9

Solids and Fluids

QUICK QUIZZES

1. Choice (c). The mass that you have of each element is:

$$m_{\text{gold}} = \rho_{\text{gold}} V_{\text{gold}} = \left(19.3\times10^3 \text{ kg/m}^3\right)\left(1 \text{ m}^3\right) = 19.3\times10^3 \text{ kg}$$

$$m_{\text{silver}} = \rho_{\text{silver}} V_{\text{silver}} = \left(10.5\times10^3 \text{ kg/m}^3\right)\left(2 \text{ m}^3\right) = 21.0\times10^3 \text{ kg}$$

$$m_{\text{aluminum}} = \rho_{\text{aluminum}} V_{\text{aluminum}} = \left(2.70\times10^3 \text{ kg/m}^3\right)\left(6 \text{ m}^3\right) = 16.2\times10^3 \text{ kg}$$

2. Choice (a). At a fixed depth, the pressure in a fluid is directly proportional to the density of the fluid. Since ethyl alcohol is less dense than water, the pressure is smaller than P when the glass is filled with alcohol.

3. Choice (c). For a fixed pressure, the height of the fluid in a barometer is inversely proportional to the density of the fluid. Of the fluids listed in the selection, ethyl alcohol is the least dense.

4. Choice (b). The blood pressure measured at the calf would be larger than that measured at the arm. If we imagine the vascular system of the body to be a vessel containing a liquid (blood), the pressure in the liquid will increase with depth. The blood at the calf is deeper in the liquid than that at the arm and is at a higher pressure.

Blood pressures are normally taken at the arm because that is approximately the same height as the heart. If blood pressures at the calf were used as a standard, adjustments would need to be made for the height of the person, and the blood pressure would be different if the person were lying down.

5. Choice (c). The level of a floating ship is unaffected by the atmospheric pressure. The buoyant force results from the pressure differential in the fluid. On a high-pressure day, the pressure at all points in the water is higher than on a low-pressure day. Because water is almost incompressible, however, the rate of change of pressure with depth is the same, resulting in no change in the buoyant force.

6. Choice (b). Since both lead and iron are denser than water, both objects will be fully submerged and (since they have the same dimensions) will displace equal volumes of water. Hence, the buoyant forces acting on the two objects will be equal.

7. Choice (a). When there is a moving air stream in the region between the balloons, the pressure in this region will be less than on the opposite sides of the balloons where the air is not moving. The pressure differential will cause the balloons to move toward each other. This is a demonstration of Bernoulli's principle in action.

ANSWERS TO MULTIPLE CHOICE QUESTIONS

1. From Pascal's principle, $F_1/A_1 = F_2/A_2$, so if the output force is to be $F_2 = 1.2\times10^3$ N, the required input force is $F_1 = (A_1/A_2)F_2 = (0.050 \text{ m}^2/0.70 \text{ m}^2)(1.2\times10^3 \text{ N}) = 86$ N, making (c) the correct answer.

2. On average, the support force each nail exerts on the body is

$$\overline{F}_1 = \frac{mg}{1\,208} = \frac{(66.0 \text{ kg})(9.80 \text{ m/s}^2)}{1\,208} = 0.535 \text{ N}$$

so the average pressure exerted on the body by each nail is

$$P_{\text{av}} = \frac{\overline{F}_1}{A_{\substack{\text{nail}\\\text{end}}}} = \frac{0.535 \text{ N}}{1.00\times10^{-6} \text{ m}^2} = 5.35\times10^5 \text{ Pa}$$

and (d) is the correct choice.

3. $m = \rho_{\text{gold}} V = \left(19.3 \times 10^3 \text{ kg/m}^3\right)\left(4.50 \times 10^{-2} \text{ m}\right)\left(11.0 \times 10^{-2} \text{ m}\right)\left(26.0 \times 10^{-2} \text{ m}\right) = 24.8 \text{ kg}$, and choice (a) is the correct response.

4. If the bullet is to float, the buoyant force must equal the weight of the bullet. Thus, the bullet will sink until the weight of the displaced mercury equals the weight of the bullet, or $\rho_{\text{mercury}} V_{\text{submerged}} g = \rho_{\text{lead}} V_{\text{bullet}} g$, and

$$\frac{V_{\text{submerged}}}{V_{\text{bullet}}} = \frac{\rho_{\text{lead}}}{\rho_{\text{mercury}}} = \frac{11.3 \times 10^3 \text{ kg/m}^3}{13.6 \times 10^3 \text{ kg/m}^3} = 0.831$$

so the correct response is (d).

5. The absolute pressure at depth *h* below the surface of a liquid with density ρ, and with pressure P_0 at its surface, is $P = P_0 + \rho g h$. Thus, at a depth of 754 ft in the waters of Loch Ness,

$$P = 1.013 \times 10^5 \text{ Pa} + \left(1.00 \times 10^3 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)\left[(754 \text{ ft})\left(\frac{1 \text{ m}}{3.281 \text{ ft}}\right)\right] = 2.35 \times 10^6 \text{ Pa}$$

and (c) is the correct response.

6. Both the block and the steel object are in equilibrium. Thus, the sum of the buoyant force on the steel object and the tension in the string must equal the weight of the steel object, so this buoyant force and the tension in the string must each be less than the weight of the object. The buoyant force on the block equals the weight of the water displaced by the block. This buoyant force must equal the sum of the weight of the block and the tension in the string, and hence, exceeds the magnitude of each of these individual forces. Therefore, the only correct answers to this question are choices (d) and (e).

7. From the equation of continuity, $A_1 v_1 = A_2 v_2$, the speed of the water in the smaller pipe is

$$v_2 = \left(\frac{A_1}{A_2}\right) v_1 = \left[\frac{\pi (0.250\ \text{m})^2}{\pi (0.100\ \text{m})^2}\right] (1.00\ \text{m/s}) = 6.25\ \text{m/s}$$

so (d) is the correct answer.

8. Since water is denser than the air-filled ball, the buoyant force acting on the ball exceeds the weight of the fully submerged ball. This means that choice (b) is true and choice (d) is false. Neglecting a very small variation in the density of water with depth, the weight of the displaced water (i.e., the buoyant force on the ball) remains constant as long as the ball is totally submerged and its size does not change. Therefore, both choices (a) and (c) are false. That choice (e) is true follows directly from Archimedes' principle, meaning the correct responses to this question are choices (b) and (e).

9. The boat, even after it sinks, experiences a buoyant force, *B*, equal to the weight of whatever water it is displacing. This force will support part of the weight, *w*, of the boat. The force exerted on the boat by the bottom of the lake will be $F_{\text{bottom}} = w - B < w$ and will support the balance of the boat's weight. The correct response is (c).

10. The absolute pressure at depth *h* below the surface of a fluid having density ρ is $P = P_0 + \rho g h$, where P_0 is the pressure at the upper surface of that fluid. The fluid in each of the three vessels has density $\rho = \rho_{\text{water}}$, the top of each vessel is open to the atmosphere so that $P_0 = P_{\text{atmo}}$ in each case, and the bottom is at the same depth *h* below the upper surface for the three vessels. Thus, the pressure *P* at the bottom of each vessel is the same and (c) is the correct choice.

11. The two spheres displace equal volumes (and hence, equal weights) of water. Therefore, they experience the same magnitude buoyant forces. This means that choice (a) is true while choices (b) and (d) are false. The tension in the string attached to each sphere must equal the difference between the weight of that sphere and the buoyant force. Since the lead sphere has the greater weight, and the two buoyant forces are equal, the tension in the string attached to the lead sphere is greater than the tension in the string attached to the iron sphere. Thus, choice (c) is also true and the correct responses are choices (a) and (c).

12. As the ball moves to a greater depth in the pool, the pressure exerted due to the water increases significantly. The thin plastic wall of the ball is not rigid enough to prevent the air in the ball from being compressed into a smaller volume as the water pressure increases. Since the buoyant force is the weight of the displaced water, and this weight decreases because the volume of water displaced by the ball decreases while the density of the water is essentially constant, the buoyant force exerted on the ball by the water decreases. Hence, choice (c) is the correct answer.

13. When the anchor was in the boat, sufficient water was displaced to fully support the total weight of the person, boat, and anchor. After the anchor is thrown overboard, the bottom of the lake supports most of the anchor's weight. Thus, less water must be displaced to keep the person plus boat afloat and also support the small remainder of the anchor's weight. The correct response is choice (b).

14. Since most of the ice at the south pole is supported by land, it does not displace any seawater, and hence, does not contribute to the water level in the oceans. However, after this ice melts and flows into the sea, it will significantly add to the water level in the oceans. On the contrary, the ice at the north pole is currently displacing its own weight in water, just as it will after melting. Thus, the ice at the south pole will have the greater impact on sea levels as it melts and the correct choice is (b).

ANSWERS TO EVEN NUMBERED CONCEPTUAL QUESTIONS

2. We approximate the thickness of the atmosphere by using $P = P_0 + \rho g h$ with $P_0 = 0$ at the top of the atmosphere and $P = 1\text{ atm}$ at sea level. This gives an approximation of

$$h = \frac{P - P_0}{\rho g} \sim \frac{10^5\text{ Pa} - 0}{\left(1\text{ kg/m}^3\right)\left(10^1\text{ m/s}^2\right)} = 10^4\text{ m} \qquad \text{or} \qquad h \sim 10\text{ km}$$

Because both the density of the air, ρ, and the acceleration of gravity, g, decrease with altitude, the actual thickness of the atmosphere will be greater than our estimate.

4. The two dams must have the same strength. The force on the back of each dam is the average pressure of the water times the area of the dam. If the two reservoirs are equally deep, the forces exerted on the two dams by the water have equal magnitudes.

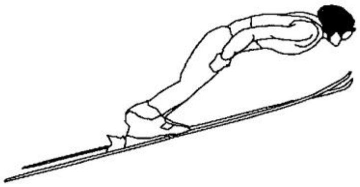
6. A fan driven by the motor removes air, and hence decreases the pressure inside the cleaner. The greater air pressure outside the cleaner pushes air in through the nozzle toward this region of lower pressure. This inward rush of air pushes or carries the dirt along with it.

8. The external pressure exerted on the chest by the water makes it difficult to expand the chest cavity and take a breath while under water. Thus, a snorkel will not work in deep water.

10. The water level on the side of the glass stays the same. The floating ice cube displaces its own weight of liquid water, and so does the liquid water into which it melts.

12. The higher the density of a fluid, the higher an object will float in it. Thus, an object will float lower in low-density alcohol.

14. The ski jumper gives her body the shape of an airfoil. She deflects the air stream downward as it rushes past and it deflects her upward in agreement with Newton's third law. Thus, the air exerts a lift force on her, giving a higher and longer trajectory.



ANSWERS TO EVEN NUMBERED PROBLEMS

2. **(a)** 7.322×10^{-3} kg **(b)** $V_{gold} = 3.79 \times 10^{-7}$ m^3, $V_{copper} = 7.46 \times 10^{-8}$ m^3

(c) 1.76×10^4 kg/m^3

4. 24.8 kg

6. 1.9×10^4 N

8. 1.00×10^{11} Pa

10. **(a)** 1.77×10^6 N

(b) The superhero would be thrown backward by a reaction force of 1.77×10^6 N exerted on him by the wall according to Newton's third law.

12. **(a)** 3.14×10^4 N **(b)** 6.28×10^4 N

14. 22 N toward the bottom of the page in Figure P9.14

16. **(a)** 2.5 mm **(b)** 0.70 mm **(c)** 6.9×10^3 kg

18. Yes, the average stress is 5.5×10^7 Pa, considerably less than 16×10^7 Pa.

20. 2.11 m

22. **(a)** 20.0 cm **(b)** 0.490 cm

24. **(a)** $\Delta V = -0.054\ \text{m}^3$ **(b)** $1.1 \times 10^3\ \text{kg/m}^3$

(c) With only a 5.4% change in volume in this extreme case, liquid water is indeed nearly incompressible in biological and student laboratory situations.

26. **(a)** 10.5 m

(b) No. Since water and alcohol are more volatile than mercury, more liquid will evaporate and degrade the vacuum above the liquid column inside the tube of this barometer.

28. 2.3 lb

30. **(a)** 23.2% after inhaling, 17.1% after exhaling

(b) In general, “sinkers” would be expected to be thinner with heavier bones, whereas “floaters” would have lighter bones and more fat.

32. **(a)** See Solution. **(b)** $\Sigma F_y = B - w - w_r = 0$ **(c)** 964 N

(d) 356 N **(e)** 101 kg/m^3 **(f)** $3.62 \times 10^3 \text{ N}$

(g) 333 kg

34. **(a)** See Solution. **(b)** $4.11 \times 10^3 \text{ N}$

(c) $\Sigma F_y = +1.33 \times 10^3$ N, the balloon rises when released **(d)** 136 kg

(e) The balloon and its load accelerate upward.

(f) As the balloon rises, decreasing atmospheric density decreases the buoyancy force.

36. **(a)** $\Sigma F_y = \rho_w g V - mg = ma_y$ **(b)** $a_y = \left[(\rho_w/\rho) - 1\right] g$ **(c)** 0.467 m/s^2 down

(d) 5.85 s

38. $3.33 \times 10^3 \text{ kg/m}^3$

40. 16.5 cm

42. **(a)** $8.57 \times 10^3 \text{ kg/m}^3$ **(b)** 715 kg/m^3

44. **(a)** 0.471 m/s **(b)** 4.24 m/s

46. **(a)** 11.0 m/s **(b)** $2.64 \times 10^4 \text{ Pa}$

48. $4.4 \times 10^{-2} \text{ Pa}$

50. $P_{\substack{\text{upper}\\\text{surface}}} = P_{\substack{\text{lower}\\\text{surface}}} - Mg/A_{\text{wings}}$

52. **(a)** 2.02 m/s **(b)** 8.08 m/s **(c)** $5.71 \times 10^{-3} \text{ m}^3/\text{s}$

54. **(a)** 17.7 m/s **(b)** 1.73 mm

56. **(a)** 15.1 MPa **(b)** 2.95 m/s **(c)** 4.35 kPa

58. **(a)** 1.91 m/s

(b) $8.64 \times 10^{-4} \text{ m}^3/\text{s}$

60. $7.32 \times 10^{-2} \text{ N/m}$

62. 5.6 m

64. 0.12 N

66. 1.5 m/s

68. $1.5 \times 10^5 \text{ Pa}$

70. 455 kPa

72. $8.0\ \text{cm/s}$

74. $9.5\times10^{-10}\ \text{m}^2/\text{s}$

76. $1.02\times10^{3}\ \text{kg/m}^3$

78. See Solution.

80. **(a)** See Solution. **(b)** $1.23\times10^{4}\ \text{Pa}$

82. **(a)** 10.3 m **(b)** 0

84. See Solution.

86. 1.9 m

88. **(a)** 1.25 cm **(b)** $13.8\ \text{m/s}$

90. 1.71 cm

PROBLEM SOLUTIONS

9.1 The average density of either of the two original worlds was

$$\rho_0 = \frac{M}{V} = \frac{M}{4\pi R^3/3} = \frac{3M}{4\pi R^3}$$

The average density of the combined world is

$$\rho = \frac{M_{\text{total}}}{V'} = \frac{2M}{\frac{4\pi}{3}\left(\frac{3}{4}R\right)^3} = \frac{4^2(2M)}{\pi(3^2)R^3} = \frac{32M}{9\pi R^3}$$

so $\frac{\rho}{\rho_0} = \left(\frac{32M}{9\pi R^3}\right)\left(\frac{4\pi R^3}{3M}\right) = \frac{128}{27} = 4.74$ or $\boxed{\rho = 4.74\rho_0}$

9.2 (a) The mass of gold in the coin is

$$m_{\text{Au}} = \frac{(\#\ \text{karats})\, m_{\text{total}}}{24} = \frac{22}{24} m_{\text{total}} = \frac{11}{12}\left(7.988\times10^{-3}\ \text{kg}\right) = \boxed{7.322\times10^{-3}\ \text{kg}}$$

and the mass of copper is $m_{\text{Cu}} = m_{\text{total}}/12 = \left(7.988\times10^{-3}\ \text{kg}\right)/12 = 6.657\times10^{-4}\ \text{kg}$.

(b) The volume of the gold present is

$$V_{\text{Au}} = \frac{m_{\text{Au}}}{\rho_{\text{Au}}} = \frac{7.322\times10^{-3}\ \text{kg}}{19.3\times10^{3}\ \text{kg/m}^3} = \boxed{3.79\times10^{-7}\ \text{m}^3}$$

and the volume of the copper is

$$V_{\text{Cu}} = \frac{m_{\text{Cu}}}{\rho_{\text{Cu}}} = \frac{6.657\times10^{-4}\ \text{kg}}{8.92\times10^{3}\ \text{kg/m}^3} = \boxed{7.46\times10^{-8}\ \text{m}^3}$$

(c) The average density of the British sovereign coin is

$$\rho_{\text{av}} = \frac{m_{\text{total}}}{V_{\text{total}}} = \frac{m_{\text{total}}}{V_{\text{Au}}+V_{\text{Cu}}} = \frac{7.988\times10^{-3}\ \text{kg}}{3.79\times10^{-7}\ \text{m}^3 + 7.46\times10^{-8}\ \text{m}^3} = \boxed{1.76\times10^{4}\ \text{kg/m}^3}$$

9.3 (a) The total normal force exerted on the bottom acrobat's shoes by the floor equals the total weight of the acrobats in the tower. That is

$$n = m_{\text{total}}g = \left[(75.0+68.0+62.0+55.0)\ \text{kg}\right]\left(9.80\ \text{m/s}^2\right) = \boxed{2.55\times10^{3}\ \text{N}}$$

(b) $$P = \frac{n}{A_{\text{total}}} = \frac{n}{2A_{\substack{\text{shoe}\\\text{sole}}}} = \frac{2.55\times10^{3}\ \text{N}}{2\left[425\ \text{cm}^2\left(1\ \text{m}^2/10^4\ \text{cm}^2\right)\right]} = \boxed{3.00\times10^{4}\ \text{Pa}}$$

(c) If the acrobats are rearranged so different ones are at the bottom of the tower, the total weight supported, and hence the total normal force n, will be unchanged. However, the total area $A_{\text{total}} = 2A_{\text{shoe sole}}$, and hence the pressure, will change unless all the acrobats wear the same size shoes.

9.4 $$M_{\text{bar}} = \rho_{\text{Au}}V_{\text{bar}} = \rho_{\text{Au}}(\ell\times w\times h) = \left(19.3\times10^{3}\ \text{kg/m}^3\right)\left[(0.045\,0\ \text{m})(0.110\ \text{m})(0.260\ \text{m})\right]$$

or $$M_{\text{bar}} = \boxed{24.8\ \text{kg}}$$

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

$$\rho_{\text{nucleus}} \approx \frac{m_{\text{proton}}}{V_{\text{proton}}} = \frac{m_{\text{proton}}}{4\pi r^3/3} \sim \frac{3\left(1.67\times10^{-27}\text{ kg}\right)}{4\pi\left(1\times10^{-15}\text{ m}\right)^3} \quad \boxed{\sim 4\times10^{17}\text{ kg/m}^3}$$

(b) The density of iron is $\rho_{\text{Fe}} = 7.86\times10^3\text{ kg/m}^3$ and the densities of other solids and liquids are on the order of 10^3 kg/m^3. Thus, the nuclear density is about 10^{14} times greater than that of common solids and liquids, which suggests that atoms must be mostly empty space. Solids and liquids, as well as gases, are mostly empty space.

9.6 Let the weight of the car be *W*. Then, each tire supports $W/4$, and the gauge pressure is $P = F/A = (W/4)/A = W/4A$. Thus,

$$W = 4\,A\,P = 4\left(0.024\text{ m}^2\right)\left(2.0\times10^5\text{ Pa}\right) = \boxed{1.9\times10^4\text{ N}}$$

9.7 (a) $F_{\text{atm}} = PA = P_{\text{atm}}\left(\pi r^2\right) = \left(8.04\times10^4\text{ Pa}\right)\pi\left(2.00\text{ m}\right)^2 = \boxed{1.01\times10^6\text{ N}}$

(b) $F_g = mg = \left(\rho V\right)g = \rho\left[\left(\pi r^2\right)h\right]g$

$$= \left(415\text{ kg/m}^3\right)\left[\pi\left(2.00\text{ m}\right)^2\left(10.0\text{ m}\right)\right]\left(7.44\text{ m/s}^2\right) = \boxed{3.88\times10^5\text{ N}}$$

(c) Now, consider the thin disk-shaped region 2.00 m in radius at the bottom end of the column of methane. The total downward force on it is the weight of the 10.0-meter tall column of methane plus the downward force exerted on the upper end of the column by the atmosphere. Thus, the pressure (force per unit area) on the disk-shaped region located 10.0 meters below the ocean surface is

$$P = \frac{F_{\text{total}}}{A} = \frac{F_{\text{atm}} + F_g}{\pi r^2} = \frac{1.01\times10^6\text{ N} + 3.88\times10^5\text{ N}}{\pi\left(2.00\text{ m}\right)^2} = \boxed{1.11\times10^5\text{ Pa}}$$

9.8 By definition, Young's modulus is the ratio of the tensile stress to the tensile strain in an elastic material. Thus, Young's modulus for this material is the slope of the linear portion of the graph in the "elastic behavior" region. This is

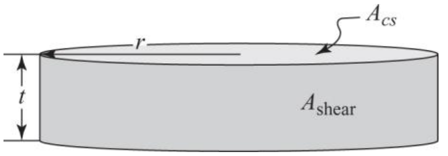
$$Y = \frac{\Delta(stress)}{\Delta(strain)} = \frac{200\ \text{MPa} - 0}{0.002 - 0} = 1.00 \times 10^5\ \text{MPa} = 1.00 \times 10^5\left(10^6\ \text{Pa}\right) = \boxed{1.00 \times 10^{11}\ \text{Pa}}$$

9.9 Young's modulus is defined as $Y = stress/strain = (F/A)/(\Delta L/L_0) = (F \cdot L_0)/(A \cdot \Delta L)$. Thus, the elongation of the wire is

$$\Delta L = \frac{F \cdot L_0}{A \cdot Y} = \frac{\left[(200\ \text{kg})\left(9.80\ \text{m/s}^2\right)\right] \cdot (4.00\ \text{m})}{\left(0.200 \times 10^{-4}\ \text{m}^2\right)\left(8.00 \times 10^{10}\ \text{N/m}^2\right)} = 4.90 \times 10^{-3}\ \text{m} = \boxed{4.90\ \text{mm}}$$

9.10 (a) In order to punch a hole in the steel plate, the superhero must punch out a plug with cross-sectional area, A_{cs}, equal to that of his fist and a height *t* equal to the thickness of the steel plate. The area A_{shear} of the face that is sheared as the plug is removed is the cylindrical surface with radius *r* and height *t* as shown in the sketch. Since $A_{cs} = \pi r^2$, then $r = \sqrt{A_{cs}/\pi}$ and

$$A_{\text{shear}} = (2\pi r)t = 2\pi t\sqrt{\frac{A_{cs}}{\pi}} = 2\pi(2.00\ \text{cm})\sqrt{\frac{1.00 \times 10^2\ \text{cm}^2}{\pi}} = 70.9\ \text{cm}^2$$



If the ultimate shear strength of steel (i.e., the maximum shear stress it can withstand before shearing) is $2.50 \times 10^8\ \text{Pa} = 2.50 \times 10^8\ \text{N/m}^2$, the minimum force required to punch out this plug is

$$F = A_{\text{shear}} \cdot stress = \left[70.9\ \text{cm}^2\left(\frac{1\ \text{m}^2}{10^4\ \text{cm}^2}\right)\right]\left(2.50 \times 10^8\ \frac{\text{N}}{\text{m}^2}\right) = \boxed{1.77 \times 10^6\ \text{N}}$$

(b) By $\boxed{\text{Newton's third law}}$, the wall would exert a force of equal magnitude in the opposite direction on the superhero, $\boxed{\text{who would be thrown backward}}$ at a very high recoil speed.

9.11 Two cross-sectional areas in the plank, with one directly above the rail and one at the outer end of the plank, separated by distance $h = 2.00$ m and each with area $A = (2.00\text{ cm})(15.0\text{ cm}) = 30.0\text{ cm}^2$, move a distance $\Delta x = 5.00\times10^{-2}$ m parallel to each other. The force causing this shearing effect in the plank is the weight of the man $F = mg$ applied perpendicular to the length of the plank at its outer end. Since the shear modulus is given by S = *shear stress/shear strain* = $(F/A)/(\Delta x/h) = Fh/(\Delta x)A$, the shear modulus for the wood in this plank must be

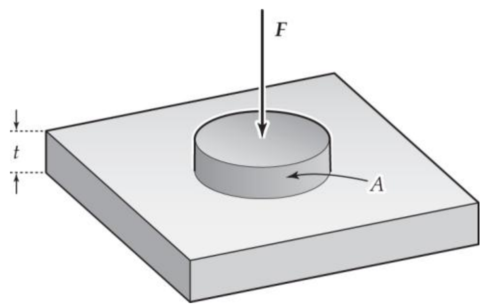
$$S = \frac{(80.0\text{ kg})(9.80\text{ m/s}^2)(2.00\text{ m})}{(5.00\times10^{-2}\text{ m})\left[(30.0\text{ cm}^2)(1\text{ m}^2/10^4\text{ cm}^2)\right]} = \boxed{1.05\times10^7\text{ Pa}}$$

9.12 (a) The force needed to shear the bolt through its cross-sectional area is $F = (A)(\mathit{stress})$, or

$$F = \pi\left(5.00\times10^{-3}\text{ m}\right)^2\left(4.00\times10^8\text{ N/m}^2\right) = \boxed{3.14\times10^4\text{ N}}$$

(b) The area over which the shear occurs is equal to the circumference of the hole times its thickness. Thus,

$$A = (2\pi r)t = \left[2\pi\left(5.00\times10^{-3}\text{ m}\right)\right]\left(5.00\times10^{-3}\text{ m}\right) = 1.57\times10^{-4}\text{ m}^2$$



The force required to punch a hole of this area in the 0.500-cm thick steel plate is then

$$F = (A)(stress) = \left(1.57\times10^{-4}\ \text{m}^2\right)\left(4.00\times10^{8}\ \text{N/m}^2\right) = \boxed{6.28\times10^{4}\ \text{N}}$$

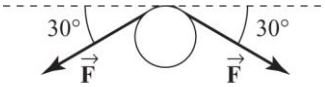
9.13 Using $Y = \dfrac{F\,L_0}{A(\Delta L)}$ with $A = \pi d^2/4$ and $F = mg$, we get

$$Y = \frac{4\left[(90\ \text{kg})\left(9.80\ \text{m/s}^2\right)\right](50\ \text{m})}{\pi\left(1.0\times10^{-2}\ \text{m}\right)^2(1.6\ \text{m})} = \boxed{3.5\times10^{8}\ \text{Pa}}$$

9.14 From $Y = F\,L_0/A(\Delta L)$, the tension needed to stretch the wire by 0.10 mm is

$$F = \frac{Y\,A(\Delta L)}{L_0} = \frac{Y\left(\pi r^2\right)(\Delta L)}{L_0}$$

$$= \frac{\left(18\times10^{10}\ \text{Pa}\right)\pi\left(0.11\times10^{-3}\ \text{m}\right)^2\left(0.10\times10^{-3}\ \text{m}\right)}{\left(3.1\times10^{-2}\ \text{m}\right)} = 22\ \text{N}$$



The tension in the wire exerts a force of magnitude F on the tooth in each direction along the length of the wire as shown in the above sketch. The resultant force exerted on the tooth has an x-component of $R_x = \Sigma F_x = -F\cos 30° + F\cos 30° = 0$, and a y-component of $R_y = \Sigma F_y = -F\sin 30° - F\sin 30° = -F = -22\ \text{N}$.

Thus, the resultant force is

$\vec{\mathbf{R}} = \boxed{\text{22 N directed down the page in the diagram}}$.

9.15 From $Y = stress/strain = (stress)(L_0/\Delta L)$, the maximum compression the femur can withstand before breaking is

$$\Delta L_{max} = \frac{(stress)_{max}(L_0)}{Y} = \frac{(160\times10^6 \text{ Pa})(0.50 \text{ m})}{18\times10^9 \text{ Pa}} = 4.4\times10^{-3} \text{ m} = \boxed{4.4 \text{ mm}}$$

9.16 (a) When at rest, the tension in the cable equals the weight of the 800-kg object, 7.84×10^3 N. Thus, from $Y = \frac{F L_0}{A(\Delta L)}$, the initial elongation of the cable is

$$\Delta L = \frac{F\cdot L_0}{A\cdot Y} = \frac{(7.84\times10^3 \text{ N})(25.0 \text{ m})}{(4.00\times10^{-4} \text{ m}^2)(20\times10^{10} \text{ Pa})} = 2.5\times10^{-3} \text{ m} = \boxed{2.5 \text{ mm}}$$

(b) When the load is accelerating upward, Newton's second law gives the tension in the cable as

$$F - mg = ma_y, \quad \text{or} \quad F = m(g + a_y) \qquad \textbf{[1]}$$

If $m = 800$ kg and $a_y = +3.0$ m/s², the elongation of the cable will be

$$\Delta L = \frac{F\cdot L_0}{A\cdot Y} = \frac{[(800 \text{ kg})(9.80 + 3.0) \text{ m/s}^2](25.0 \text{ m})}{(4.00\times10^{-4} \text{ m}^2)(20\times10^{10} \text{ Pa})} = 3.2\times10^{-3} \text{ m} = 3.2 \text{ mm}$$

Thus, the increase in the elongation has been

$$increase = (\Delta L) - (\Delta L)_{initial} = 3.2 \text{ mm} - 2.5 \text{ mm} = \boxed{0.70 \text{ mm}}$$

(c) From the definition of the tensile stress, $stress = F/A$, the maximum tension the cable can withstand is

$$F_{\max} = A\cdot(stress)_{\max} = (4.00\times10^{-4}\ \text{m}^2)(2.2\times10^{8}\ \text{Pa}) = 8.8\times10^{4}\ \text{N}$$

Then, Equation [1] above gives the mass of the maximum load as

$$m_{\max} = \frac{F_{\max}}{g+a} = \frac{8.8\times10^{4}\ \text{N}}{(9.8+3.0)\ \text{m/s}^2} = \boxed{6.9\times10^{3}\ \text{kg}}$$

9.17 The upward force supporting the $8\ 500\ \text{N}$ load is the sum of the compression force exerted by the column and the tension force exerted by the cable.

$$F_{\text{column}} + F_{\text{cable}} = F_{g,\ \text{load}} = 8\ 500\ \text{N}$$

Since the magnitude of the change in length is the same for the column and the cable, this becomes

$$Y_{\text{Al}}A_{\text{column}}\left(\frac{\Delta L}{L_{0,\ \text{column}}}\right) + Y_{\text{steel}}A_{\text{cable}}\left(\frac{\Delta L}{L_{0,\ \text{cable}}}\right) = 8.50\times10^{3}\ \text{N}$$

yielding
$$\Delta L = \frac{8.50\times10^{3}\ \text{N}}{\dfrac{Y_{\text{Al}}}{L_{0,\ \text{column}}}\left(\dfrac{\pi d_{\text{outer}}^2}{4} - \dfrac{\pi d_{\text{inner}}^2}{4}\right) + \dfrac{Y_{\text{steel}}}{L_{0,\ \text{cable}}}\left(\dfrac{\pi d_{\text{cable}}^2}{4}\right)}$$

or
$$\Delta L = \frac{8.50\times10^{3}\ \text{N}}{\dfrac{7.0\times10^{10}\ \text{Pa}}{3.25\ \text{m}}\left[\dfrac{\pi(0.1624\ \text{m})^2}{4} - \dfrac{\pi(0.1614\ \text{m})^2}{4}\right] + \dfrac{20\times10^{10}\ \text{Pa}}{5.75\ \text{m}}\left[\dfrac{\pi(0.012\ 7\ \text{m})^2}{4}\right]}$$

$$\Delta L = 8.6\times10^{-4}\ \text{m} = \boxed{0.86\ \text{mm}}$$

9.18 The acceleration of the forearm has magnitude

$$a = \frac{|\Delta v|}{\Delta t} = \frac{80\ \text{km/h}\left(10^3\ \text{m/1 km}\right)\left(1\ \text{h/3 600 s}\right)}{5.0\times10^{-3}\ \text{s}} = 4.4\times10^3\ \text{m/s}^2$$

The compression force exerted on the arm is $F = ma$ and the compressional stress on the bone material is

$$\textit{Stress} = \frac{F}{A} = \frac{(3.0\ \text{kg})\left(4.4\times10^3\ \text{m/s}^2\right)}{2.4\ \text{cm}^2\left(10^{-4}\ \text{m}^2/1\ \text{cm}^2\right)} = \boxed{5.5\times10^7\ \text{Pa}}$$

Since the calculated stress is less than the maximum stress bone material can withstand without breaking, $\boxed{\text{the arm should survive}}$.

9.19 The tension and cross-sectional area are constant through the entire length of the rod, and the total elongation is the sum of that of the aluminum section and that of the copper section.

$$\Delta L_{\text{rod}} = \Delta L_{\text{Al}} + \Delta L_{\text{Cu}} = \frac{F(L_0)_{\text{Al}}}{AY_{\text{Al}}} + \frac{F(L_0)_{\text{Cu}}}{AY_{\text{Cu}}} = \frac{F}{A}\left[\frac{(L_0)_{\text{Al}}}{Y_{\text{Al}}} + \frac{(L_0)_{\text{Cu}}}{Y_{\text{Cu}}}\right]$$

where $A = \pi r^2$ with $r = 0.20\ \text{cm} = 2.0\times10^{-3}\ \text{m}$. Thus,

$$\Delta L_{\text{rod}} = \frac{\left(5.8\times10^3\ \text{N}\right)}{\pi\left(2.0\times10^{-3}\ \text{m}\right)^2}\left[\frac{1.3\ \text{m}}{7.0\times10^{10}\ \text{Pa}} + \frac{2.6\ \text{m}}{11\times10^{10}\ \text{Pa}}\right] = 1.9\times10^{-2}\ \text{m} = \boxed{1.9\ \text{cm}}$$

9.20 Assuming the spring obeys Hooke's law, the increase in force on the piston required to compress the spring an additional amount Δx is $\Delta F = F - F_0 = (P - P_0)A = k(\Delta x)$. The gauge pressure at depth *h* beneath the surface of a fluid is $P - P_0 = \rho gh$, so we have $\rho ghA = k(\Delta x)$, or the required depth is $h = k(\Delta x)/\rho gA$. If $k = 1\,250\ \text{N/m}$, $A = \pi r^2$ with $r = 1.20 \times 10^{-2}\ \text{m}$, and the fluid is water $(\rho = 1.00 \times 10^3\ \text{kg/m}^3)$, the depth required to compress the spring an additional $0.750\ \text{cm} = 7.50 \times 10^{-3}\ \text{m}$ is

$$h = \frac{(1\,250\ \text{N/m})(7.50 \times 10^{-3}\ \text{m})}{(1.00 \times 10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)\left[\pi(1.20 \times 10^{-2}\ \text{m})^2\right]} = \boxed{2.11\ \text{m}}$$

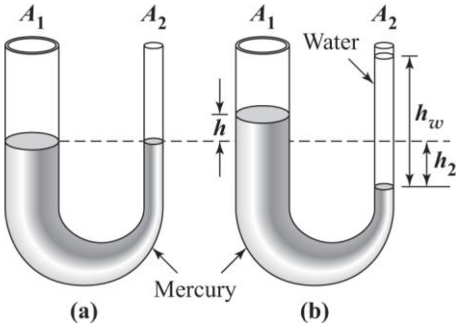
9.21 (a) $P = P_0 + \rho gh = 101.3 \times 10^3\ \text{Pa} + (1.00 \times 10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(27.5\ \text{m})$
$= \boxed{3.71 \times 10^5\ \text{Pa}}$

(b) The inward force the water will exert on the window is

$$F = PA = P(\pi r^2) = (3.71 \times 10^5\ \text{Pa})\pi\left(\frac{35.0 \times 10^{-2}\ \text{m}}{2}\right)^2 = \boxed{3.57 \times 10^4\ \text{N}}$$

9.22 (a) Consider the tube as shown in part (b) of the sketch at the right. The volume of water in the right arm is

$$V_w = \frac{m_w}{\rho_w} = \frac{100\ \text{g}}{1.00\ \text{g/cm}^3} = 100\ \text{cm}^3$$



But, we also know that $V_w = A_2 h_w$, giving

$$h_w = \frac{V_w}{A_2} = \frac{100\ \text{cm}^3}{5.00\ \text{cm}^2} = \boxed{20.0\ \text{cm}}$$

(b) From the sketch above, observe that the mercury that has been forced out of the right arm into the left arm is $V_{\text{displaced}} = A_1 h = A_2 h_2$, so $h_2 = \left(A_1/A_2\right)h$

or $$h_2 = \left(\frac{10.0\ \text{cm}^2}{5.00\ \text{cm}^2}\right)h = 2.00\,h$$

The absolute pressure at the water-mercury interface in the right arm is

$$P = P_0 + \rho_w g h_w \qquad \textbf{[1]}$$

The absolute pressure at the same level in the left arm is

$$P = P_0 + \rho_{Hg} g\left(h + h_2\right) = P_0 + \rho_{Hg} g\left(h + 2.00h\right)$$

or $$P = P_0 + 3.00\rho_{Hg} g h \qquad \textbf{[2]}$$

Since the pressure is the same at all points at a given level in a static fluid, we equate the pressures in Equations [1] and [2] to obtain $P_0 + 3.00\rho_{Hg} g h = P_0 + \rho_w g h_w$, which yields

$$h = \left(\frac{\rho_w}{3.00\rho_{Hg}}\right)h_w = \left[\frac{1.00\times10^3\ \text{kg/m}^3}{(3.00)\left(13.6\times10^3\ \text{kg/m}^3\right)}\right](20.0\ \text{cm}) = \boxed{0.490\ \text{cm}}$$

9.23 The density of the solution is $\rho = 1.02\,\rho_{\text{water}} = 1.02\times 10^3\ \text{kg/m}^3$. If the glucose solution is to flow into the vein, the minimum required gauge pressure of the fluid at the level of the needle is equal to the gauge pressure in the vein, giving

$$P_{\text{gauge}} = P - P_0 = \rho g h_{\min} = 1.33\times 10^3\ \text{Pa}$$

and $$h_{\min} = \frac{1.33\times 10^3\ \text{Pa}}{\rho g} = \frac{1.33\times 10^3\ \text{Pa}}{\left(1.02\times 10^3\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)} = \boxed{0.133\ \text{m}}$$

9.24 (a) From the definition of bulk modulus, $B = -\Delta P/\left(\Delta V/V_0\right)$, the change in volume of the $1.00\ \text{m}^3$ of seawater will be

$$\Delta V = -\frac{V_0\left(\Delta P\right)}{B_{\text{water}}} = -\frac{\left(1.00\ \text{m}^3\right)\left(1.13\times 10^8\ \text{Pa} - 1.013\times 10^5\ \text{Pa}\right)}{0.21\times 10^{10}\ \text{Pa}} = \boxed{-0.054\ \text{m}^3}$$

(b) The quantity of seawater that had volume $V_0 = 1.00\ \text{m}^3$ at the surface has a mass of 1 030 kg. Thus, the density of this water at the ocean floor is

$$\rho = \frac{m}{V} = \frac{m}{V_0 + \Delta V} = \frac{1\,030\ \text{kg}}{\left(1.00 - 0.054\right)\ \text{m}^3} = \boxed{1.1\times 10^3\ \text{kg/m}^3}$$

(c) With only a 5.4% change in volume in this extreme case, liquid water is indeed nearly incompressible in biological and student-laboratory situations.

9.25 We first find the absolute pressure at the interface between oil and water.

$$P_1 = P_0 + \rho_{\text{oil}}\, g h_{\text{oil}}$$

$$= 1.013 \times 10^5 \text{ Pa} + \left(700 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)\left(0.300 \text{ m}\right) = 1.03 \times 10^5 \text{ Pa}$$

This is the pressure at the top of the water. To find the absolute pressure at the bottom, we use $P_2 = P_1 + \rho_{\text{water}}\, g h_{\text{water}}$, or

$$P_2 = 1.03 \times 10^5 \text{ Pa} + \left(10^3 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)\left(0.200 \text{ m}\right) = \boxed{1.05 \times 10^5 \text{ Pa}}$$

9.26 (a) If we assume a vacuum $(P = 0)$ inside the tube above the wine column and atmospheric pressure at the base of the column (that is, at the level of the wine in the open container), we start at the top of the liquid in the tube and calculate the pressure at depth h in the wine as $P_{\text{atmo}} = 0 + \rho g h = \rho g h$. Thus,

$$h = \frac{P_{\text{atmo}}}{\rho g} = \frac{1.013 \times 10^5 \text{ Pa}}{\left(984 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)} = \boxed{10.5 \text{ m}}$$

(b) $\boxed{\text{No.}}$ Since water and alcohol are more volatile than mercury, more liquid will evaporate and degrade the vacuum above the liquid column inside the tube of this barometer.

9.27 Pascal's principle, $F_1/A_1 = F_2/A_2$, or $F_{\text{pedal}}\big/A_{\substack{\text{Master}\\ \text{cylinder}}} = F_{\text{brake}}\big/A_{\substack{\text{brake}\\ \text{cylinder}}}$, gives

$$F_{\text{brake}} = \left(\frac{A_{\text{brake cylinder}}}{A_{\text{master cylinder}}}\right) F_{\text{pedal}}$$

This is the normal force exerted on the brake shoe. The frictional force is

$$f = \mu_k n = 0.50\,F_{\text{brake}} = 0.50\left(\frac{6.4\ \text{cm}^2}{1.8\ \text{cm}^2}\right)(44\ \text{N}) = 78\ \text{N}$$

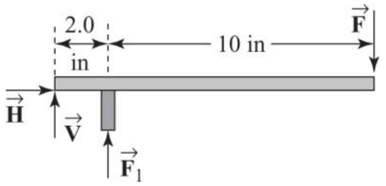
and the torque is

$$\tau = f \cdot r_{\text{drum}} = (78\ \text{N})(0.34\ \text{m}) = \boxed{27\ \text{N}\cdot\text{m}}$$

9.28 First, use Pascal's principle, $F_1/A_1 = F_2/A_2$, to find the force piston 1 will exert on the handle when a 500-lb force pushes downward on piston 2.

$$F_1 = \left(\frac{A_1}{A_2}\right)F_2 = \left(\frac{\pi\, d_1^2/4}{\pi\, d_2^2/4}\right)F_2 = \left(\frac{d_1^2}{d_2^2}\right)F_2$$

$$= \frac{(0.25\ \text{in})^2}{(1.5\ \text{in})^2}(500\ \text{lb}) = 14\ \text{lb}$$



Free-Body Diagram of Handle

Now, consider an axis perpendicular to the page, passing through the left end of the jack handle. $\Sigma\tau = 0$ yields

$$+(14\ \text{lb})(2.0\ \text{in}) - F\cdot(12\ \text{in}) = 0, \qquad \text{or} \qquad F = \boxed{2.3\ \text{lb}}$$

9.29 When held underwater, the ball will have three forces acting on it: a downward gravitational force, $mg = \rho_{\text{ball}} V g = \rho_{\text{ball}}\left(4\pi r^3/3\right)g$; an upward buoyant force, $B = \rho_{\text{water}} V g = \rho_{\text{water}}\left(4\pi r^3/3\right)g$; and an applied force, F. If the ball is to be in equilibrium, we have (taking upward as positive)

$$\Sigma F_y = F + B - mg = 0$$

or $$F = mg - B = \left[\rho_{\text{ball}}\left(\frac{4\pi r^3}{3}\right)\right]g - \rho_{\text{water}}\left(\frac{4\pi r^3}{3}\right)g = \left(\rho_{\text{ball}} - \rho_{\text{water}}\right)\left(\frac{4\pi r^3}{3}\right)g$$

giving

$$F = \left[\left(0.084\,0 - 1.00\right)\times 10^3\ \text{kg/m}^3\right]\frac{4\pi}{3}\left(\frac{0.038\,0\ \text{m}}{2}\right)^3\left(9.80\ \text{m/s}^2\right)$$
$$= -0.258\ \text{N}$$

so the required applied force is $\boxed{\vec{\mathbf{F}} = 0.258\ \text{N directed downward}}$.

9.30 (a) To float, the buoyant force acting on the person must equal the weight of that person, or the weight of the water displaced by the person must equal the person's own weight. Thus,

$$B = mg \quad \Rightarrow \quad \left(\rho_{\text{sea}} V_{\text{submerged}}\right)g = \left(\rho_{\text{body}}\, g V_{\text{total}}\right)g \qquad \text{or} \qquad \frac{V_{\text{submerged}}}{V_{\text{total}}} = \frac{\rho_{\text{body}}}{\rho_{\text{sea}}}$$

After inhaling,

$$\frac{V_{\text{submerged}}}{V_{\text{total}}} = \frac{945\ \text{kg/m}^3}{1\,230\ \text{kg/m}^3} = 0.768 = 76.8\%$$

leaving $\boxed{23.2\% \text{ above surface}}$

After exhaling,

$$\frac{V_{\text{submerged}}}{V_{\text{total}}} = \frac{1\,020\ \text{kg/m}^3}{1\,230\ \text{kg/m}^3} = 0.829 = 82.9\%$$

leaving $\boxed{17.1\% \text{ above surface}}$

(b) In general, “sinkers” would be expected to be thinner with heavier bones, whereas “floaters” would have lighter bones and more fat.

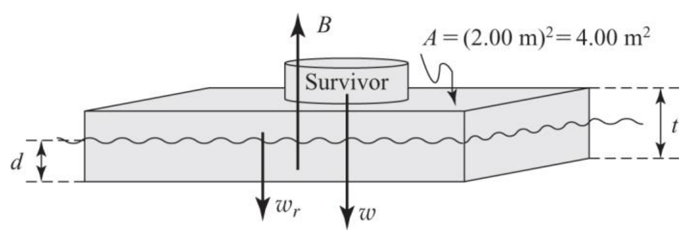
9.31 The boat sinks until the weight of the additional water displaced equals the weight of the truck. Thus,

$$w_{\text{truck}} = \left[\rho_{\text{water}}(\Delta V)\right]g$$

$$= \left(10^3\ \frac{\text{kg}}{\text{m}^3}\right)\left[(4.00\ \text{m})(6.00\ \text{m})\left(4.00\times10^{-2}\ \text{m}\right)\right]\left(9.80\ \frac{\text{m}}{\text{s}^2}\right),$$

or $w_{\text{truck}} = 9.41\times10^3\ \text{N} = \boxed{9.41\ \text{kN}}$

9.32 (a)



(b) Since the system is in equilibrium, $\boxed{\Sigma F_y = B - w - w_r = 0}$

(c) $B = \rho_w g V_{\text{submerged}} = \rho_w g\left(d \cdot A\right)$

$$= \left(1\,025\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(0.024\,0\ \text{m}\right)\left(4.00\ \text{m}^2\right) = \boxed{964\ \text{N}}$$

(d) From $B - w - w_r = 0$,

$$w_r = B - w = B - mg = 964\ \text{N} - \left(62.0\ \text{kg}\right)\left(9.80\ \text{m/s}^2\right) = \boxed{356\ \text{N}}$$

(e) $$\rho_{\text{foam}} = \frac{m_r}{V_r} = \frac{w_r/g}{t \cdot A} = \frac{356\ \text{N}}{\left(9.80\ \text{m/s}^2\right)\left(0.090\ \text{m}\right)\left(4.00\ \text{m}^2\right)} = \boxed{101\ \text{kg/m}^3}$$

(f) $B_{\max} = \rho_w g V_r = \rho_w g\left(t \cdot A\right)$

$$= \left(1\,025\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(0.090\,0\ \text{m}\right)\left(4.00\ \text{m}^2\right) = \boxed{3.62 \times 10^3\ \text{N}}$$

(g) The maximum weight of survivors the raft can support is $w_{\max} = m_{\max} g = B_{\max} - w_r$, so

$$m_{\max} = \frac{B_{\max} - w_r}{g} = \frac{3.62 \times 10^3\ \text{N} - 356\ \text{N}}{9.80\ \text{m/s}^2} = \boxed{333\ \text{kg}}$$

9.33 (a) While the system floats, $B = w_{\text{total}} = w_{\text{block}} + w_{\text{steel}}$, or

$$\rho_{\text{wood}} \not{g} V_{\text{submerged}} = \rho_{\text{block}} \not{g} V_{\text{block}} + m_{\text{steel}} \not{g}$$

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

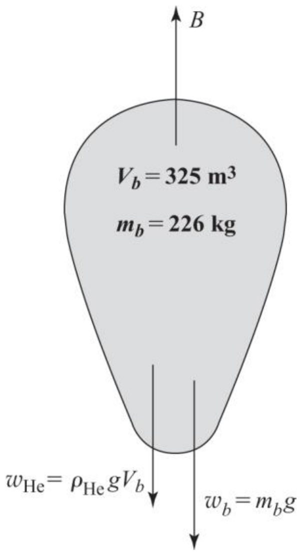
$$\rho_{\text{block}} = \frac{\rho_{\text{wood}} V_{\text{block}} - m_{\text{steel}}}{V_{\text{block}}} = \rho_{\text{wood}} - \frac{m_{\text{steel}}}{V_{\text{block}}}$$

$$= 1.00 \times 10^3\ \text{kg/m}^3 - \frac{0.310\ \text{kg}}{5.24 \times 10^{-4}\ \text{m}^3} = \boxed{408\ \text{kg/m}^3}$$

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

The block is fully submerged when $m_{\text{steel}} = 0.310\ \text{kg}$. The mass of the steel object can increase slightly above this value without causing it and the block to sink to the bottom. As the mass of the steel object is gradually increased above 0.310 kg, the steel object begins to submerge, displacing additional water, and providing a slight increase in the buoyant force. With a density of about eight times that of water, the steel object will be able to displace approximately $0.310\ \text{kg}/8 = 0.039\ \text{kg}$ of additional water before it becomes fully submerged. At this point, the steel object will have a mass of about 0.349 kg and will be unable to displace any additional water. Any further increase in the mass of the object causes it and the block to sink to the bottom. In conclusion, $\boxed{\text{the block + steel system will sink if } m_{\text{steel}} \geq 0.350\ \text{kg.}}$

9.34 (a)



(b) Since the balloon is fully submerged in air, $V_{\text{submerged}} = V_b = 325\ \text{m}^3$, and

$$B = \rho_{\text{air}} g V_b = \left(1.29\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(325\ \text{m}^3\right) = \boxed{4.11\times10^3\ \text{N}}$$

(c) $\Sigma F_y = B - w_b - w_{\text{He}} = B - m_b g - \rho_{\text{He}} g V_b = B - \left(m_b + \rho_{\text{He}} V_b\right) g$

$$= 4.11\times10^3\ \text{N} - \left[226\ \text{kg} + \left(0.179\ \text{kg/m}^3\right)\left(325\ \text{m}^3\right)\right]\left(9.80\ \text{m/s}^2\right) = \boxed{+1.33\times10^3\ \text{N}}$$

Since $\Sigma F_y = ma_y > 0$, a_y will be positive (upward), and $\boxed{\text{the balloon rises}}$.

(d) If the balloon and load are in equilibrium, $\Sigma F_y = \left(B - w_b - w_{\text{He}}\right) - w_{\text{load}} = 0$ and

$w_{\text{load}} = \left(B - w_b - w_{\text{He}}\right) = 1.33\times10^3$ N. Thus, the mass of the load is

$$m_{\text{load}} = \frac{w_{\text{load}}}{g} = \frac{1.33\times10^3\ \text{N}}{9.80\ \text{m/s}^2} = \boxed{136\ \text{kg}}$$

(e) If $m_{\text{load}} < 136$ kg, the net force acting on the balloon+load system is upward and

$\boxed{\text{the balloon and its load will accelerate upward}}$.

(f) $\boxed{\text{As the balloon rises, decreasing atmospheric density decreases the buoyancy force.}}$ At some height the balloon will come to equilibrium and go no higher.

9.35 (a) $B = \rho_{\text{air}} g V_{\text{balloon}} = \rho_{\text{air}} g \left(\dfrac{4\pi r^3}{3}\right) = \left(1.29\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(\dfrac{4\pi}{3}\right)\left(3.00\ \text{m}\right)^3$

$$= 1.43\times10^3\ \text{N} = \boxed{1.43\ \text{kN}}$$

(b) $\Sigma F_y = B - w_{\text{total}} = 1.43\times10^3\ \text{N} - \left(15.0\ \text{kg}\right)\left(9.80\ \text{m/s}^2\right)$

$$= +1.28\times10^3\ \text{N} = \boxed{1.28\ \text{kN upward}}$$

(c) The balloon expands as it rises because the external pressure (atmospheric pressure) decreases with increasing altitude.

9.36 (a) Taking upward as positive, $\Sigma F_y = B - mg = ma_y$, or $\boxed{ma_y = \rho_w g V - mg}$.

(b) Since $m = \rho V$, we have $\rho \cancel{V} a_y = \rho_w g \cancel{V} - \rho \cancel{V} g$

or $$\boxed{a_y = \left(\frac{\rho_w}{\rho} - 1\right) g}$$

(c) $a_y = \left(\dfrac{1.00 \times 10^3 \text{ m/kg}^3}{1\,050 \text{ m/kg}^3} - 1\right)\left(9.80 \text{ m/s}^2\right) = \boxed{-0.467 \text{ m/s}^2 = 0.467 \text{ m/s}^2 \text{ downward}}$

(d) From $\Delta y = v_{0y} t + a_y t^2/2$, with $v_{0y} = 0$, we find

$$t = \sqrt{\frac{2(\Delta y)}{a_y}} = \sqrt{\frac{2(-8.00 \text{ m})}{-0.467 \text{ m/s}^2}} = \boxed{5.85 \text{ s}}$$

9.37 (a) $B_{\text{total}} = 600 \cdot B_{\substack{\text{single}\\\text{balloon}}} = 600\left(\rho_{\text{air}} g V_{\text{balloon}}\right) = 600\left[\rho_{\text{air}} g \left(\dfrac{4\pi}{3} r^3\right)\right]$

$$= 600\left[\left(1.29 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)\frac{4\pi}{3}(0.50 \text{ m})^3\right] = 4.0 \times 10^3 \text{ N} = \boxed{4.0 \text{ kN}}$$

(b) $\Sigma F_y = B_{\text{total}} - m_{\text{total}} g = 4.0 \times 10^3 \text{ N} - 600(0.30 \text{ kg})\left(9.8 \text{ m/s}^2\right) = 2.2 \times 10^3 \text{ N} = \boxed{2.2 \text{ kN}}$

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

9.38 The actual weight of the object is $F_{g,\text{ actual}} = m_{\text{object}}g = 5.00\text{ N}$, and its mass is $m_{\text{object}} = 5.00\text{ N}/g$. When fully submerged, the upward buoyant force (equal to the weight of the displaced water) and the upward force exerted on the object by the scale $\left(F_{g,\text{ apparent}} = 3.50\text{ N}\right)$ together support the actual weight of the object. That is,

$$\Sigma F_y = 0 \quad \Rightarrow \quad B + F_{g,\text{ apparent}} - F_{g,\text{ actual}} = 0$$

and $$B = F_{g,\text{ actual}} - F_{g,\text{ apparent}} = 5.00\text{ N} - 3.50\text{ N} = 1.50\text{ N}$$

Thus, $B = \rho_{\text{water}} g V_{\text{object}}$ gives $V_{\text{object}} = B/\left(\rho_{\text{water}} g\right)$ and the density of the object is

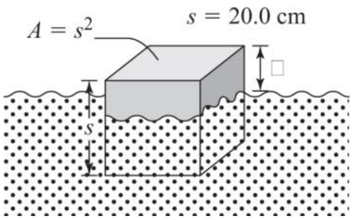
$$\rho_{\text{object}} = \frac{m_{\text{object}}}{V_{\text{object}}} = \left(\frac{5.00\text{ N}}{g}\right)\left(\frac{\rho_{\text{water}} g}{1.50\text{ N}}\right) = 3.33\rho_{\text{water}} = \boxed{3.33\times10^3\ \text{kg/m}^3}$$

9.39 (a) The wooden block sinks until the buoyant force (weight of the displaced water) equals the weight of the block. That is, when equilibrium is reached,

$$B = \rho_{\text{water}} g\left[(s-h)s^2\right] = \rho_{\text{wood}} g \cdot s^3\text{, giving}$$

$$s - h = \left(\frac{\rho_{\text{wood}}}{\rho_{\text{water}}}\right)\cdot s$$

or $$h = s\cdot\left(1 - \frac{\rho_{\text{wood}}}{\rho_{\text{water}}}\right) = (20.0\text{ cm})\left(1 - \frac{650\ \text{kg/m}^3}{1000\ \text{kg/m}^3}\right) = \boxed{7.00\text{ cm}}$$



(b) When the upper surface of the block is level with the water surface, the buoyant force is

$$B = \rho_{\text{water}} g V_{\text{block}} = \rho_{\text{water}} g \cdot s^3$$

This must equal the weight of the block plus the weight of the added lead, or $m_{\text{Pb}} g + m_{\text{block}} g = B$, and

$$m_{\text{Pb}} = \frac{B}{g} - m_{\text{block}} = \rho_{\text{water}} V_{\text{block}} - \rho_{\text{wood}} V_{\text{block}} = \left(\rho_{\text{water}} - \rho_{\text{wood}}\right) \cdot s^3$$

giving $m_{\text{Pb}} = \left(1000 \text{ kg/m}^3 - 650 \text{ kg/m}^3\right)(0.200 \text{ m})^3 = \boxed{2.80 \text{ kg}}$

9.40 At equilibrium, $\Sigma F_y = B - F_{\text{spring}} - mg = 0$, so the spring force is $F_{\text{spring}} = B - mg = \left[\left(\rho_{\text{water}} V_{\text{block}}\right) - m\right] g$, where

$$V_{\text{block}} = \frac{m}{\rho_{\text{wood}}} = \frac{5.00 \text{ kg}}{650 \text{ kg/m}^3} = 7.69 \times 10^{-3} \text{ m}^3$$

Thus, $F_{\text{spring}} = \left[\left(10^3 \text{ kg/m}^3\right)\left(7.69 \times 10^{-3} \text{ m}^3\right) - 5.00 \text{ kg}\right]\left(9.80 \text{ m/s}^2\right) = 26.4 \text{ N}.$

The elongation of the spring is then

$$\Delta x = \frac{F_{\text{spring}}}{k} = \frac{26.4 \text{ N}}{160 \text{ N/m}} = 0.165 \text{ m} = \boxed{16.5 \text{ cm}}$$

9.41 (a) The buoyant force is the difference between the weight in air and the apparent weight when immersed in the alcohol, or $B = 300\text{ N} - 200\text{ N} = 100\text{ N}$. But, from Archimedes' principle, this is also the weight of the displaced alcohol, so $B = (\rho_{\text{alcohol}} V)g$. Since the sample is fully submerged, the volume of the displaced alcohol is the same as the volume of the sample. This volume is

$$V = \frac{B}{\rho_{\text{alcohol}}\, g} = \frac{100\text{ N}}{(700\text{ kg/m}^3)(9.80\text{ m/s}^2)} = \boxed{1.46 \times 10^{-2}\text{ m}^3}$$

(b) The mass of the sample is

$$m = \frac{\textit{weight in air}}{g} = \frac{300\text{ N}}{9.80\text{ m/s}^2} = 30.6\text{ kg}$$

and its density is

$$\rho = \frac{m}{V} = \frac{30.6\text{ kg}}{1.46 \times 10^{-2}\text{ m}^3} = \boxed{2.10 \times 10^3\text{ kg/m}^3}$$

9.42 The difference between the weight in air and the apparent weight when immersed is the buoyant force exerted on the object by the fluid.

(a) The mass of the object is

$$m = \frac{\textit{weight in air}}{g} = \frac{300\text{ N}}{9.80\text{ m/s}^2} = 30.6\text{ kg}$$

The buoyant force when immersed in water is the weight of a volume of water equal to the volume of the object, or $B_{\text{water}} = (\rho_{\text{water}} V)g$. Thus, the volume of the object is

$$V = \frac{B_{\text{water}}}{\rho_{\text{water}}\, g} = \frac{300\text{ N} - 265\text{ N}}{(10^3\text{ kg/m}^3)(9.80\text{ m/s}^2)} = 3.57 \times 10^{-3}\text{ m}^3$$

and its density is

$$\rho_{\text{object}} = \frac{m}{V} = \frac{30.6 \text{ kg}}{3.57 \times 10^{-3} \text{ m}^3} = \boxed{8.57 \times 10^3 \text{ kg/m}^3}$$

(b) The buoyant force when immersed in oil is equal to the weight of a volume $V = 3.57 \times 10^{-3} \text{ m}^3$ of oil. Hence, $B_{\text{oil}} = (\rho_{\text{oil}} V)g$, or the density of the oil is

$$\rho_{\text{oil}} = \frac{B_{\text{oil}}}{Vg} = \frac{300 \text{ N} - 275 \text{ N}}{(3.57 \times 10^{-3} \text{ m}^3)(9.80 \text{ m/s}^2)} = \boxed{715 \text{ kg/m}^3}$$

9.43 The volume of the iron block is

$$V = \frac{m_{\text{iron}}}{\rho_{\text{iron}}} = \frac{2.00 \text{ kg}}{7.86 \times 10^3 \text{ kg/m}^3} = 2.54 \times 10^{-4} \text{ m}^3$$

and the buoyant force exerted on the iron by the oil is

$$B = (\rho_{\text{oil}} V)g = (916 \text{ kg/m}^3)(2.54 \times 10^{-4} \text{ m}^3)(9.80 \text{ m/s}^2) = 2.28 \text{ N}$$

Applying $\Sigma F_y = 0$ to the iron block gives the support force exerted by the upper scale (and hence the reading on that scale) as

$$F_{\text{upper}} = m_{\text{iron}} g - B = 19.6 \text{ N} - 2.28 \text{ N} = \boxed{17.3 \text{ N}}$$

From Newton's third law, the iron exerts force B downward on the oil (and hence the beaker). Applying $\Sigma F_y = 0$ to the system consisting of the beaker and the oil gives

$$F_{\text{lower}} - B - \left(m_{\text{oil}} + m_{\text{beaker}}\right)g = 0$$

The support force exerted by the lower scale (and the lower scale reading) is then

$$F_{\text{lower}} = B + \left(m_{\text{oil}} + m_{\text{beaker}}\right)g = 2.28\ \text{N} + \left[(2.00 + 1.00)\ \text{kg}\right]\left(9.80\ \text{m/s}^2\right) = \boxed{31.7\ \text{N}}$$

9.44 (a) The cross-sectional area of the hose is $A = \pi r^2 = \pi d^2/4 = \pi(2.74\ \text{cm})^2/4$, and the volume flow rate (volume per unit time) is $Av = 25.0\ \text{L}/1.50\ \text{min}$. Thus,

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

$$= (47.1\ \text{cm/s})\left(\frac{1\ \text{m}}{10^2\ \text{cm}}\right) = \boxed{0.471\ \text{m/s}}$$

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

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

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

9.45 (a) The volume flow rate is Av, and the mass flow rate is

$$\rho A v = \left(1.0\ \text{g/cm}^3\right)\left(2.0\ \text{cm}^2\right)\left(40\ \text{cm/s}\right) = \boxed{80\ \text{g/s}}$$

(b) From the equation of continuity, the speed in the capillaries is

$$v_{\text{capiliaries}} = \left(\frac{A_{\text{aorta}}}{A_{\text{capillaries}}}\right) v_{\text{aorta}} = \left(\frac{2.0\ \text{cm}^2}{3.0\times 10^3\ \text{cm}^2}\right)\left(40\ \text{cm/s}\right)$$

or $$v_{\text{capiliaries}} = 2.7\times 10^{-2}\ \text{cm/s} = \boxed{0.27\ \text{mm/s}}$$

9.46 (a) From the equation of continuity, the flow speed in the second section of the pipe is

$$v_2 = \left(\frac{A_1}{A_2}\right) v_1 = \left(\frac{10.0\ \text{cm}^2}{2.50\ \text{cm}^2}\right)\left(2.75\ \text{m/s}\right) = \boxed{11.0\ \text{m/s}}$$

(b) Using Bernoulli's equation and choosing $y = 0$ along the centerline of the pipe gives

$$P_2 = P_1 + \frac{1}{2}\rho\left(v_1^2 - v_2^2\right)$$

$$= 1.20\times 10^5\ \text{Pa} + \frac{1}{2}\left(1.65\times 10^3\ \text{kg/m}^3\right)\left[\left(2.75\ \text{m/s}\right)^2 - \left(11.0\ \text{m/s}\right)^2\right]$$

or $$P_2 = \boxed{2.64\times 10^4\ \text{Pa}}$$

9.47 From Bernoulli's equation, choosing $y = 0$ at the level of the syringe and needle, $P_2 + \frac{1}{2}\rho v_2^2 = P_1 + \frac{1}{2}\rho v_1^2$, so the flow speed in the needle is

$$v_2 = \sqrt{v_1^2 + \frac{2(P_1 - P_2)}{\rho}}$$

In this situation,

$$P_1 - P_2 = P_1 - P_{\text{atm}} = (P_1)_{\text{gauge}} = \frac{F}{A_1} = \frac{2.00\ \text{N}}{2.50 \times 10^{-5}\ \text{m}^2} = 8.00 \times 10^4\ \text{Pa}$$

Thus, assuming $v_1 \approx 0$,

$$v_2 = \sqrt{0 + \frac{2(8.00 \times 10^4\ \text{Pa})}{1.00 \times 10^3\ \text{kg/m}^3}} = \boxed{12.6\ \text{m/s}}$$

9.48 We apply Bernoulli's equation, ignoring the very small change in vertical position, to obtain

$P_1 - P_2 = \frac{1}{2}\rho\left(v_2^2 - v_1^2\right) = \frac{1}{2}\rho\left[(2v_1)^2 - v_1^2\right] = \frac{3}{2}\rho v_1^2$, or

$$\Delta P = \frac{3}{2}(1.29\ \text{kg/m}^3)(15 \times 10^{-2}\ \text{m/s})^2 = \boxed{4.4 \times 10^{-2}\ \text{Pa}}$$

9.49 (a) Assuming the airplane is in level flight, the net lift (the difference in the upward and downward forces exerted on the wings by the air flowing over them) must equal the weight of the plane, or $(P_{\substack{\text{lower}\\\text{surface}}} - P_{\substack{\text{upper}\\\text{surface}}})A_{\text{wings}} = mg$. This yields

$$P_{\substack{\text{lower}\\\text{surface}}} - P_{\substack{\text{upper}\\\text{surface}}} = \frac{mg}{A_{\text{wings}}} = \frac{\left(8.66\times10^{4}\text{ kg}\right)\left(9.80\text{ m/s}^2\right)}{90.0\text{ m}^2} = \boxed{9.43\times10^{3}\text{ Pa}}$$

(b) Neglecting the small difference in altitude between the upper and lower surfaces of the wings, and applying Bernoulli's equation, yields

$$P_{\text{lower}} + \frac{1}{2}\rho_{\text{air}}v_{\text{lower}}^2 = P_{\text{upper}} + \frac{1}{2}\rho_{\text{air}}v_{\text{upper}}^2$$

so $$v_{\text{upper}} = \sqrt{v_{\text{lower}}^2 + \frac{2\left(P_{\text{lower}} - P_{\text{upper}}\right)}{\rho_{\text{air}}}} = \sqrt{\left(225\text{ m/s}\right)^2 + \frac{2\left(9.43\times10^{3}\text{ Pa}\right)}{1.29\text{ kg/m}^3}} = \boxed{255\text{ m/s}}$$

(c) $\boxed{\text{The density of air decreases with increasing height}}$, resulting in a smaller pressure difference, $\Delta P = \frac{1}{2}\rho_{\text{air}}(v_{\text{upper}}^2 - v_{\text{lower}}^2)$. Beyond the maximum operational altitude, the pressure difference can no longer support the aircraft.

9.50 For level flight, the net lift (difference between the upward and downward forces exerted on the wing surfaces by air flowing over them) must equal the weight of the aircraft, or $(P_{\substack{\text{lower}\\\text{surface}}} - P_{\substack{\text{upper}\\\text{surface}}})A_{\text{wings}} = Mg$. This gives the air pressure at the upper surface as $\boxed{P_{\substack{\text{upper}\\\text{surface}}} = P_{\substack{\text{lower}\\\text{surface}}} - Mg/A_{\text{wings}}}$.

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

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

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

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

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

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

(d) The pressure at the nozzle is atmospheric pressure, or $\boxed{P_2 = 1.013 \times 10^5 \text{ Pa}}$.

(e) With the two cylinders horizontal, $y_1 \approx y_2$ and gravity terms from Bernoulli's equation $\boxed{\text{can be neglected}}$, leaving $P_1 + \rho_{\text{water}} v_1^2/2 = P_2 + \rho_{\text{water}} v_2^2/2$, so the needed pressure in the larger cylinder is

$$P_1 = P_2 + \frac{\rho_{\text{water}}}{2}\left(v_2^2 - v_1^2\right)$$

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

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

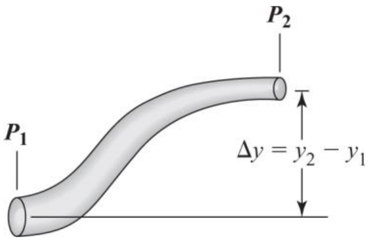
(f) To create an overpressure of $\Delta P = 2.06\times10^5\ \text{Pa} - 1.013\times10^5\ \text{Pa} = 1.05\times10^5\ \text{Pa}$ in the larger cylinder, the force that must be exerted on the piston is

$$F_1 = (\Delta P)A_1 = (\Delta P)\left(\pi r_1^2\right) = \left(1.05\times10^5\ \text{Pa}\right)\pi\left(1.00\times10^{-2}\ \text{m}\right)^2 = \boxed{33.0\ \text{N}}$$

9.52 (a) From Bernoulli's equation,

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

or $$v_2^2 - v_1^2 = 2\left[\frac{P_1 - P_2}{\rho_{\text{water}}} - g\left(y_2 - y_1\right)\right]$$



and using the given data values, we obtain

$$v_2^2 - v_1^2 = 2\left[\frac{1.75\times10^5\ \text{Pa} - 1.20\times10^5\ \text{Pa}}{1.00\times10^3\ \text{kg/m}^3} - \left(9.80\ \text{m/s}^2\right)\left(2.50\ \text{m}\right)\right]$$

and $v_2^2 - v_1^2 = 61.0\ \text{m}^2/\text{s}^2$ **[1]**

From the equation of continuity,

$$v_2 = \left(\frac{A_1}{A_2}\right)v_1 = \left(\frac{\pi r_1^2}{\pi r_2^2}\right)v_1 = \left(\frac{r_1}{r_2}\right)^2 v_1 = \left(\frac{3.00\text{ cm}}{1.50\text{ cm}}\right)^2 v_1$$

or $\quad v_2 = 4v_1$ **[2]**

Substituting Equation [2] into [1] gives $(16-1)v_1^2 = 61.0\text{ m}^2/\text{s}^2$, or

$$v_1 = \sqrt{\frac{61.0\text{ m}^2/\text{s}^2}{15}} = \boxed{2.02\text{ m/s}}$$

(b) Equation [2] above now yields $v_2 = 4(2.02\text{ m/s}) = \boxed{8.08\text{ m/s}}$.

(c) The volume flow rate through the pipe is $flow\ rate = A_1 v_1 = A_2 v_2$

Looking at the lower point:

$$flow\ rate = (\pi r_1^2)v_1 = \pi(3.00\times10^{-2}\text{ m})^2(2.02\text{ m/s}) = \boxed{5.71\times10^{-3}\text{ m}^3/\text{s}}$$

9.53 First, consider the path from the viewpoint of projectile motion to find the speed at which the water emerges from the tank. From $\Delta y = v_{0y}t + \frac{1}{2}a_y t^2$ with $v_{0y} = 0$, $\Delta y = -1.00\text{ m}$, and $a_y = -g$, we find the time of flight as

$$t = \sqrt{\frac{2(\Delta y)}{a_y}} = \sqrt{\frac{2.00\text{ m}}{g}}$$

From the horizontal motion, the speed of the water coming out of the hole is

$$v_2 = v_{0x} = \frac{\Delta x}{t} = (0.600\ \text{m})\sqrt{\frac{g}{2.00\ \text{m}}} = \sqrt{\frac{(0.600\ \text{m})^2 g}{2.00\ \text{m}}} = \sqrt{(1.80 \times 10^{-1}\ \text{m})g}$$

We now use Bernoulli's equation, with point 1 at the top of the tank and point 2 at the level of the hole. With $P_1 = P_2 = P_{\text{atm}}$ and $v_1 \approx 0$, this gives $\rho g y_1 = \frac{1}{2}\rho v_2^2 + \rho g y_2$, or

$$h = y_1 - y_2 = \frac{v_2^2}{2g} = \frac{(1.80 \times 10^{-1}\ \text{m})g}{2g} = 9.00 \times 10^{-2}\ \text{m} = \boxed{9.00\ \text{cm}}$$

9.54 (a) Apply Bernoulli's equation with point 1 at the open top of the tank and point 2 at the opening of the hole. Then, $P_1 = P_2 = P_{\text{atm}}$ and we assume $v_1 \approx 0$. This gives $\frac{1}{2}\rho v_2^2 + \rho g y_2 = \rho g y_1$, or

$$v_2 = \sqrt{2g(y_1 - y_2)} = \sqrt{2(9.80\ \text{m/s}^2)(16.0\ \text{m})} = \boxed{17.7\ \text{m/s}}$$

(b) The area of the hole is found from

$$A_2 = \frac{\textit{flow rate}}{v_2} = \frac{2.50 \times 10^{-3}\ \text{m}^3/\text{min}}{17.7\ \text{m/s}}\left(\frac{1\ \text{min}}{60\ \text{s}}\right) = 2.35 \times 10^{-6}\ \text{m}^2$$

But, $A_2 = \pi d_2^2/4$ and the diameter of the hole must be

$$d_2 = \sqrt{\frac{4A_2}{\pi}} = \sqrt{\frac{4(2.35 \times 10^{-6}\ \text{m}^2)}{\pi}} = 1.73 \times 10^{-3}\ \text{m} = \boxed{1.73\ \text{mm}}$$

9.55 First, determine the flow speed inside the larger section from

$$v_1 = \frac{\textit{flow rate}}{A_1} = \frac{1.80\times10^{-4}\ \text{m}^3/\text{s}}{\pi\left(2.50\times10^{-2}\ \text{m}\right)^2/4} = 0.367\ \text{m/s}$$

The absolute pressure inside the large section on the left is $P_1 = P_{\text{atm}} + \rho g h_1$, where h_1 is the height of the water in the leftmost standpipe. The absolute pressure in the constriction is $P_2 = P_{\text{atm}} + \rho g h_2$, so

$$P_1 - P_2 = \rho g\left(h_1 - h_2\right) = \rho g\left(5.00\ \text{cm}\right)$$

The flow speed inside the constriction is found from Bernoulli's equation with $y_1 = y_2$ (since the pipe is horizontal). This gives

$$v_2^2 = v_1^2 + \frac{2}{\rho}\left(P_1 - P_2\right) = v_1^2 + 2\,g\left(h_1 - h_2\right)$$

or $$v_2 = \sqrt{\left(0.367\ \text{m/s}\right)^2 + 2\left(9.80\ \text{m/s}\right)\left(5.00\times10^{-2}\ \text{m}\right)} = 1.06\ \text{m/s}$$

The cross-sectional area of the constriction is then

$$A_2 = \frac{\textit{flow rate}}{v_2} = \frac{1.80\times10^{-4}\ \text{m}^3/\text{s}}{1.06\ \text{m/s}} = 1.70\times10^{-4}\ \text{m}^2$$

and the diameter is

$$d_2 = \sqrt{\frac{4\,A_2}{\pi}} = \sqrt{\frac{4\left(1.70\times10^{-4}\ \text{m}^2\right)}{\pi}} = 1.47\times10^{-2}\ \text{m} = \boxed{1.47\ \text{cm}}$$

9.56 (a) For minimum input pressure so the water will just reach the level of the rim, the gauge pressure at the upper end is zero (i.e., the absolute pressure inside the upper end of the pipe is atmospheric pressure), and the flow rate is zero. Thus, Bernoulli's equation, $\left(P+\frac{1}{2}\rho v^2+\rho g y\right)_{\text{river}}=\left(P+\frac{1}{2}\rho v^2+\rho g y\right)_{\text{rim}}$, becomes

$$\left(P_{\text{river}}\right)_{\min}+0=1\text{ atm}+0+\rho g\left(y_{\text{rim}}-y_{\text{river}}\right)=1\text{ atm}+\rho g\left(y_{\text{rim}}-y_{\text{river}}\right) \qquad \textbf{[1]}$$

or, $$\left(P_{\text{river}}\right)_{\min}=1.013\times10^5\text{ Pa}+\left(10^3\ \frac{\text{kg}}{\text{m}^3}\right)\left(9.80\ \frac{\text{m}}{\text{s}^2}\right)(2096\text{ m}-564\text{ m})$$

$$\left(P_{\text{river}}\right)_{\min}=\left(1.013\times10^5+1.50\times10^7\right)\text{ Pa}=1.51\times10^7\text{ Pa}=\boxed{15.1\text{ MPa}}$$

(b) When volume flow rate is

$$\textit{flow rate}=Av=\left(\frac{\pi d^2}{4}\right)v=4\,500\ \text{m}^3/\text{d}$$

the velocity in the pipe is

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

(c) We imagine the pressure being applied to stationary water at river level, so Bernoulli's equation becomes

$$P_{\text{river}}+0=\left[1\text{ atm}+\rho g\left(y_{\text{rim}}-y_{\text{river}}\right)\right]+\frac{1}{2}\rho v_{\text{rim}}^2$$

or, using Equation [1] from above,

$$P_{\text{river}} = \left(P_{\text{river}}\right)_{\min} + \frac{1}{2}\rho v_{\text{rim}}^2 = \left(P_{\text{river}}\right)_{\min} + \frac{1}{2}\left(10^3\ \frac{\text{kg}}{\text{m3}}\right)\left(2.95\ \frac{\text{m}}{\text{s}}\right)^2$$

$$= \left(P_{\text{river}}\right)_{\min} + 4.35\ \text{kPa}$$

The additional pressure required to achieve the desired flow rate is

$$\Delta P = \boxed{4.35\ \text{kPa}}$$

9.57 (a) For the upward flight of a water-drop projectile from geyser vent to fountain-top, $v_y^2 = v_{0y}^2 + 2\,a_y\left(\Delta y\right)$, with $v_y = 0$ when $\Delta y = \Delta y_{\max}$, gives

$$v_{0y} = \sqrt{0 - 2\,a_y\left(\Delta y\right)_{\max}} = \sqrt{-2\left(-9.80\ \text{m/s}^2\right)\left(40.0\ \text{m}\right)} = \boxed{28.0\ \text{m/s}}$$

(b) Because of the low density of air and the small change in altitude, atmospheric pressure at the fountain top will be considered equal to that at the geyser vent. Bernoulli's equation, with $v_{\text{top}} = 0$, then gives $\frac{1}{2}\rho\, v_{\text{vent}}^2 = 0 + \rho\, g(y_{\text{top}} - y_{\text{vent}})$, or

$$v_{\text{vent}} = \sqrt{2\,g\left(y_{\text{top}} - y_{\text{vent}}\right)} = \sqrt{2\left(9.80\ \text{m/s}^2\right)\left(40.0\ \text{m}\right)} = \boxed{28.0\ \text{m/s}}$$

(c) Between the chamber and the geyser vent, Bernoulli's equation with $v_{\text{chamber}} \approx 0$ yields

$$\left(P + 0 + \rho g y\right)_{\text{chamber}} = P_{\text{atm}} + \frac{1}{2}\rho v_{\text{vent}}^2 + \rho g\, y_{\text{vent}},\ \text{or}$$

$$P - P_{\text{atm}} = \rho\left[\frac{1}{2}v_{\text{vent}}^2 + g\left(y_{\text{vent}} - y_{\text{chamber}}\right)\right]$$

$$= \left(10^3\ \frac{\text{kg}}{\text{m}^3}\right)\left[\frac{\left(28.0\ \text{m/s}\right)^2}{2} + \left(9.80\ \frac{\text{m}}{\text{s}^2}\right)\left(175\ \text{m}\right)\right] = 2.11\times 10^6\ \text{Pa}$$

or $P_{\text{gauge}} = P - P_{\text{atm}} = \boxed{2.11\ \text{MPa}} = 20.8\ \text{atmospheres}$

9.58 (a) Since the tube is horizontal, $y_1 = y_2$ and the gravity terms in Bernoulli's equation cancel, leaving

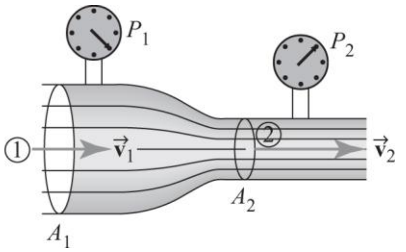
$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

or

$$v_2^2 - v_1^2 = \frac{2(P_1 - P_2)}{\rho} = \frac{2(1.20\times10^3\ \text{Pa})}{7.00\times10^2\ \text{kg/m}^3}$$

and

$$v_2^2 - v_1^2 = 3.43\ \text{m}^2/\text{s}^2 \qquad \textbf{[1]}$$



From the continuity equation, $A_1 v_1 = A_2 v_2$, we find

$$v_2 = \left(\frac{A_1}{A_2}\right)v_1 = \left(\frac{r_1}{r_2}\right)^2 v_1 = \left(\frac{2.40\ \text{cm}}{1.20\ \text{cm}}\right)^2 v_1$$

or

$$v_2 = 4v_1 \qquad \textbf{[2]}$$

Substituting Equation [2] into [1] yields $15v_1^2 = 3.43 \text{ m}^2/\text{s}^2$, and $v_1 = 0.478 \text{ m/s}$.

Then, Equation [2] gives $v_2 = 4(0.478 \text{ m/s}) = \boxed{1.91 \text{ m/s}}$.

(b) The volume flow rate is

$$A_1 v_1 = A_2 v_2 = \left(\pi r_2^2\right) v_2 = \pi\left(1.20\times10^{-2} \text{ m}\right)^2 (1.91 \text{ m/s}) = \boxed{8.64\times10^{-4} \text{ m}^3/\text{s}}$$

9.59 From $\Sigma F_y = T - mg - F_y = 0$, the balance reading is found to be $T = mg + F_y$, where F_y is the vertical component of the surface tension force. Since this is a two-sided surface, the surface tension force is $F = \gamma(2L)$ and its vertical component is $F_y = \gamma(2L)\cos\phi$, where ϕ is the contact angle. Thus, $T = mg + 2\gamma L\cos\phi$.

$$T = 0.40 \text{ N when } \phi = 0° \Rightarrow \quad mg + 2\gamma L = 0.40 \text{ N} \qquad \textbf{[1]}$$

$$T = 0.39 \text{ N when } \phi = 180° \Rightarrow \quad mg - 2\gamma L = 0.39 \text{ N} \qquad \textbf{[2]}$$

Subtracting Equation [2] from [1] gives

$$\gamma = \frac{0.40 \text{ N} - 0.39 \text{ N}}{4L} = \frac{0.40 \text{ N} - 0.39 \text{ N}}{4\left(3.0\times10^{-2} \text{ m}\right)} = \boxed{8.3\times10^{-2} \text{ N/m}}$$

9.60 Because there are two edges (the inside and outside of the ring), we have

$$\gamma = \frac{F}{L_{\text{total}}} = \frac{F}{2\,(circumference)}$$

$$= \frac{F}{4\pi r} = \frac{1.61\times10^{-2}\ \text{N}}{4\pi\left(1.75\times10^{-2}\ \text{m}\right)} = \boxed{7.32\times10^{-2}\ \text{N/m}}$$

9.61 The total vertical component of the surface tension force must equal the weight of the column of fluid, or

$F\cos\phi = \gamma(2\pi r)\cdot\cos\phi = \rho(\pi r^2)h\cdot g$. Thus,

$$\gamma = \frac{h\rho g r}{2\cos\phi} = \frac{\left(2.1\times10^{-2}\ \text{m}\right)\left(1\,080\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(5.0\times10^{-4}\ \text{m}\right)}{2\cos 0^\circ} = \boxed{5.6\times10^{-2}\ \text{N/m}}$$

9.62 The blood will rise in the capillary until the weight of the fluid column equals the total vertical component of the surface tension force, or until

$$\rho(\pi r^2)h\cdot g = F\cos\phi = \gamma(2\pi r)\cdot\cos\phi$$

This gives

$$h = \frac{2\gamma\cos\phi}{\rho g r} = \frac{2\left(0.058\ \text{N/m}\right)\cos 0^\circ}{\left(1\,050\ \text{kg/m}^2\right)\left(9.80\ \text{m/s}^2\right)\left(2.0\times10^{-6}\ \text{m}\right)} = \boxed{5.6\ \text{m}}$$

9.63 From the definition of the coefficient of viscosity, $\eta = F\,d/A\,v$, the required force is

$$F = \frac{\eta\,A\,v}{d} = \frac{\left(1.79\times10^{-3}\ \text{N}\cdot\text{s/m}^2\right)\left[\left(0.800\ \text{m}\right)\left(1.20\ \text{m}\right)\right]\left(0.50\ \text{m/s}\right)}{0.10\times10^{-3}\ \text{m}} = \boxed{8.6\ \text{N}}$$

9.64 From the definition of the coefficient of viscosity, $\eta = F\,d/A\,v$, the required force is

$$F = \frac{\eta\,A\,v}{d} = \frac{\left(1\,500\times10^{-3}\ \text{N}\cdot\text{s/m}^2\right)\left[(0.010\ \text{m})(0.040\ \text{m})\right](0.30\ \text{m/s})}{1.5\times10^{-3}\ \text{m}} = \boxed{0.12\ \text{N}}$$

9.65 Poiseuille's law gives $\textit{flow rate} = (P_1 - P_2)\pi R^4/8\eta L$, and $P_2 = P_{\text{atm}}$ in this case. Thus, the desired gauge pressure is

$$P_1 - P_{\text{atm}} = \frac{8\eta L(\textit{flow rate})}{\pi R^4} = \frac{8\left(0.12\ \text{N}\cdot\text{s/m}^2\right)(50\ \text{m})\left(8.6\times10^{-5}\ \text{m}^3/\text{s}\right)}{\pi\left(0.50\times10^{-2}\ \text{m}\right)^4}$$

or $\quad P_1 - P_{\text{atm}} = 2.1\times10^6\ \text{Pa} = \boxed{2.1\ \text{MPa}}$

9.66 From Poiseuille's law, the flow rate in the artery is

$$\textit{flow rate} = \frac{(\Delta P)\pi R^4}{8\eta L} = \frac{(400\ \text{Pa})\pi\left(2.6\times10^{-3}\ \text{m}\right)^4}{8\left(2.7\times10^{-3}\ \text{N}\cdot\text{s/m}^2\right)\left(8.4\times10^{-2}\ \text{m}\right)} = 3.2\times10^{-5}\ \text{m}^3/\text{s}$$

Thus, the flow speed is

$$v = \frac{\textit{flow rate}}{A} = \frac{3.2\times10^{-5}\ \text{m}^3/\text{s}}{\pi\left(2.6\times10^{-3}\ \text{m}\right)^2} = \boxed{1.5\ \text{m/s}}$$

9.67 If a particle is still in suspension after 1 hour, its terminal velocity must be less than

$$(v_t)_{\text{max}} = \left(5.0\ \frac{\text{cm}}{\text{h}}\right)\left(\frac{1\ \text{h}}{3\,600\ \text{s}}\right)\left(\frac{1\ \text{m}}{100\ \text{cm}}\right) = 1.4\times10^{-5}\ \text{m/s}$$

Thus, from $v_t = 2r^2 g(\rho - \rho_f)/9\eta$, we find the maximum radius of the particle:

$$r_{\text{max}} = \sqrt{\frac{9\eta_{\text{water}}(v_t)_{\text{max}}}{2g(\rho_{\text{protein}} - \rho_{\text{water}})}}$$

$$= \sqrt{\frac{9(1.00\times10^{-3}\ \text{N}\cdot\text{s/m}^2)(1.4\times10^{-5}\ \text{m/s})}{2(9.80\ \text{m/s}^2)\left[(1\,800-1\,000)\ \text{kg/m}^3\right]}} = 2.8\times10^{-6}\ \text{m} = \boxed{2.8\ \mu\text{m}}$$

9.68 From Poiseuille's law, the pressure difference required to produce a given volume flow rate of fluid with viscosity η through a tube of radius R and length L is

$$\Delta P = \frac{8\eta L(\Delta V/\Delta t)}{\pi R^4}$$

If the mass flow rate is $(\Delta m/\Delta t) = 1.0\times10^{-3}\ \text{kg/s}$, the volume flow rate of the water is

$$\frac{\Delta V}{\Delta t} = \frac{\Delta m/\Delta t}{\rho} = \frac{1.0\times10^{-3}\ \text{kg/s}}{1.0\times10^{3}\ \text{kg/m}^3} = 1.0\times10^{-6}\ \text{m}^3/\text{s}$$

and the required pressure difference is

$$\Delta P = \frac{8(1.0\times10^{-3}\ \text{Pa}\cdot\text{s})(3.0\times10^{-2}\ \text{m})(1.0\times10^{-6}\ \text{m}^3/\text{s})}{\pi(0.15\times10^{-3}\ \text{m})^4} = \boxed{1.5\times10^{5}\ \text{Pa}}$$

9.69 With the IV bag elevated 1.0 m above the needle and atmospheric pressure in the vein, the pressure difference between the input and output points of the needle is

$$\Delta P = \left(P_{\text{atm}} + \rho g h\right) - P_{\text{atm}} = \rho g h = \left(1.0\times10^{3}\ \text{kg/m}^{3}\right)\left(9.8\ \text{m/s}^{2}\right)\left(1.0\ \text{m}\right) = 9.8\times10^{3}\ \text{Pa}$$

The desired flow rate is

$$\frac{\Delta V}{\Delta t} = \frac{500\ \text{cm}^{3}\left(1\ \text{m}^{3}/10^{6}\ \text{cm}^{3}\right)}{30\ \text{min}\left(60\ \text{s}/1\ \text{min}\right)} = 2.8\times10^{-7}\ \ \text{m}^{3}/\text{s}$$

Poiseuille's law then gives the required radius of the needle as

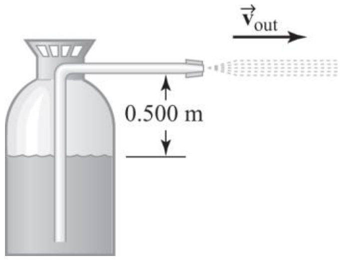
$$R = \left[\frac{8\eta L\left(\Delta V/\Delta t\right)}{\pi\left(\Delta P\right)}\right]^{1/4} = \left[\frac{8\left(1.0\times10^{-3}\ \text{Pa}\cdot\text{s}\right)\left(2.5\times10^{-2}\ \text{m}\right)\left(2.8\times10^{-7}\ \ \text{m}^{3}/\text{s}\right)}{\pi\left(9.8\times10^{3}\ \text{Pa}\right)}\right]^{1/4}$$

or $R = 2.1\times10^{-4}\ \text{m} = \boxed{0.21\ \text{mm}}$

9.70 We write Bernoulli's equation as

$$P_{\text{out}} + \tfrac{1}{2}\rho v_{\text{out}}^{2} + \rho g y_{\text{out}} = P_{\text{in}} + \tfrac{1}{2}\rho v_{\text{in}}^{2} + \rho g y_{\text{in}}$$

or $P_{\text{gauge}} = P_{\text{in}} - P_{\text{out}} = \rho\left[\tfrac{1}{2}\left(v_{\text{out}}^{2} - v_{\text{in}}^{2}\right) + g\left(y_{\text{out}} - y_{\text{in}}\right)\right]$



Approximating the speed of the fluid inside the tank as $v_{in} \approx 0$, we find

$$P_{gauge} = \left(1.00\times10^3 \text{ kg/m}^3\right)\left[\frac{1}{2}(30.0 \text{ m/s})^2 - 0 + \left(9.80 \text{ m/s}^2\right)(0.500 \text{ m})\right]$$

or $P_{gauge} = 4.55\times10^5 \text{ Pa} = \boxed{455 \text{ kPa}}$

9.71 The Reynolds number is

$$RN = \frac{\rho v d}{\eta} = \frac{\left(1\,050 \text{ kg/m}^3\right)(0.55 \text{ m/s})\left(2.0\times10^{-2} \text{ m}\right)}{2.7\times10^{-3} \text{ N}\cdot\text{s/m}^2} = 4.3\times10^3$$

In this region (*RN* > 3000), the flow is $\boxed{\text{turbulent}}$.

9.72 From the definition of the Reynolds number, the maximum flow speed for streamlined (or laminar) flow in this pipe is

$$v_{max} = \frac{\eta\cdot(RN)_{max}}{\rho\, d} = \frac{\left(1.0\times10^{-3} \text{ N}\cdot\text{s/m}^2\right)(2\,000)}{\left(1\,000 \text{ kg/m}^3\right)\left(2.5\times10^{-2} \text{ m}\right)} = 0.080 \text{ m/s} = \boxed{8.0 \text{ cm/s}}$$

9.73 The observed diffusion rate is $(8.0\times10^{-14}\ \text{kg})/(15\ \text{s}) = 5.3\times10^{-15}\ \text{kg/s}$. Then, from Fick's law, the difference in concentration levels is found to be

$$C_2 - C_1 = \frac{(Diffusion\ rate)L}{DA}$$

$$= \frac{\left(5.3\times10^{-15}\ \text{kg/s}\right)(0.10\ \text{m})}{\left(5.0\times10^{-10}\ \text{m}^2/\text{s}\right)\left(6.0\times10^{-4}\ \text{m}^2\right)} = \boxed{1.8\times10^{-3}\ \text{kg/m}^3}$$

9.74 Fick's law gives the diffusion coefficient as $D = (Diffusion\ rate)/[A\cdot(\Delta C/L)]$, where $\Delta C/L$ is the concentration gradient.

Thus, $$D = \frac{5.7\times10^{-15}\ \text{kg/s}}{\left(2.0\times10^{-4}\ \text{m}^2\right)\cdot\left(3.0\times10^{-2}\ \text{kg/m}^4\right)} = \boxed{9.5\times10^{-10}\ \text{m}^2/\text{s}}$$

9.75 Stokes's law gives the viscosity of the air as

$$\eta = \frac{F_r}{6\pi r v} = \frac{3.0\times10^{-13}\ \text{N}}{6\pi\left(2.5\times10^{-6}\ \text{m}\right)\left(4.5\times10^{-4}\ \text{m/s}\right)} = \boxed{1.4\times10^{-5}\ \text{N}\cdot\text{s/m}^2}$$

9.76 Using $v_t = 2r^2 g\left(\rho - \rho_f\right)/9\eta$, the density of the sphere is found to be $\rho_{\text{sphere}} = \rho_{\text{water}} + 9\eta_{\text{water}} v_t/2r^2 g$. Thus, if $r = d/2 = 0.500\times10^{-3}\ \text{m}$ and $v_t = 1.10\times10^{-2}\ \text{m/s}$ when falling through 20°C water,

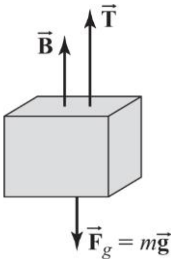
$$\rho_{\text{sphere}} = 1.00\times10^3\ \frac{\text{kg}}{\text{m}^3} + \frac{9\left(1.00\times10^{-3}\ \text{N}\cdot\text{s/m}^2\right)\left(1.10\times10^{-2}\ \text{m/s}\right)}{2\left(5.00\times10^{-4}\ \text{m}\right)^2\left(9.80\ \text{m/s}^2\right)} = \boxed{1.02\times10^3\ \text{kg/m}^3}$$

9.77 (a) Both iron and aluminum are denser than water, so both blocks will be fully submerged. Since the two blocks have the same volume, they displace equal amounts of water and

$\boxed{\text{the buoyant forces acting on the two blocks are equal.}}$

(b) Since the block is held in equilibrium, the force diagram at the right shows that

$$\Sigma F_y = 0 \;\Rightarrow\; T = mg - B$$



The buoyant force $\vec{\mathbf{B}}$ is the same for the two blocks, so the spring scale reading $\vec{\mathbf{T}}$ is $\boxed{\text{largest for the iron block}}$, which has a higher density, and hence weight, than the aluminum block.

(c) The buoyant force in each case is

$$B = (\rho_{\text{water}} V)g = (1.00\times10^3 \text{ kg/m}^3)(0.20 \text{ m}^3)(9.80 \text{ m/s}^2) = \boxed{2.0\times10^3 \text{ N}}$$

For the iron block:

$$T_{\text{iron}} = (\rho_{\text{iron}} V)g - B = (7.86\times10^3 \text{ kg/m}^3)(0.20 \text{ m}^3)(9.8 \text{ m/s}^2) - B$$

or $$T_{\text{iron}} = 1.5\times10^4 \text{ N} - 2.0\times10^3 \text{ N} = \boxed{13\times10^3 \text{ N}}$$

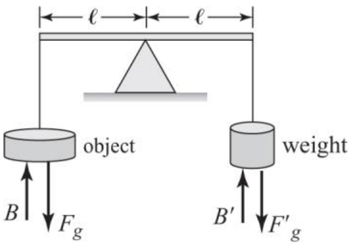
For the aluminum block:

$$T_{\text{aluminum}} = (\rho_{\text{aluminum}} V)g - B = (2.70\times10^3 \text{ kg/m}^3)(0.20 \text{ m}^3)(9.8 \text{ m/s}^2) - B$$

or $$T_{\text{aluminum}} = 5.3\times10^3 \text{ N} - 2.0\times10^3 \text{ N} = \boxed{3.3\times10^3 \text{ N}}$$

9.78 The object has volume V and true weight F_g. It also experiences a buoyant force $B = (\rho_{air} V)g$ exerted on it by the surrounding air. The counterweight, of density ρ, on the opposite end of the balance has a true weight F_g' and experiences a buoyant force

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



The balance is in equilibrium when the net downward forces acting on its two ends are equal, that is, when $F_g - B = F_g' - B'$. Thus, the true weight of the object may be expressed as

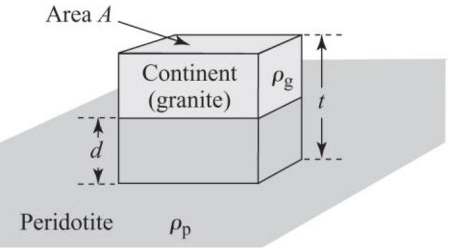
$$F_g = F_g' + B - B' = F_g' + (\rho_{air} V)g - \left(\frac{\rho_{air}}{\rho}\right)F_g'$$

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

9.79 (a) From Archimedes' principle, the granite continent will sink down into the peridotite layer until the weight of the displaced peridotite equals the weight of the continent. Thus, at equilibrium,

$$\left[\rho_g (At)\right]g = \left[\rho_p (Ad)\right]g$$

or $$\boxed{\rho_g t = \rho_p d}$$



(b) If the continent sinks 5.0 km below the surface of the peridotite, then $d = 5.0$ km, and the result of part (a) gives the first approximation of the thickness of the continent as

$$t = \left(\frac{\rho_p}{\rho_g}\right)d = \left(\frac{3.3\times10^3 \text{ kg/m}^3}{2.8\times10^3 \text{ kg/m}^3}\right)(5.0 \text{ km}) = \boxed{5.9 \text{ km}}$$

9.80 (a) Starting with $P = P_0 + \rho g h$, we choose the reference level at the level of the heart, so $P_0 = P_H$. The pressure at the feet, a depth h_H below the reference level in the pool of blood in the body, is $P_F = P_H + \rho g h_H$. The pressure difference between feet and heart is then $\boxed{P_F - P_H = \rho g h_H}$.

(b) Using the result of part (a),

$$P_F - P_H = (1.05\times10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(1.20 \text{ m}) = \boxed{1.23\times10^4 \text{ Pa}}$$

9.81 The cross-sectional area of the aorta is $A_1 = \pi d_1^2/4$ and that of a single capillary is $A_c = \pi d_2^2/4$. If the circulatory system has N such capillaries, the total cross-sectional area carrying blood from the aorta is $A_2 = NA_c = N\pi d_2^2/4$.

From the equation of continuity, $A_2 = (v_1/v_2)A_1$, or

$$\frac{N\pi d_2^2}{4} = \left(\frac{v_1}{v_2}\right)\frac{\pi d_1^2}{4}$$

yielding

$$N = \left(\frac{v_1}{v_2}\right)\left(\frac{d_1}{d_2}\right)^2 = \left(\frac{1.0 \text{ m/s}}{1.0\times10^{-2} \text{ m/s}}\right)\left(\frac{0.50\times10^{-2} \text{ m}}{10\times10^{-6} \text{ m}}\right)^2 = \boxed{2.5\times10^7}$$

9.82 (a) We imagine that a superhero is capable of producing a perfect vacuum above the water in the straw. Then $P = P_0 + \rho g h$, with the reference level at the water surface inside the straw and P being atmospheric pressure on the water in the cup outside the straw, gives the maximum height of the water in the straw as

$$h_{max} = \frac{P_{atm} - 0}{\rho_{water} g} = \frac{P_{atm}}{\rho_{water} g} = \frac{1.013\times10^5 \text{ N/m}^2}{\left(1.00\times10^3 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)} = \boxed{10.3 \text{ m}}$$

(b) The Moon has no atmosphere so $P_{atm} = 0$, which yields $h_{max} = \boxed{0}$.

9.83 (a) $P = 160 \text{ mm of } H_2O = \rho_{H_2O}\, g(160 \text{ mm})$

$$= \left(10^3 \ \frac{\text{kg}}{\text{m}^3}\right)\left(9.80 \ \frac{\text{m}}{\text{s}^2}\right)(0.160 \text{ m}) = \boxed{1.57 \text{ kPa}}$$

$$P = \left(1.57\times10^3 \text{ Pa}\right)\left(\frac{1 \text{ atm}}{1.013\times10^5 \text{ Pa}}\right) = \boxed{1.55\times10^{-2} \text{ atm}}$$

The pressure is $P = \rho_{H_2O}\, g h_{H_2O} = \rho_{Hg}\, g h_{Hg}$, so

$$h_{Hg} = \left(\frac{\rho_{H_2O}}{\rho_{Hg}}\right) h_{H_2O} = \left(\frac{10^3 \text{ kg/m}^3}{13.6\times10^3 \text{ kg/m}^3}\right)(160 \text{ mm}) = \boxed{11.8 \text{ mm of Hg}}$$

(b) The fluid level in the tap should rise.

(c) Blockage of flow of the cerebrospinal fluid

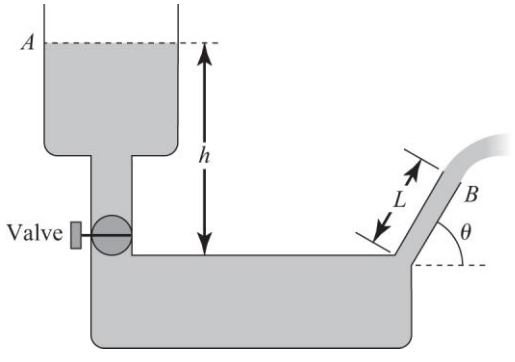
9.84 When the rod floats, the weight of the displaced fluid equals the weight of the rod, or $(\rho_f V_{\text{displaced}})g = (\rho_0 V_{\text{rod}})g$. Assuming a cylindrical rod, $V_{\text{rod}} = \pi r^2 L$. The volume of fluid displaced is the same as the volume of the rod that is submerged

or $V_{\text{displaced}} = \pi r^2 (L - h)$.

Thus, $\rho_f\left[\pi r^2 (L-h)\right]g = \rho_0\left[\pi r^2 L\right]g$ which reduces to $\boxed{\rho_f = \rho_0 L/(L-h)}$.

9.85 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 $v_A \approx 0$. This gives

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



Recognize that $P_A = P_B = P_{\text{atm}}$ since both points are open to the atmosphere. Thus, we obtain $v_B = \sqrt{2g(h - L\sin\theta)}$.

Now the problem reduces to one of projectile motion with $v_{0y} = v_B \sin\theta$. At the top of the arc $v_y = 0,\ y = y_{\max}$, and $v_y^2 = v_{0y}^2 + 2\,a_y(\Delta y)$ gives

$$y_{\max} - 0 = \frac{v_y^2 - v_{0y}^2}{2a_y} = \frac{0 - v_B^2 \sin^2\theta}{2(-g)} = \frac{2g\,(h - L\sin\theta)\sin^2\theta}{2g}$$

or

$$y_{\max} = \left[10.0\text{ m} - (2.00\text{ m})\sin 30.0°\right]\sin^2 30.0° = \boxed{2.25\text{ m above the level of point } B}$$

9.86 When the balloon comes into equilibrium, the weight of the displaced air equals the weight of the filled balloon plus the weight of string that is above ground level. If m_s and L are the total mass and length of the string, the mass of string that is above ground level is $(h/L)\,m_s$. Thus, $(\rho_{\text{air}} V_{\text{balloon}})g = m_{\text{balloon}}\,g + (\rho_{\text{helium}} V_{\text{balloon}})g + (h/L)\,m_s\,g$, which reduces to

$$h = \left[\frac{(\rho_{\text{air}} - \rho_{\text{helium}})V_{\text{balloon}} - m_{\text{balloon}}}{m_s}\right]L$$

This yields

$$h = \left[\frac{\left(1.29\ \text{kg/m}^3 - 0.179\ \text{kg/m}^3\right)\left[4\pi\,(0.40\text{ m})^3/3\right] - 0.25\text{ kg}}{0.050\text{ kg}}\right](2.0\text{ m}) = \boxed{1.9\text{ m}}$$

9.87 Four forces are acting on the balloon: an upward buoyant force exerted by the surrounding air, $B = (\rho_{\text{air}} V_{\text{balloon}})g$; the downward weight of the balloon envelope, $F_{g,\text{ balloon}} = mg$; the downward weight of the helium filling the balloon, $F_{g,\text{ He}} = (\rho_{\text{He}} V_{\text{balloon}})g$; and the downward spring force, $F_s = k|\Delta x|$. At equilibrium, $|\Delta x| = L$, and we have

$$\Sigma F_y = 0 \quad \Rightarrow \quad B - F_s - F_{g,\text{ balloon}} - F_{g,\text{ He}} = 0$$

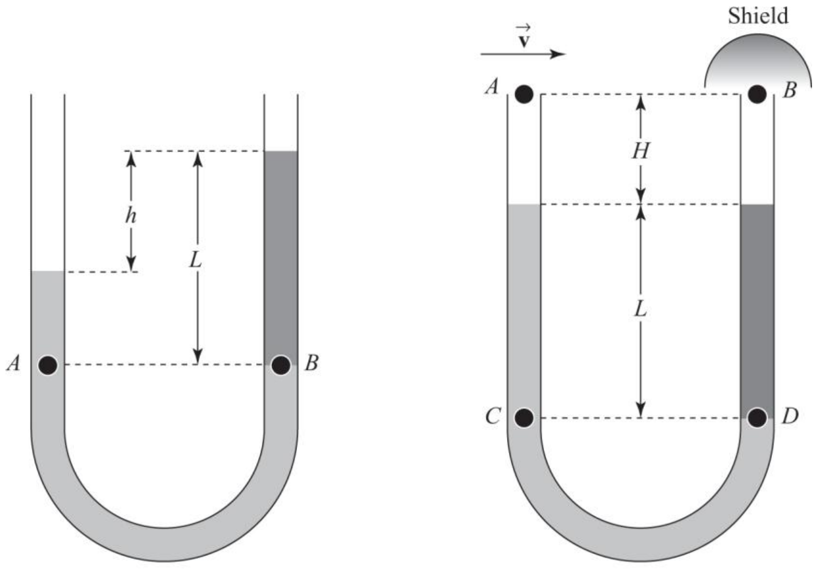
or $$F_s = kL = B - F_{g,\text{ balloon}} - F_{g,\text{ He}} = (\rho_{\text{air}} V_{\text{balloon}})g - mg - (\rho_{\text{He}} V_{\text{balloon}})g$$

and $$L = \frac{\left[(\rho_{\text{air}} - \rho_{\text{He}})V_{\text{balloon}} - m\right]g}{k}$$

This yields $$L = \frac{\left\{\left[(1.29 - 0.179)\text{ kg/m}^3\right](5.00\text{ m}^3) - 2.00 \times 10^{-3}\text{ kg}\right\}(9.80\text{ m/s}^2)}{90.0\text{ N/m}}$$

or $$\boxed{L = 0.605\text{ m}}$$

9.88



(b) **(c)**

(a) Consider the pressure at points A and B in part (b) of the figure by applying $P = P_0 + \rho_f gh$. Looking at the left tube gives $P_A = P_{\text{atm}} + \rho_{\text{water}}\, g(L-h)$, and looking at the tube on the right, $P_B = P_{\text{atm}} + \rho_{\text{oil}}\, gL$. Pascal's principle says that $P_B = P_A$. Therefore, $P_{\text{atm}} + \rho_{\text{oil}}\, gL = P_{\text{atm}} + \rho_{\text{water}}\, g(L-h)$, giving

$$h = \left(1 - \frac{\rho_{\text{oil}}}{\rho_{\text{water}}}\right)L = \left(1 - \frac{750\ \text{kg/m}^3}{1\,000\ \text{kg/m}^3}\right)(5.00\ \text{cm}) = \boxed{1.25\ \text{cm}}$$

(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. This gives $P_A + \frac{1}{2}\rho_{\text{air}} v_A^2 + \rho_{\text{air}}\, g y_A = P_B + \frac{1}{2}\rho_{\text{air}} v_B^2 + \rho_{\text{air}}\, g y_B$. Since $y_A = y_B$, $v_A = v$, and $v_B = 0$, this reduces to

$$P_B - P_A = \frac{1}{2}\rho_{\text{air}} v^2 \qquad \textbf{[1]}$$

Now use $P = P_0 + \rho_f gh$ to find the pressure at points C and D, both at the level of the oil–water interface in the right tube. From the left tube, $P_C = P_A + \rho_{\text{water}}\, gL$, and from the right tube, $P_D = P_B + \rho_{\text{oil}}\, gL$.

Pascal's principle says that $P_D = P_C$, and equating these two gives $P_B + \rho_{\text{oil}}\, g L = P_A + \rho_{\text{water}}\, g L$, or

$$P_B - P_A = \left(\rho_{\text{water}} - \rho_{\text{oil}}\right) g L \qquad \textbf{[2]}$$

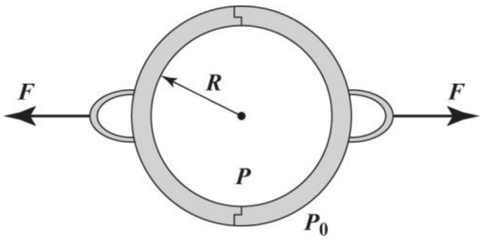
Combining Equations [1] and [2] yields

$$v = \sqrt{\frac{2\left(\rho_{\text{water}} - \rho_{\text{oil}}\right) g L}{\rho_{\text{air}}}} = \sqrt{\frac{2\left(1\,000 - 750\right)\left(9.80\ \text{m/s}^2\right)\left(5.00\times 10^{-2}\ \text{m}\right)}{1.29}} = \boxed{13.8\ \text{m/s}}$$

9.89 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 horizontal axis must balance the net force on the "effective" area, which is the cross-sectional area of the sphere,

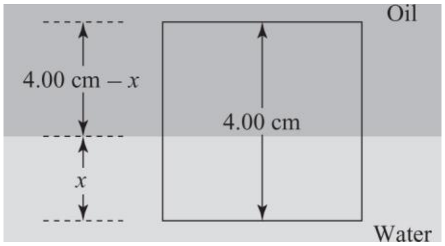
$$A_{\text{effective}} = \pi R^2$$

and $$F = P_{\text{gauge}} A_{\text{effective}} = \boxed{\left(P_0 - P\right)\pi R^2}$$



9.90 Since the block is floating, the total buoyant force must equal the weight of the block. Thus,

$$\rho_{\text{oil}}\left[A\left(4.00\ \text{cm} - x\right)\right]g + \rho_{\text{water}}\left[A\cdot x\right]g = \rho_{\text{wood}}\left[A\left(4.00\ \text{cm}\right)\right]g$$

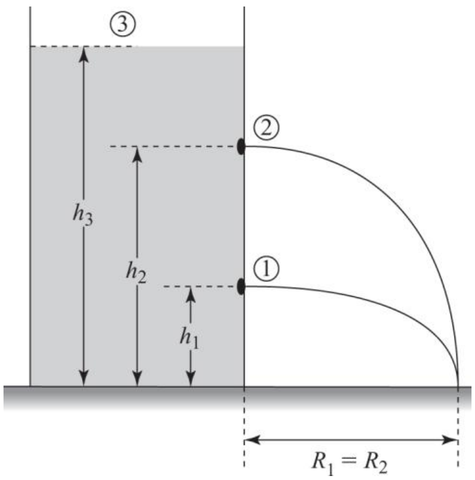


where A is the surface area of the top or bottom of the rectangular block.

Solving for the distance x gives

$$x = \left(\frac{\rho_{\text{wood}} - \rho_{\text{oil}}}{\rho_{\text{water}} - \rho_{\text{oil}}}\right)(4.00\text{ cm}) = \left(\frac{960 - 930}{1\,000 - 930}\right)(4.00\text{ cm}) = \boxed{1.71\text{ cm}}$$

9.91 A water droplet emerging from one of the holes becomes a projectile with $v_{0y} = 0$ and $v_{0x} = v$. The time for this droplet to fall distance h to the floor is found from $\Delta y = v_{0y}t + \frac{1}{2}a_y t^2$ to be $t = \sqrt{2h/g}$.



The horizontal range is $R = vt = v\sqrt{2h/g}$.

If the two streams hit the floor at the same spot, it is necessary that $R_1 = R_2$, or

$$v_1\sqrt{\frac{2h_1}{g}} = v_2\sqrt{\frac{2h_2}{g}}$$

With $h_1 = 5.00$ cm and $h_2 = 12.0$ cm, this reduces to $v_1 = v_2\sqrt{h_2/h_1} = v_2\sqrt{12.0 \text{ cm}/5.00 \text{ cm}}$, or

$$v_1 = v_2\sqrt{2.40} \qquad \textbf{[1]}$$

Apply Bernoulli's equation to points 1 (the lower hole) and 3 (the surface of the water). The pressure is atmospheric pressure at both points and, if the tank is large in comparison to the size of the holes, $v_3 \approx 0$. Thus, $P_{\text{atm}} + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_{\text{atm}} + 0 + \rho g h_3$, or

$$v_1^2 = 2g(h_3 - h_1) \qquad \textbf{[2]}$$

Similarly, applying Bernoulli's equation to point 2 (the upper hole) and point 3 gives $P_{\text{atm}} + \frac{1}{2}\rho v_2^2 + \rho g h_2 = \rho_{\text{atm}} + 0 + \rho g h_3$, or

$$v_2^2 = 2g(h_3 - h_2) \qquad \textbf{[3]}$$

Square Equation [1] and substitute from Equations [2] and [3] to obtain

$$2g(h_3 - h_1) = 2.40\left[2g(h_3 - h_2)\right]$$

Solving for h_3 yields

$$h_3 = \frac{2.40\,h_2 - h_1}{1.40} = \frac{2.40(12.0 \text{ cm}) - 5.00 \text{ cm}}{1.40} = 17.0 \text{ cm}$$

so the surface of the water in the tank is $\boxed{\text{17.0 cm above floor level}}$.