} = [2(9.8)(3.3)]^{1/2} = \boxed{8.04\ \text{m/s}}$

(b) $\boxed{\text{The gravitational force and the buoyant force.}}$
The gravitational force is $mg = (2.1\ \text{kg})(9.8\ \text{N/kg}) = 20.6$ N down and the buoyant force is

$m_{fluid}g = \rho_{fluid}V_{object}\,g = \rho_{\text{fluid}}(4/3)\pi r^3 g = (1230\ \text{kg/m}^3)(4\pi/3)(0.09\ \text{m})^3(9.8\ \text{m/s}^2) = 36.8$ 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.

$(1/2)mv_2^2 + F_{net}\cdot\Delta y = (1/2)mv_3^2$
$(1/2)(2.1\ \text{kg})(8.04\ \text{m/s})^2 + (36.8\ \text{N} - 20.6\ \text{N})(-\Delta y) = 0$
$\Delta y = 67.9\ \text{J}/16.2\ \text{N} = \boxed{4.18\ \text{m}}$

(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) With friction present, Δt_{down} is less than Δt_{up}. 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.

***P14.57** First consider a hovering rocket that creates the gas it blows downward. The impulse-momentum theorem is

$F_g \Delta t = \Delta(mv)$ $\quad F_g = v\, dm/dt$ $\quad dm/dt = 950\text{ kg}(9.8\text{ N/kg})/(40\text{ m/s}) = 233\text{ kg/s}$

If the helicopter could create the air it expels downward, the mass flow rate of the air would have to be at least 233 kg/s. Really the rotor takes in air from above, moving over a larger area with lower speed, and blows it downward at higher speed. The incoming air from above brings momentum with it, so the mass flow rate must be a few times larger than 233 kg every second, or more.

P14.58 $P = \rho g h$ $\quad 1.013\times10^5 = 1.29(9.80)h$

$h = \boxed{8.01\text{ km}}$ For Mt. Everest, $29\,300\text{ ft} = 8.88\text{ km}$ $\boxed{\text{Yes}}$

P14.59 The torque is $\tau = \int d\tau = \int r\,dF$

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

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

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

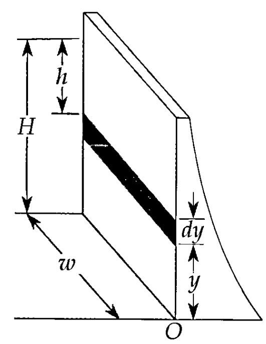

FIG. P14.59

P14.60 (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,

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

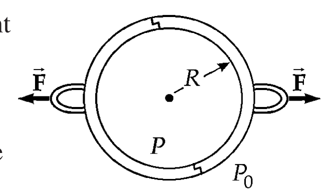

FIG. P14.60

(b) For the values given $F = (P_0 - 0.100P_0)\left[\pi(0.300\text{ m})^2\right] = 0.254P_0 = \boxed{2.58\times10^4\text{ N}}$

P14.61 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

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

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

$$T_1 = \left(1 - \frac{\rho_{\text{oil}}}{\rho_{\text{iron}}}\right) m_{\text{iron}} g = \left(1 - \frac{916}{7\,860}\right)(2.00)(9.80) = \boxed{17.3\ \text{N}}$$

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

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

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

P14.62 Looking at the top scale and the iron block:

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

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

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

or $$T_1 = \boxed{\left(1 - \frac{\rho_0}{\rho_{\text{Fe}}}\right) m_{\text{Fe}} g}$$ 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.

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

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

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

P14.63 $\rho_{Cu}V = 3.083$ g

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

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

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

$x = 0.900\,4$

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

P14.64 The incremental version of $P - P_0 = \rho g y$ is $\quad dP = -\rho g dy$

We assume that the density of air is proportional to pressure, or $\quad \dfrac{P}{\rho} = \dfrac{P_0}{\rho_0}$

Combining these two equations we have $\quad dP = -P\dfrac{\rho_0}{P_0}gdy$

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

and integrating gives $\quad \ln\left(\dfrac{P}{P_0}\right) = -\dfrac{\rho_0 gh}{P_0}$

so where $\alpha = \dfrac{\rho_0 g}{P_0}$ $\quad P = P_0 e^{-\alpha h}$

P14.65 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 $f = \dfrac{-I\alpha}{d}$

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

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

Gauge pressure: $P = \dfrac{n}{A} = \dfrac{1.49\text{ N}}{\pi(2.50\times10^{-2}\text{ m})^2} = \boxed{758\text{ Pa}}$

P14.66 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

$$\rho_{ice}gs^3 = \rho_w ghs^2 \Rightarrow h = s\frac{\rho_{ice}}{\rho_w}$$

With $\quad \rho_{ice} = 0.917\times10^3\text{ kg/m}^3$

$\rho_w = 1.00\times10^3\text{ kg/m}^3$

and $\quad s = 20.0$ mm

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

continued on next page

(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

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

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

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

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

P14.67 Energy for the fluid-Earth system is conserved.

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

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

P14.68 (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 π 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 $v_1 = 0.295$ 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

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

or

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

P14.69 **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.

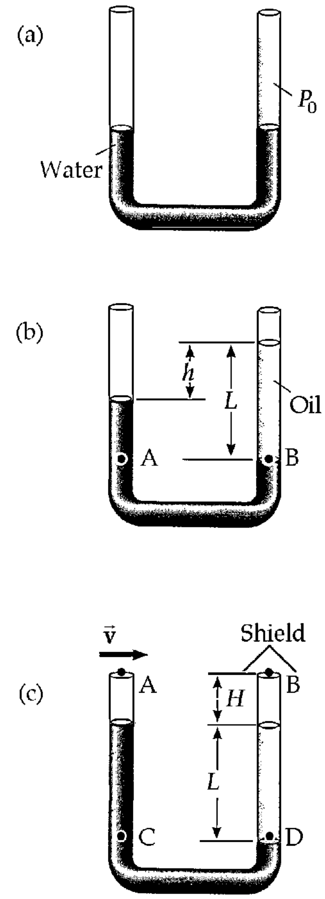

FIG. P14.69

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

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

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

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

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

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

$$h = \left(\frac{\rho_w - \rho_0}{\rho_w - \rho_a}\right)L = \left(\frac{1\,000 - 750}{1\,000 - 1.29}\right)5.00 \text{ cm} = \boxed{1.25 \text{ cm}}$$

(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 $(y_A = y_B,\ v_A = v,\ \text{and } v_B = 0)$

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

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

$P_C = P_A + \rho_a gH + \rho_w gL$ and $P_D = P_B + \rho_a gH + \rho_0 gL$

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

$P_B + \rho_a gH + \rho_0 gL = P_A + \rho_a gH + \rho_w gL$ or $P_B - P_A = (\rho_w - \rho_0)gL$ (2)

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

or

$$v = \sqrt{\frac{2gL(\rho_w - \rho_0)}{\rho_a}} = \sqrt{2\left(9.80 \text{ m/s}^2\right)(0.050\,0 \text{ m})\left(\frac{1\,000 - 750}{1.29}\right)}$$

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

P14.70 (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) $t = \dfrac{(0.5\text{ m})^2\, 0.5\text{ m}}{2\times 10^{-4}\text{ m}^2\sqrt{2(9.8\text{ m/s}^2)10\text{ m}}} = \boxed{44.6\text{ s}}$

P14.71 (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 $y_t \approx y_b$

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

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

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.

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

$$A = \frac{2(800\text{ kg})9.8\text{ m/s}^2}{(9.5\text{ m/s})^2 (1.05^2 - 1)1\,000\text{ kg/m}^3} = \boxed{1.70\text{ m}^2}$$

ANSWERS TO EVEN PROBLEMS

P14.2 $\sim 10^{18}$ kg/m^3. An atom is mostly empty space, so the matter we perceive is mostly empty space.

P14.4 5.27×10^{18} kg

P14.6 (a) 1.01×10^7 Pa (b) 7.09×10^5 N outward

P14.8 255 N

P14.10 (a) 65.1 N (b) 275 N

P14.12 (a) 29.4 kN to the right (b) 16.3 kN·m counterclockwise

P14.14 (a) 10.3 m (b) zero

P14.16 (a) 20.0 cm (b) 0.490 cm

P14.18 (a) 101.3 kPa + (9.80 kPa/m)h (b) Mg/A (c) 116 kPa; 52.0 Pa

P14.20 (a) 444 kg (b) 480 kg

P14.22 3.33×10^3 kg/m^3

P14.24 (a) see the solution (b) 25.0 N up (c) horizontally inward (d) tension increases; see the solution (e) 62.5% (f) 18.7%

P14.26 ~10^4 balloons of 25-cm diameter

P14.28 (a) 6.70 cm (b) 5.74 cm

P14.30 (a) 11.6 cm (b) 0.963 g/cm^3 (c) Not quite. The number 1.06 is halfway between 0.98 and 1.14 but the mark for that density is 0.0604 cm below the geometric halfway point between the ends of the scale. The marks get closer together as you go down.

P14.32 2.67×10^3 kg

P14.34 1.28×10^4 m^2

P14.36 (a) 27.9 N (b) 3.32×10^4 kg (c) 7.26×10^4 Pa

P14.38 (a) 0.825 m/s (b) 3.30 m/s (c) 4.15 L/s

P14.40 (a) see the solution (b) 616 MW

P14.42 (a) $\left(3.93 \times 10^{-6}\ \text{m}^3/\text{s}\right)\sqrt{\Delta P}$ where ΔP is in pascals. (b) 0.305 L/s (c) 0.431 L/s (d) The flow rate is proportional to the square root of the pressure difference.

P14.44 (a), (b) 28.0 m/s (c) The answers agree. (d) 2.11 MPa

P14.46 6.80×10^4 Pa

P14.48 347 m/s

P14.50 (a) 489 N outward (b) 1.96 kN outward

P14.52 2.25 m above the level where the water emerges

P14.54 455 kPa

P14.56 (a) 8.04 m/s (b) The gravitational force 20.6 N down and the buoyant force 36.8 N up. (c) The net upward force on the ball brings its downward motion to a stop over 4.18 m (d) 8.04 m/s (e) The time intervals are equal. (f) With friction present, Δt_{down} is less than Δt_{up}. 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.

P14.58 8.01 km; yes

P14.60 (a) see the solution (b) 2.58×10^4 N

P14.62 top scale: $\left(1 - \dfrac{\rho_0}{\rho_{\mathrm{Fe}}}\right) m_{\mathrm{Fe}} g$ bottom scale: $\left(m_b + m_0 + \dfrac{\rho_0 m_{\mathrm{Fe}}}{\rho_{\mathrm{Fe}}}\right) g$

P14.64 see the solution

P14.66 (a) 18.3 mm (b) 14.3 mm (c) 8.56 mm

P14.68 (a) 2.65 m/s (b) 2.31×10^4 Pa

P14.70 (a) see the solution (b) 44.6 s