Chapter 9
Solids and Fluids

Quick Quizzes

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

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

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

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

2. (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. (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. (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. (c). The level of floating of a 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. (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. (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 demonstration of Bernoulli's principle in action.

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

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

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. Both 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 both reservoirs are equally deep, the force is the same.

6. 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.

8. 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.

10. The larger the density of a fluid, the higher does an object float in it. Thus, an object will float lower in low density alcohol.

12. 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.

14. A breeze from any direction speeds up to go over the mound, and the air pressure drops at this opening. Air then flows through the burrow from the lower to the upper entrance.

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

18. Although the area and pressures is the same at the base of each vessel, the volumes of the vessels differ, so the weight of the liquid in each vessel increases as its volume increases.

Answers to Even Numbered Problems

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

4. 1.65×10^8 Pa

6. 22 N directed down the page in the figure

8. 7.5×10^6 Pa

10. **(a)** 2.5 mm **(b)** 0.75 mm **(c)** 6.9×10^3 kg

12. The stress is 5.6×10^7 Pa, so the arm should survive.

14. 1.9×10^4 N

16. 1.2×10^6 Pa

18. **(a)** $-0.053\,8$ m^3 **(b)** 1.09×10^3 kg/m^3
(c) Yes, in most practical circumstances.

20. **(a)** 65.1 N **(b)** 275 N

22. 10.5 m; no, some alcohol and water evaporate.

24. 2.3 lb

26. 0.611 kg

28. 10.7% of the volume is exposed

30. **(a)** 1 017.9 N, 1 029.7 N **(b)** 86.2 N **(c)** 11.8 N for both

32. 1.28×10^4 m^2

34. 16.5 cm

36. **(a)** 8.57×10^3 kg/m^3 **(b)** 714 kg/m^3

38. 78 kg

40. 154 in/s

42. **(a)** 11.0 m/s **(b)** 2.64×10^4 Pa

44. 4.4×10^{-2} Pa

46. **(a)** $17.7\ \text{m/s}$ **(b)** 1.73 mm

48. **(a)** 15.1 MPa **(b)** $2.95\ \text{m/s}$ **(c)** 4.34 kPa

50. $347\ \text{m/s}$

52. $7.32 \times 10^{-2}\ \text{N/m}$

54. 5.6 m

56. 0.694 mm

58. 0.12 N

60. $1.5\ \text{m/s}$

62. $1.5 \times 10^{5}\ \text{Pa}$

64. 455 kPa

66. $8.0\ \text{cm/s}$

68. $9.5 \times 10^{-10}\ \text{m}^2/\text{s}$

70. $1.02 \times 10^{3}\ \text{kg/m}^3$

72. **(b)** $1.25 \times 10^{4}\ \text{Pa}$

74. **(a)** 10.3 m **(b)** zero

78. 1.9 m

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

82. 0.72 mm

84. **(b)** 26 kN

86. **(a)** 18.3 mm **(b)** 14.3 mm **(c)** 8.56 mm

88. 1.71 cm

90. 0.86 mm

Problem Solutions

9.1 The elastic limit is the maximum stress, F/A where F is the tension in the wire, that the wire can withstand and still return to its original length when released. Thus, if the wire is to experience a tension equal to the weight of the performer without exceeding the elastic limit, the minimum cross-sectional area is

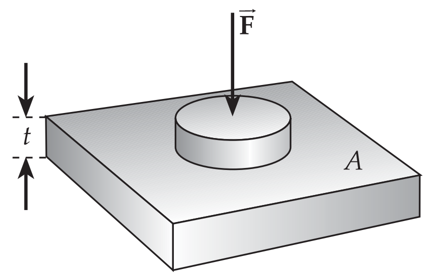
$$A_{\min} = \frac{\pi D_{\min}^2}{4} = \frac{F}{elastic\ limit} = \frac{mg}{elastic\ limit}$$

and the minimum acceptable diameter is

$$D_{\min} = \sqrt{\frac{4mg}{\pi(elastic\ limit)}} = \sqrt{\frac{4(70\text{ kg})(9.8\text{ m/s}^2)}{\pi(5.0\times10^8\text{ Pa})}} = 1.3\times10^{-3}\text{ m} = \boxed{1.3\text{ mm}}$$

9.2 (a) $F = A\cdot stress = \left[\pi\left(5.00\times10^{-3}\text{ m}\right)^2\right]\left(4.00\times10^8\text{ N/m}^2\right)\boxed{3.14\times10^4\text{ N}}$

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



$$A = (2\pi r)t$$

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

$$= 1.57\times10^{-4}\text{ m}^2$$

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

9.3 $Stress = \dfrac{F}{A}$, where $F = 0.30(weight)$ and $A = \pi r^2$

Thus, $Stress = \dfrac{0.30(480\text{ N})}{\pi\left(5.0\times10^{-3}\text{ m}\right)^2} = \boxed{1.8\times10^6\text{ Pa}}$

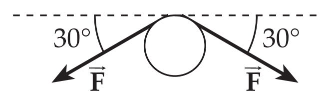
9.4 As a liquid, the water occupied some volume V_l. As ice, the water would occupy volume $1.090V_l$ if it was not compressed and forced to occupy the original volume. Consider the pressure change required to squeeze ice back into volume V_l. Then, $V_0 = 1.09V_l$ and $\Delta V = -0.090V_l$, so

$$\Delta P = -B\left(\frac{\Delta V}{V_0}\right) = -\left(2.00\times 10^9\ \frac{\text{N}}{\text{m}^2}\right)\left(\frac{-0.090\,V_l}{1.09\,V_l}\right) = \boxed{1.65\times 10^8\ \text{Pa}} \approx 1600\ \text{atm}$$

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

$$Y = \frac{4\left[(90\ \text{kg})(9.80\ \text{m/s}^2)\right](50\ \text{m})}{\pi\left(1.0\times 10^{-2}\ \text{m}\right)^2(1.6\ \text{m})} = \boxed{3.5\times 10^8\ \text{Pa}}$$

9.6 From $Y = \dfrac{F\,L_0}{A(\Delta L)}$, the tension needed to stretch the wire by 0.10 mm is



$$F = \frac{Y\,A(\Delta L)}{L_0} = \frac{Y\left(\pi d^2\right)(\Delta L)}{4\,L_0}$$

$$= \frac{\left(18\times 10^{10}\ \text{Pa}\right)\pi\left(0.22\times 10^{-3}\ \text{m}\right)^2\left(0.10\times 10^{-3}\ \text{m}\right)}{4\left(3.1\times 10^{-2}\ \text{m}\right)} = 22\ \text{N}$$

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

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

9.7 From $Y = \left(\dfrac{F}{A}\right)\left(\dfrac{L_0}{\Delta L}\right) = (stress)\left(\dfrac{L_0}{\Delta L}\right)$, the maximum compression the femur can withstand is

$$\Delta L = \frac{(stress)(L_0)}{Y} = \frac{\left(160\times 10^6\ \text{Pa}\right)(0.50\ \text{m})}{18\times 10^9\ \text{Pa}} = 4.4\times 10^{-3}\ \text{m} = \boxed{4.4\ \text{mm}}.$$

9.8 The shear modulus is given by $S = \dfrac{shear\ stress}{shear\ strain} = \dfrac{stress}{(\Delta x/h)}$.

Hence, the stress is

$$stress = S\left(\frac{\Delta x}{h}\right) = \left(1.5\times 10^{10}\ \text{Pa}\right)\left(\frac{5.0\ \text{m}}{10\times 10^{3}\ \text{m}}\right) = \boxed{7.5\times 10^{6}\ \text{Pa}}$$

9.9 From the defining equation for the shear modulus, we find the displacement, Δx, as

$$\Delta x = \frac{h(F/A)}{S} = \frac{h\cdot F}{S\cdot A} = \frac{\left(5.0\times 10^{-3}\ \text{m}\right)(20\ \text{N})}{\left(3.0\times 10^{6}\ \text{Pa}\right)\left(14\ \text{cm}^2\right)}\left(\frac{10^4\ \text{cm}^2}{1\ \text{m}^2}\right)$$

$$= 2.4\times 10^{-5}\,\text{m} = \boxed{0.024\ \text{mm}}$$

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

$$\Delta L = \frac{F\cdot L_0}{A\cdot Y} = \frac{\left(7.48\times 10^{3}\ \text{N}\right)(25.0\ \text{m})}{\left(4.00\times 10^{-4}\ \text{m}^2\right)\left(20\times 10^{10}\ \text{Pa}\right)} = 2.45\times 10^{-3}\ \text{m} = \boxed{2.5\ \text{mm}}$$

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

$$F - mg = ma_y\text{, or } F = m\left(g + a_y\right) \tag{1}$$

If $m = 800\ \text{kg}$ and $a_y = +3.0\ \text{m/s}^2$, the elongation of the cable will be

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

Thus, the increase in the elongation has been

$$increase = (\Delta L) - (\Delta L)_{initial} = 3.20\ \text{mm} - 2.45\ \text{mm} = \boxed{0.75\ \text{mm}}$$

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

$$F_{\max} = A \cdot (stress)_{\max} = \left(4.00 \times 10^{-4}\ \mathrm{m}^2\right)\left(2.2 \times 10^8\ \mathrm{Pa}\right) = 8.8 \times 10^4\ \mathrm{N}$$

Then, equation (1) above gives the mass of the maximum load as

$$m_{\max} = \frac{F_{\max}}{g+a} = \frac{8.8 \times 10^4\ \mathrm{N}}{(9.8+3.0)\ \mathrm{m/s^2}} = \boxed{6.9 \times 10^3\ \mathrm{kg}}.$$

9.11 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.

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

where $A = \pi r^2$ with $r = 0.20\ \mathrm{cm} = 2.0 \times 10^{-3}\ \mathrm{m}$. Thus,

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

9.12 The acceleration of the forearm has magnitude

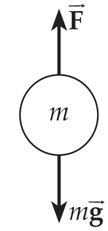
$$a = \frac{|\Delta v|}{\Delta t} = \frac{80\ \dfrac{\mathrm{km}}{\mathrm{h}}\left(\dfrac{10^3\ \mathrm{m}}{1\ \mathrm{km}}\right)\left(\dfrac{1\ \mathrm{h}}{3\,600\ \mathrm{s}}\right)}{5.0 \times 10^{-3}\ \mathrm{s}} = 4.4 \times 10^3\ \mathrm{m/s^2}$$

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

$$Stress = \frac{F}{A} = \frac{(3.0\ \mathrm{kg})\left(4.4 \times 10^3\ \mathrm{m/s^2}\right)}{2.4\ \mathrm{cm}^2\left(10^{-4}\ \mathrm{m}^2/1\ \mathrm{cm}^2\right)} = \boxed{5.6 \times 10^7\ \mathrm{Pa}}$$

Since the stress is less than the allowed maximum, $\boxed{\text{the arm should survive}}$.

9.13 Applying Newton's second law to the dancer gives



$$F - mg = ma, \quad \text{or} \quad F = m(g + a)$$

where F is the normal force exerted on the dancer by the floor, and a is the upward acceleration (if any) the dancer is given.

(a) When $a = 0$, then $F = mg = (50.0 \text{ kg})(9.80 \text{ m/s}^2) = 490 \text{ N}$, and the pressure is

$$P = \frac{F}{A} = \frac{490 \text{ N}}{26.0 \times 10^{-4} \text{ m}^2} = \boxed{1.88 \times 10^5 \text{ Pa}}$$

(b) When $a = +4.00 \text{ m/s}^2$, the normal force is

$$F = (50.0 \text{ kg})(13.8 \text{ m/s}^2) = 690 \text{ N} \text{ and } P = \frac{690 \text{ N}}{26.0 \times 10^{-4} \text{ m}^2} = \boxed{2.65 \times 10^5 \text{ Pa}}.$$

9.14 Let the weight of the car be W. Then, each tire supports $\frac{W}{4}$,

and the gauge pressure is $P = \frac{F}{A} = \frac{W}{4A}$.

Thus, $W = 4AP = 4(0.024 \text{ m}^2)(2.0 \times 10^5 \text{ Pa}) = \boxed{1.9 \times 10^4 \text{ N}}$

9.15 Neglecting surface tension effects, the pressure inside the bubble is the same as the pressure in the alcohol at this distance below its surface. This is

$$P = P_0 + \rho_{alcohol} gh = 1.10 \text{ atm} + \left(806 \frac{\text{kg}}{\text{m}^3}\right)\left(9.80 \frac{\text{m}}{\text{s}^2}\right)(4.0 \text{ m})\left(\frac{1 \text{ atm}}{1.013 \times 10^5 \text{ Pa}}\right)$$

$$P = \boxed{1.4 \text{ atm}}$$

9.16 The total downward force is the combined weight of the man and chair. This force is distributed over an area equal to 2 times the cross-sectional area of a leg. Hence, the pressure is

$$P = \frac{F}{A} = \frac{(m_{man} + m_{chair})g}{2(\pi r^2)} = \frac{(75 \text{ kg})(9.80 \text{ m/s}^2)}{2\pi(1.0 \times 10^{-2} \text{ m})^2} = \boxed{1.2 \times 10^6 \text{ Pa}}$$

9.17 The volume of concrete in a pillar of height h and cross-sectional area A is $V = Ah$, and its weight is $F_g = (Ah)(5.0\times10^4\ \text{N/m}^3)$. The pressure at the base of the pillar is then

$$P = \frac{F_g}{A} = \frac{(Ah)(5.0\times10^4\ \text{N/m}^3)}{A} = h(5.0\times10^4\ \text{N/m}^3)$$

Thus, if the maximum acceptable pressure is, $P_{\max} = 1.7\times10^7\ \text{Pa}$, the maximum allowable height is

$$h_{\max} = \frac{P_{\max}}{5.0\times10^4\ \text{N/m}^3} = \frac{1.7\times10^7\ \text{Pa}}{5.0\times10^4\ \text{N/m}^3} = \boxed{3.4\times10^2\ \text{m}}$$

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

$$\Delta V = -\frac{V_0(\Delta P)}{B_{water}} = -\frac{(1.00\ \text{m}^3)(1.13\times10^8\ \text{Pa} - 1.013\times10^5\ \text{Pa})}{0.210\times10^{10}\ \text{Pa}} = \boxed{-0.053\,8\ \text{m}^3}$$

(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

$$\rho = \frac{m}{V} = \frac{m}{V_0 + \Delta V} = \frac{1\,030\ \text{kg}}{(1.00 - 0.053\,8)\ \text{m}^3} = \boxed{1.09\times10^3\ \text{kg/m}^3}$$

(c) Considering the small fractional change in volume (about 5%) an enormous change in pressure generated, we conclude that $\boxed{\text{it is a good approximation to think of water as incompressible}}$

9.19 The density of the solution is $\rho = 1.02\rho_{water} = 1.02\times10^3\ \text{kg/m}^3$. The gauge pressure of the fluid at the level of the needle must equal the gauge pressure in the vein, so $P_{gauge} = \rho g h = 1.33\times10^4\ \text{Pa}$, and

$$h = \frac{P_{gauge}}{\rho g} = \frac{1.33\times10^4\ \text{Pa}}{(1.02\times10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)} = \boxed{1.33\ \text{m}}$$

9.20 (a) Suppose the "vacuum cleaner" functions as a high–vacuum pump and produces "zero" pressure inside the hose. The air below the brick will then exert a net upward force of

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

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

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

$$= \left[1.013 \times 10^5 \text{ Pa} + \left(1\,030 \ \frac{\text{kg}}{\text{m}^3}\right)\left(9.80 \ \frac{\text{m}}{\text{s}^2}\right)(32.3 \text{ m})\right]\left[\pi\left(1.43 \times 10^{-2} \text{ m}\right)^2\right]$$

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

9.21 The excess water pressure (over air pressure) acting on the wall is

$$\left(P_{gauge}\right)_{\text{av}} = \rho g h_{\text{av}} = \left(10^3 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)\left(\frac{0 + 2.40 \text{ m}}{2}\right) = 1.18 \times 10^4 \text{ Pa}$$

Hence, the net inward, horizontal force exerted on the wall by the water is

$$F = \left(P_{gauge}\right)_{\text{av}} A = \left(1.18 \times 10^4 \text{ Pa}\right)\left[(9.60 \text{ m})(2.40 \text{ m})\right] = 2.71 \times 10^5 \text{ N} = \boxed{271 \text{ kN}}$$

9.22 If we assume a vacuum exists inside the tube above the wine column, the pressure at the base of the tube (that is, at the level of the wine in the open container) is $P_{atmo} = 0 + \rho g h = \rho g h$. Thus,

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

Some alcohol and water will evaporate, degrading the vacuum above the column.

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

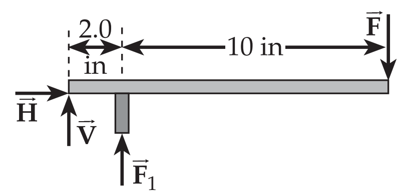
$$P_1 = P_0 + \rho_{oil} g h_{oil}$$

$$= 1.013\times10^5\ \text{Pa} + \left(700\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(0.300\ \text{m}\right) = 1.03\times10^5\ \text{Pa}$$

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

$$P_2 = 1.03\times10^5\ \text{Pa} + \left(10^3\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(0.200\ \text{m}\right) = \boxed{1.05\times10^5\ \text{Pa}}$$

9.24 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.



Free-Body Diagram of Handle

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

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

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

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

9.25 Pascal's principle, $F_1/A_1 = F_2/A_2$, gives

$$F_{brake} = \left(\frac{A_{brake\ cylinder}}{A_{master\ cylinder}}\right)F_{pedal} = \left(\frac{1.8\ \text{cm}^2}{6.4\ \text{cm}^2}\right)(44\ \text{N}) = 12.4\ \text{N}\,.$$

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

$$f = \mu_k n = 0.50(12.4\ \text{N}) = 6.2\ \text{N}\,,$$

and the torque is $\tau = f\cdot r_{drum} = (6.2\ \text{N})(0.34\ \text{m}) = \boxed{2.1\ \text{N}\cdot\text{m}}$

9.26 Since the frog floats, the buoyant force must equal the weight of the frog. Then, from Archimedes' principle, the weight of the displaced fluid equals the weight of the frog. Hence, $(\rho_{fluid} V)g = m_{frog}\, g$, or

$$m_{frog} = \rho_{fluid} V = \left(1.35\ \frac{\text{g}}{\text{cm}^3}\right)\left[\frac{1}{2}\left(\frac{4\pi(6.00\ \text{cm})^3}{3}\right)\right] = 611\ \text{g} = \boxed{0.611\ \text{kg}}$$

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

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

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

or $\quad W_{truck} = 9.41\times 10^3\ \text{N} = \boxed{9.41\ \text{kN}}$

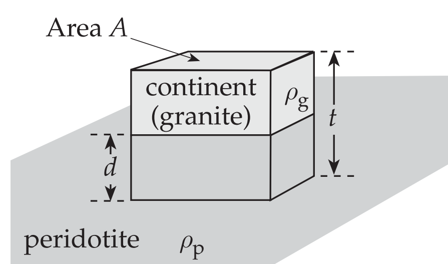
9.28 When the iceberg floats, the weight of the displaced water must equal the weight of the ice. Thus,

$$(\rho_{water} V_{water})g = (\rho_{ice} V_{ice})g\text{, or } \frac{V_{water}}{V_{ice}} = \frac{\rho_{ice}}{\rho_{water}}$$

The volume of the displaced water equals the volume of ice submerged, so the volume of ice exposed is $V_{exposed} = V_{ice} - V_{submerged} = V_{ice} - V_{water}$ and the fraction of the ice exposed is

$$\frac{V_{exposed}}{V_{ice}} = 1 - \frac{V_{water}}{V_{ice}} = 1 - \frac{\rho_{ice}}{\rho_{water}} = 1 - \frac{920\ \text{kg/m}^3}{1\,030\ \text{kg/m}^3} = 0.107\text{, or } \boxed{10.7\%}$$

9.29 (a) From Archimedes's 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 $\quad \boxed{\rho_g t = \rho_p d}$

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

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

9.30 **Note**: We deliberately violate the rules of significant figures in this problem to illustrate a point.

(a) The absolute pressure at the level of the top of the block is

$$P_{top} = P_0 + \rho_{water}\, g h_{top}$$

$$= 1.0130\times10^{5}\text{ Pa} + \left(10^{3}\ \frac{\text{kg}}{\text{m}^{3}}\right)\left(9.80\ \frac{\text{m}}{\text{s}^{2}}\right)\left(5.00\times10^{-2}\text{ m}\right)$$

$$= 1.0179\times10^{5}\text{ Pa}$$

and that at the level of the bottom of the block is

$$P_{bottom} = P_0 + \rho_{water}\, g h_{bottom}$$

$$= 1.0130\times10^{5}\text{ Pa} + \left(10^{3}\ \frac{\text{kg}}{\text{m}^{3}}\right)\left(9.80\ \frac{\text{m}}{\text{s}^{2}}\right)\left(17.0\times10^{-2}\text{ m}\right)$$

$$= 1.0297\times10^{5}\text{ Pa}$$

Thus, the downward force exerted on the top by the water is

$$F_{top} = P_{top}A = \left(1.0179\times10^{5}\text{ Pa}\right)\left(0.100\text{ m}\right)^{2} = \boxed{1017.9\text{ N}}$$

and the upward force the water exerts on the bottom of the block is

$$F_{bot} = P_{bot}A = \left(1.0297\times10^{5}\text{ Pa}\right)\left(0.100\text{ m}\right)^{2} = \boxed{1029.7\text{ N}}$$

(b) The scale reading equals the tension, T, in the cord supporting the block. Since the block is in equilibrium, $\Sigma F_y = T + F_{bot} - F_{top} - mg = 0$, or

$$T = (10.0\text{ kg})\left(9.80\text{ m/s}^{2}\right) - (1029.7 - 1017.9)\text{ N} = \boxed{86.2\text{ N}}$$

(c) From Archimedes's principle, the buoyant force on the block equals the weight of the displaced water. Thus,

$$B = \left(\rho_{water} V_{block}\right)g$$

$$= \left(10^3 \text{ kg/m}^3\right)\left[(0.100 \text{ m})^2 (0.120 \text{ m})\right]\left(9.80 \text{ m/s}^2\right) = \boxed{11.8 \text{ N}}$$

From part (a), $F_{bot} - F_{top} = (1\,029.7 - 1\,017.9)\text{ N} = 11.8 \text{ N}$, which is the same as the buoyant force found above.

9.31 Constant velocity means that the submersible is in equilibrium under the gravitational force, the upward buoyant force, and the upward resistance force:

$$\Sigma F_y = ma_y = 0$$

$$-\left(1.20 \times 10^4 \text{ kg} + m\right)g + \rho_{sea\ water} gV + 1\,100 \text{ N} = 0$$

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

Thus, $m = \left(1.03 \times 10^3 \ \dfrac{\text{kg}}{\text{m}^3}\right)\left[\left(\dfrac{4\pi}{3}\right)(1.50 \text{ m})^3\right] + \dfrac{1\,100 \text{ N}}{9.80 \text{ m/s}^2} - 1.20 \times 10^4 \text{ kg}$

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

9.32 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, or

$$50\left(m_{plane}\, g\right) = \Delta B = \rho_{water}\, g(\Delta V) = \left(1\,030 \text{ k/m}^3\right)g\left(11.0 \times 10^{-2} \text{ m}\right)A$$

Thus, $\quad A = \dfrac{50\left(29\,000 \text{ kg}\right)g}{\left(1\,030 \text{ k/m}^3\right)g\left(11.0 \times 10^{-2} \text{ m}\right)} = \boxed{1.28 \times 10^4 \text{ m}^2}$

Note that the free-fall acceleration cancels in this calculation and does not affect the answer.

9.33 The balloon is in equilibrium under the action of three forces. These are the buoyant force, B, the total weight, W, of the balloon and the helium, and the tension T in the string. Hence,

$$\Sigma F_y = B - \left(m_{balloon} + m_{helium}\right)g - T = 0\text{, or } T = B - \left(m_{balloon} + m_{helium}\right)g$$

The buoyant force is

$$B = \left(\rho_{air} V_{balloon}\right)g \text{ and } m_{helium} = \rho_{helium} V_{balloon}\text{, where } V_{balloon} = \frac{4\pi r^3}{3}$$

Thus, $T = \left(\rho_{air} - \rho_{helium}\right)g\left(\dfrac{4\pi r^3}{3}\right) - m_{balloon}\, g$

$$= \left[(1.29 - 0.181)\ \text{kg/m}^3\right]\left(9.80\ \text{m/s}^2\right)\left(\frac{4\pi}{3}\right)(0.500\ \text{m})^3 - (0.0120\ \text{kg})\left(9.80\ \text{m/s}^2\right)$$

or $T = \boxed{5.57\ \text{N}}$

9.34 At equilibrium, $\Sigma F_y = B - F_{spring} - mg = 0$ so the spring force is

$$F_{spring} = B - mg = \left[\left(\rho_{water} V_{block}\right) - m\right]g$$

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

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

The elongation of the spring is then

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

9.35 (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's principle, this is also the weight of the displaced alcohol, so $B = \left(\rho_{alcohol} V\right)g$. Since the sample is fully submerged, the volume of the displaced alcohol is the same as the volume of the sample. This volume is

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

(b) The mass of the sample is $m = \dfrac{weight\ in\ air}{g} = \dfrac{300\ \text{N}}{9.80\ \text{m/s}^2} = 30.6\ \text{kg}$,

and its density is $\rho = \dfrac{m}{V} = \dfrac{30.6\ \text{kg}}{1.46 \times 10^{-2}\ \text{m}^3} = \boxed{2.10 \times 10^3\ \text{kg/m}^3}$

9.36 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 $m = \dfrac{weight\ in\ air}{g} = \dfrac{300\ \text{N}}{9.80\ \text{m/s}^2} = 30.6\ \text{kg}$. The buoyant force when immersed in water is the weight of a volume of water equal to the volume of the object, or $B_w = (\rho_w V)g$. Thus, the volume of the object is

$$V = \frac{B_w}{\rho_w g} = \frac{300\ \text{N} - 265\ \text{N}}{\left(10^3\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)} = 3.57 \times 10^{-3}\ \text{m}^3,$$

and its density is $\rho_{object} = \dfrac{m}{V} = \dfrac{30.6\ \text{kg}}{3.57 \times 10^{-3}\ \text{m}^3} = \boxed{8.57 \times 10^3\ \text{kg/m}^3}$

(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, $B_{oil} = (\rho_{oil} V)g$, or the density of the oil is

$$\rho_{oil} = \frac{B_{oil}}{Vg} = \frac{300\ \text{N} - 275\ \text{N}}{\left(3.57 \times 10^{-3}\ \text{m}^3\right)\left(9.80\ \text{m/s}^2\right)} = \boxed{714\ \text{kg/m}^3}$$

9.37 The volume of the shell is $V = \dfrac{4\pi}{3}r^3 = \dfrac{4\pi}{3}\left(\dfrac{0.200\ \text{m}}{2}\right)^3 = 4.19 \times 10^{-3}\ \text{m}^3$, so the mass of alcohol filling the shell is

$$m_a = \rho_a V = \left(806\ \text{kg/m}^3\right)\left(4.19 \times 10^{-3}\ \text{m}^3\right) = 3.38\ \text{kg},$$

and the mass of the filled shell is

$$m = m_{shell} + m_a = (0.400 + 3.38)\ \text{kg} = 3.78\ \text{kg}$$

The buoyant force exerted on the shell by the water is

$$B = (\rho_{water} V) g = (10^3 \text{ kg/m}^3)(4.19 \times 10^{-3} \text{ m}^3)(9.80 \text{ m/s}^2) = 41.1 \text{ N},$$

and the upward acceleration is

$$a_y = \frac{\Sigma F_y}{m} = \frac{B - mg}{m} = \frac{B}{m} - g = \frac{41.1 \text{ N}}{3.78 \text{ kg}} - 9.80 \text{ m/s}^2 = \boxed{1.07 \text{ m/s}^2}$$

9.38 When the mattress is fully submerged, the buoyant force exerted by the water (and hence the total weight that can be supported) is

$$\begin{aligned} B &= (\rho_{water} V) g \\ &= (10^3 \text{ kg/m}^3) \left[(2.0 \text{ m})(0.50 \text{ m})(0.080 \text{ m})\right](9.80 \text{ m/s}^2) = 7.8 \times 10^2 \text{ N} \end{aligned}$$

Thus, the total mass that can be supported is

$$m_{total} = \frac{B}{g} = \frac{7.8 \times 10^2 \text{ N}}{9.80 \text{ m/s}^2} = 80 \text{ kg}$$

The addition mass that can be placed on the mattress is then

$$m_{additional} = m_{total} - m_{mattress} = 80 \text{ kg} - 2.0 \text{ kg} = \boxed{78 \text{ kg}}$$

9.39 The volume of the iron block is

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

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

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

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

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

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

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

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

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

9.40 The volume flow rate of an incompressible fluid through a conduit is $\Delta V/\Delta t = Av$, where A is the cross-sectional area of the conduit and v is the average velocity of the fluid. Thus, for the specified pipe,

$$v = \frac{\Delta V}{A(\Delta t)} = \frac{\left(20.0\ \text{gal}\right)\left(231\ \text{in}^3/1\ \text{gal}\right)}{\left(1.00\ \text{in}^2\right)\left(30.0\ \text{s}\right)} = \boxed{154\ \text{in/s}}$$

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

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

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

$$v_{capiliaries} = \left(\frac{A_{aorta}}{A_{capillaries}}\right)v_{aorta} = \left(\frac{2.0\ \text{cm}^2}{3.0\times10^3\ \text{cm}^2}\right)\left(40\ \text{cm/s}\right),$$

or $v_{capiliaries} = 2.7\times10^{-2}\ \text{cm/s} = \boxed{0.27\ \text{mm/s}}$

9.42 (a) From the equation of continuity, the flow speed in the second 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 pipes 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 $P_2 = \boxed{2.64 \times 10^4 \text{ Pa}}$

9.43 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 $v_2 = \sqrt{v_1^2 + \dfrac{2\left(P_1 - P_2\right)}{\rho}}$

In this situation,

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

Thus, assuming $v_1 \approx 0$, $\qquad v_2 = \sqrt{0 + \dfrac{2\left(8.00 \times 10^4 \text{ Pa}\right)}{1.00 \times 10^3 \text{ kg/m}^3}} = \boxed{12.6 \text{ m/s}}$

9.44 We apply Bernoulli's equation, ignoring the very small change in vertical position, to obtain $P_1 - P_2 = \frac{1}{2}\rho\left(v_2^2 - v_1^2\right) = \frac{1}{2}\rho\left[\left(2v_1\right)^2 - v_1^2\right] = \frac{3}{2}\rho v_1^2$, or

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

9.45 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 $v_{0y} = 0$, we find the time of flight as

$$t = \sqrt{\frac{2(\Delta y)}{a_y}} = \sqrt{\frac{2(-1.00\text{ m})}{-9.80\text{ m/s}^2}} = 0.452\text{ s}$$

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

$$v_2 = v_{0x} = \frac{\Delta x}{t} = \frac{0.600\text{ m}}{0.452\text{ s}} = 1.33\text{ m/s}$$

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 $P_1 = P_2 = P_{atmo}$ and $v_1 \approx 0$, this gives

$$\rho g y_1 = \frac{1}{2}\rho v_2^2 + \rho g y_2\text{, or}$$

$$h = y_1 - y_2 = \frac{v_2^2}{2g} = \frac{(1.33\text{ m/s})^2}{2(9.80\text{ m/s}^2)} = 9.00\times10^{-2}\text{ m} = \boxed{9.00\text{ cm}}$$

9.46 (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, $P_1 = P_2 = P_{atmo}$ 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

$$A_2 = \frac{\textit{flow rate}}{v_2} = \frac{2.50\times10^{-3}\text{ m}^3/\text{min}}{17.7\text{ m/s}}\left(\frac{1\text{ min}}{60\text{ s}}\right) = 2.35\times10^{-6}\text{ m}^2$$

The diameter is then

$$d_2 = \sqrt{\frac{4A_2}{\pi}} = \sqrt{\frac{4(2.35\times10^{-6}\text{ m}^2)}{\pi}} = 1.73\times10^{-3}\text{ m} = \boxed{1.73\text{ mm}}$$

9.47 First, determine the flow speed inside the larger portions from

$$v_1 = \frac{\textit{flow rate}}{A_1} = \frac{1.80\times 10^{-4}\ \text{m}^3/\text{s}}{\pi\left(2.50\times 10^{-2}\ \text{m}\right)^2/4} = 0.367\ \text{m/s}$$

The absolute pressure inside the large section on the left is $P_1 = P_0 + \rho g h_1$, where h_1 is the height of the water in the leftmost standpipe. The absolute pressure in the constriction is $P_2 = P_0 + \rho g h_2$, so

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

The flow speed inside the constriction is found from Bernoulli's equation with $y_1 = y_2$. This gives $v_2^2 = v_1^2 + \frac{2}{\rho}\left(P_1 - P_2\right) = v_1^2 + 2g\left(h_1 - h_2\right)$, or

$$v_2 = \sqrt{\left(0.367\ \text{m/s}\right)^2 + 2\left(9.80\ \text{m/s}\right)\left(5.00\times 10^{-2}\ \text{m}\right)} = 1.06\ \text{m/s}$$

The cross-sectional area of the constriction is then

$$A_2 = \frac{\textit{flow rate}}{v_2} = \frac{1.80\times 10^{-4}\ \text{m}^3/\text{s}}{1.06\ \text{m/s}} = 1.71\times 10^{-4}\ \text{m}^2,$$

and the diameter is

$$d_2 = \sqrt{\frac{4A_2}{\pi}} = \sqrt{\frac{4\left(1.71\times 10^{-4}\ \text{m}^2\right)}{\pi}} = 1.47\times 10^{-2}\ \text{m} = \boxed{1.47\ \text{cm}}$$

9.48 (a) For minimum pressure, we assume the flow is very slow. Then, Bernoulli's equation gives

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

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

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

$$\left(P_{river}\right)_{min} = \left(1.013\times 10^5 + 1.50\times 10^7\right)\ \text{Pa} = 1.51\times 10^7\ \text{Pa} = \boxed{15.1\ \text{MPa}}$$

(b) The volume flow rate is $flow\ rate = Av = \left(\dfrac{\pi d^2}{4}\right)v$. Thus, the velocity in

the pipe is $v = \dfrac{4(flow\ rate)}{\pi d^2} = \dfrac{4(4500\ \text{m}^3/\text{d})}{\pi(0.150\ \text{m})^2}\left(\dfrac{1\ \text{d}}{86\,400\ \text{s}}\right) = \boxed{2.95\ \text{m/s}}$

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

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

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

$$= \left(P_{river}\right)_{min} + 4.34\ \text{kPa}$$

The additional pressure required to achieve the desired flow rate is

$$\Delta P = \boxed{4.34\ \text{kPa}}$$

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

$$v_{0y} = \sqrt{0 - 2a_y(\Delta y)_{\max}} = \sqrt{-2\left(-9.8\ \text{m/s}^2\right)(40.0\ \text{m})} = \boxed{28.0\ \text{m/s}}$$

(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 $v_{top} = 0$, then gives

$$\frac{1}{2}\rho v_{vent}^2 = 0 + \rho g\left(y_{top} - y_{vent}\right)\text{, or}$$

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

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

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

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

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

or $P_{gauge} = P - P_{atmo} = 20.8$ atmospheres

9.50 The assumption of incompressibility is surely unrealistic, but allows an estimate of the speed. From $P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$, with $y_i = y_2 = 0$ and $v \approx 0$ inside the passenger compartment, we have

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

or $$v_2 = \sqrt{\frac{2(1.00 \text{ atm} - 0.287 \text{ atm})}{1.20 \ \text{kg/m}^3}\left(\frac{1.013 \times 10^5 \ \text{N/m}^2}{1 \text{ atm}}\right)} = \boxed{347 \ \text{m/s}}$$

9.51 (a) Choosing point 1 at the top of the tank and point 2 at the exit from the tube, Bernoulli's equation with $v_1 \approx 0$ gives

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

But, $P_1 = P_2 = 1 \text{ atm}$, and $y_1 - y_2 = h$. Thus, $v_2 = \boxed{\sqrt{2gh}}$

(b) Use Bernoulli's equation with point 1 at the top of the tank and point 2 at the highest point in the tube. This gives

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

When the siphon ceases to work, the fluid will be at rest at point 2,

so $v_2 = v_1 = 0$ and $y_2 - y_1 = y_{\max}$. Thus, $P_{atm} = P_2 + \rho g y_{\max}$.

Since the minimum value of P_2 is 0, $\boxed{y_{\max} = \frac{P_{atm}}{\rho g} = \frac{P_0}{\rho g}}$

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

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

$$= \frac{F}{4\pi r} = \frac{1.61 \times 10^{-2}\text{ N}}{4\pi(1.75 \times 10^{-2}\text{ m})} = \boxed{7.32 \times 10^{-2}\text{ N/m}}$$

9.53 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 $\phi = 0° \Rightarrow$ $\qquad mg + 2\gamma L = 0.40\text{ N}$ (1)

$T = 0.39\text{ N}$ when $\phi = 180° \Rightarrow$ $\qquad mg - 2\gamma L = 0.39\text{ N}$ (2)

Subtracting equation (2) from (1) gives

$$\gamma = \frac{0.40\text{ N} - 0.39\text{ N}}{4L} = \frac{0.40\text{ N} - 0.39\text{ N}}{4(3.0 \times 10^{-2}\text{ m})} = \boxed{8.3 \times 10^{-2}\text{ N/m}}.$$

9.54 The height the blood can rise is given by

$$h = \frac{2\gamma\cos\phi}{\rho g r} = \frac{2(0.058\text{ N/m})\cos 0°}{(1\,050\text{ kg/m}^2)(9.80\text{ m/s}^2)(2.0 \times 10^{-6}\text{ m})} = \boxed{5.6\text{ m}}$$

9.55 From $h = \dfrac{2\gamma\cos\phi}{\rho g r}$, the surface tension is

$$\gamma = \frac{h\rho g r}{2\cos\phi}$$

$$= \frac{(2.1\times10^{-2}\ \text{m})(1\,080\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(5.0\times10^{-4}\ \text{m})}{2\cos 0°} = \boxed{5.6\times10^{-2}\ \text{N/m}}$$

9.56 From $h = \dfrac{2\gamma\cos\phi}{\rho g r}$, the radius of the capillary tube is

$$r = \frac{2\gamma\cos\phi}{\rho g h} = \frac{2(0.088\ \text{N/m})\cos 0°}{(1\,035\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(5.00\times10^{-2}\ \text{m})} = 3.47\times10^{-4}\ \text{m}$$

The diameter is then

$$d = 2r = 2(3.47\times10^{-4}\ \text{m}) = 6.94\times10^{-4}\ \text{m} = \boxed{0.694\ \text{mm}}$$

9.57 From the definition of the coefficient of viscosity, $\eta = \dfrac{FL}{Av}$, the required force is

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

9.58 From the definition of the coefficient of viscosity, $\eta = \dfrac{FL}{Av}$, the required force is

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

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

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

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

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

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

Thus, the flow speed is $$v = \frac{flow\ rate}{A} = \frac{3.2\times10^{-5}\ \mathrm{m^3/s}}{\pi\left(2.6\times10^{-3}\ \mathrm{m}\right)^2} = \boxed{1.5\ \mathrm{m/s}}$$

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

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

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

$$r_{\max} = \sqrt{\frac{9\eta(v_t)_{\max}}{2g\left(\rho-\rho_f\right)}}$$

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

9.62 From Poiseuille's law, the excess pressure 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 $(\Delta m/\Delta t) = 1.0\times 10^{-3}\ \text{kg/s}$, the volume flow rate of the water is

$$\frac{\Delta V}{\Delta t} = \frac{\Delta m/\Delta t}{\rho} = \frac{1.0\times 10^{-3}\ \text{kg/s}}{1.0\times 10^{3}\ \text{kg/m}^3} = 1.0\times 10^{-6}\ \text{m}^3/\text{s}$$

and the required excess pressure is

$$\Delta P = \frac{8(1.0\times 10^{-3}\ \text{Pa}\cdot\text{s})(3.0\times 10^{-2}\ \text{m})(1.0\times 10^{-6}\ \text{m}^3/\text{s})}{\pi(0.15\times 10^{-3}\ \text{m})^4} = \boxed{1.5\times 10^{5}\ \text{Pa}}$$

9.63 With the IV bag elevated 1.0 m above the needle, the pressure difference across the needle is

$$\Delta P = \rho g h = (1.0\times 10^{3}\ \text{kg/m}^3)(9.8\ \text{m/s}^2)(1.0\ \text{m}) = 9.8\times 10^{3}\ \text{Pa}$$

and the desired flow rate is

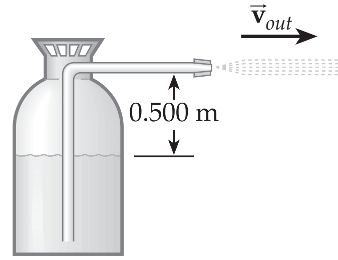
$$\frac{\Delta V}{\Delta t} = \frac{500\ \text{cm}^3(1\ \text{m}^3/10^6\ \text{cm}^3)}{30\ \text{min}(60\ \text{s}/1\ \text{min})} = 2.8\times 10^{-7}\ \text{m}^3/\text{s}$$

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

$$D = 2R = 2\left[\frac{8\eta L(\Delta V/\Delta t)}{\pi(\Delta P)}\right]^{1/4} = 2\left[\frac{8(1.0\times 10^{-3}\ \text{Pa}\cdot\text{s})(2.5\times 10^{-2}\ \text{m})(2.8\times 10^{-7}\ \text{m}^3/\text{s})}{\pi(9.8\times 10^{3}\ \text{Pa})}\right]^{1/4}$$

or $\quad D = 4.1\times 10^{-4}\ \text{m} = \boxed{0.41\ \text{mm}}$

9.64 We write Bernoulli's equation as



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

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

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

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

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

9.65 The Reynolds number is

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

In this region (RN > 3 000), the flow is $\boxed{\text{turbulent}}$.

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

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

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

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

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

9.68 Fick's law gives the diffusion coefficient as $D = \dfrac{\text{Diffusion rate}}{A\cdot(\Delta C/L)}$, where $\Delta C/L$ is the concentration gradient.

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

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

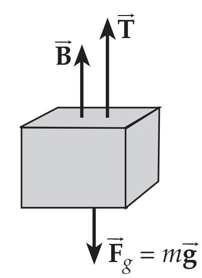
$$\eta = \frac{F}{6\pi r v} = \frac{3.0\times10^{-13}\ \text{N}}{6\pi(2.5\times10^{-6}\ \text{m})(4.5\times10^{-4}\ \text{m/s})} = \boxed{1.4\times10^{-5}\ \text{N}\cdot\text{s/m}^2}$$

9.70 Using $v_t = \dfrac{2r^2 g}{9\eta}(\rho - \rho_f)$, the density of the droplet is found to be $\rho = \rho_f + \dfrac{9\eta v_t}{2r^2 g}$. Thus, if $r = \dfrac{d}{2} = 0.500\times10^{-3}\ \text{m}$ and $v_t = 1.10\times10^{-2}\ \text{m/s}$ when falling through 20 °C water $(\eta = 1.00\times10^{-3}\ \text{N}\cdot\text{s/m}^2)$, the density of the oil is

$$\rho = 1\,000\ \frac{\text{kg}}{\text{m}^3} + \frac{9(1.00\times10^{-3}\ \text{N}\cdot\text{s/m}^2)(1.10\times10^{-2}\ \text{m/s})}{2(5.00\times10^{-4}\ \text{m})^2(9.80\ \text{m/s}^2)} = \boxed{1.02\times10^{3}\ \text{kg/m}^3}$$

9.71 (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

$$B = (\rho_{\text{water}}V)g = (1.0\times10^3\ \text{kg/m}^3)(0.20\ \text{m}^3)(9.8\ \text{m/s}^2) = \boxed{2.0\times10^3\ \text{N}}$$

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 $T_{\text{aluminum}} = 5.2\times10^3\ \text{N} - 2.0\times10^3\ \text{N} = \boxed{3.3\times10^3\ \text{N}}$

9.72 (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),

$$P_F - P_H = (1.06\times10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(1.20\ \text{m}) = \boxed{1.25\times10^4\ \text{Pa}}$$

9.73 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

$A_2 = NA_c = \dfrac{N\pi d_2^2}{4}$ From the equation of continuity,

$$A_2 = \left(\frac{v_1}{v_2}\right)A_1\text{, or } \frac{N\pi d_2^2}{4} = \left(\frac{v_1}{v_2}\right)\frac{\pi d_1^2}{4},$$

which gives

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

9.74 (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

$$h_{\max} = \frac{P_{atm} - 0}{\rho_{water} g} = \frac{P_{atm}}{\rho_{water} g} = \frac{1.013 \times 10^5 \text{ N/m}^2}{\left(1.00 \times 10^3 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)} = \boxed{10.3 \text{ m}}$$

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

9.75 (a) $P = 160 \text{ mm of H}_2\text{O} = \rho_{\text{H}_2\text{O}}\, g(160 \text{ mm})$

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

$$P = \left(1.57 \times 10^3 \text{ Pa}\right)\left(\frac{1 \text{ atm}}{1.013 \times 10^5 \text{ Pa}}\right) = 1.55 \times 10^{-2} \text{ atm}$$

The pressure is $P = \rho_{\text{H}_2\text{O}}\, g h_{\text{H}_2\text{O}} = \rho_{\text{Hg}}\, g h_{\text{Hg}}$, so

$$h_{\text{Hg}} = \left(\frac{\rho_{\text{H}_2\text{O}}}{\rho_{\text{Hg}}}\right) h_{\text{H}_2\text{O}} = \left(\frac{10^3 \text{ kg/m}^3}{13.6 \times 10^3 \text{ kg/m}^3}\right)(160 \text{ mm}) = \boxed{11.8 \text{ mm of Hg}}$$

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

(c) Blockage of flow of the cerebrospinal fluid.

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

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

9.77 When the balloon floats, the weight of the displaced air equals the combined weights of the filled balloon and its load. Thus,

$$\rho_{air}\, g V_{balloon} = m_{balloon}\, g + \rho_{helium}\, g V_{balloon} + m_{load}\, g,$$

or $$V_{balloon} = \frac{m_{balloon} + m_{load}}{\rho_{air} - \rho_{helium}} = \frac{600 \text{ kg} + 4\,000 \text{ kg}}{(1.29\text{-}0.179) \text{ kg/m}^3} = \boxed{4.14 \times 10^3 \text{ m}^3}$$

9.78 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 $\left(\frac{h}{L}\right)m_s$. Thus,

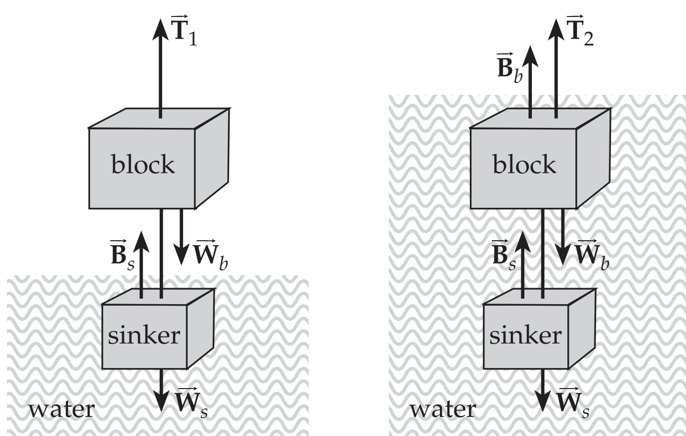
$$\rho_{air}\, gV_{balloon} = m_{balloon}\, g + \rho_{helium}\, gV_{balloon} + \left(\frac{h}{L}\right)m_s\, g\,,$$

which reduces to $h = \left[\dfrac{(\rho_{air} - \rho_{helium})V_{balloon} - m_{balloon}}{m_s}\right]L$.

This yields

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

9.79 In the sketches below, $T_1 = 200\ \text{N}$ is the scale reading when only the sinker is submerged and $T_2 = 140\ \text{N}$ is the reading when both sinker and block are submerged.



Applying the first condition of equilibrium to the entire system shown in each case gives

With only sinker submerged: $\Sigma F_y = 0 \Rightarrow T_1 = W_b + W_s - B_s$

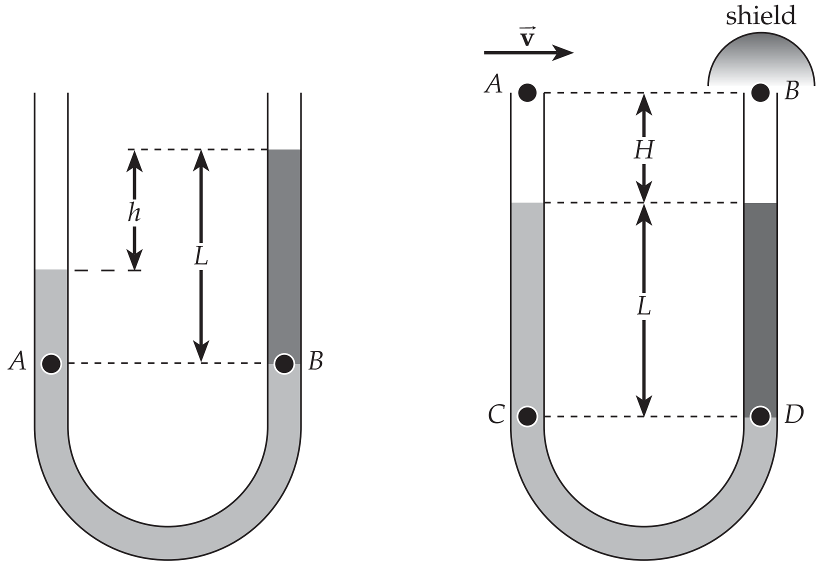
With both block and sinker submerged: $\Sigma F_y = 0 \Rightarrow T_2 = W_b + W_s - B_s - B_b$

Thus, the buoyant force on the submerged block is $B_b = \rho_{water} Vg = T_1 - T_2$, or the volume of the wooden block is $V = (T_1 - T_2)/(\rho_{water}\, g)$.

The mass of the wooden block is: $m = W_b/g = (50.0\text{ N})/g$
so the density of the wood is

$$\rho_{wood} = \frac{m}{V} = \frac{(50.0\text{ N})/g}{(T_1 - T_2)/(\rho_{water}\, g)} = \frac{(50.0\text{ N})\rho_{water}}{T_1 - T_2} = \frac{(50.0\text{ N})(1.00\times 10^3\text{ kg/m}^3)}{200\text{ N} - 140\text{ N}} = \boxed{833\text{ kg/m}^3}$$

9.80



(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 $P_A = P_{atm} + \rho_{water}\, g(L-h)$, and looking at the tube on the right, $P_B = P_{atm} + \rho_{oil}\, gL$.

Pascal's principle says that $P_B = P_A$. Therefore,

$P_{atm} + \rho_{oil}\, gL = P_{atm} + \rho_{water}\, g(L-h)$, giving

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

(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

$$P_A + \frac{1}{2}\rho_{air} v_A^2 + \rho_{air}\, g y_A = P_B + \frac{1}{2}\rho_{air} v_B^2 + \rho_{air}\, g y_B$$

Since $y_A = y_B$, $v_A = v$, and $v_B = 0$, this reduces to

$$P_B - P_A = \frac{1}{2}\rho_{air} v^2 \tag{1}$$

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, $P_C = P_A + \rho_{water}\, gL$, and from the right tube, $P_D = P_B + \rho_{oil}\, gL$.

Pascal's principle says that $P_D = P_C$, and equating these two gives

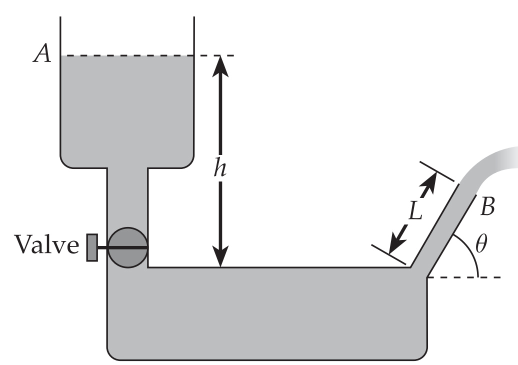
$$P_B + \rho_{oil}\, gL = P_A + \rho_{water}\, gL \text{, or } P_B - P_A = \left(\rho_{water} - \rho_{oil}\right) gL \tag{2}$$

Combining equations (1) and (2) yields

$$v = \sqrt{\frac{2\left(\rho_{water} - \rho_{oil}\right) gL}{\rho_{air}}}$$

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

9.81 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



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

Recognize that $P_A = P_B = P_{atm}$ since both points are open to the atmosphere. Thus, we obtain

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

Now the problem reduces to one of projectile motion with

$$v_{0y} = v_B \sin 30.0° = 6.64 \text{ m/s}$$

At the top of the arc, $v_y = 0$, and $y = y_{\text{max}}$.

Then, $v_y^2 = v_{0y}^2 + 2a_y(\Delta y)$ gives $0 = (6.64 \text{ m/s})^2 + 2(-9.80 \text{ m/s}^2)(y_{\text{max}} - 0)$,

or $$y_{\text{max}} = \boxed{2.25 \text{ m above the level of point B}}$$

9.82 The increase in pressure as the ball sinks is $\Delta P = \rho_w g h$, where h is the depth at the ocean bottom.

From the definition of bulk modulus, $B = -\dfrac{\Delta P}{(\Delta V/V_i)}$, the change in volume will be $\Delta V = -(\Delta P)V_i/B = -(\rho_w g h)V_i/B$. Since the volume of a sphere is $V = \dfrac{4\pi}{3}r^3$, this result may be written as $\dfrac{4\pi}{3}(r_f^3 - r_i^3) = -\dfrac{(\rho_w g h)}{B}\dfrac{4\pi}{3}r_i^3$, which reduces to $r_f^3 = r_i^3\left[1 - \dfrac{(\rho_w g h)}{B}\right]$.

Thus, the final diameter is

$$D_f = 2r_f = 2r_i\left[1 - \frac{(\rho_w g h)}{B}\right]^{1/3} = D_i\left[1 - \frac{(\rho_w g h)}{B}\right]^{1/3}$$

and the decrease in the diameter has been

$$|\Delta D| = D_i - D_f = D_i\left\{1 - \left[1 - \frac{(\rho_w g h)}{B}\right]^{1/3}\right\}$$

$$= (3.00 \text{ m})\left\{1 - \left[1 - \frac{\left[(1\,030 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(10.0\times 10^3 \text{ m})\right]}{14\times 10^{10} \text{ Pa}}\right]^{1/3}\right\}$$

$$|\Delta D| = \boxed{0.72 \text{ mm}}$$

9.83 While the ball is submerged, the buoyant force acting on it is $B=(\rho_w V)g$. The upward acceleration of the ball while under water is

$$a_y=\frac{\Sigma F_y}{m}=\frac{B-mg}{m}=\left[\frac{\rho_w}{m}\left(\frac{4\pi}{3}r^3\right)-1\right]g$$

$$=\left[\frac{\left(1\,000\text{ kg/m}^3\right)}{1.0\text{ kg}}\left(\frac{4\pi}{3}\right)(0.10\text{ m})^3-1\right]\left(9.80\text{ m/s}^2\right)=31\text{ m/s}^2$$

Thus, when the ball reaches the surface, the square of its speed is

$$v_y^2=v_{0y}^2+2a_y(\Delta y)=0+2\left(31\text{ m/s}^2\right)(2.0\text{ m})=125\text{ m}^2/\text{s}^2$$

When the ball leaves the water, it becomes a projectile with initial upward speed of $v_{0y}=\sqrt{125}\text{ m/s}$ and acceleration of $a_y=-g=-9.80\text{ m/s}^2$. Then, $v_y^2=v_{0y}^2+2a_y(\Delta y)$ gives the maximum height above the surface as

$$y_{\max}=\frac{0-125\text{ m}^2/\text{s}^2}{2\left(-9.80\text{ m/s}^2\right)}=\boxed{6.4\text{ m}}$$

9.84 (a) The gauge pressure on the surface of one of the hemispheres is the same at all points, and the inward force exerted on each small element of surface is directed along the radius of the hemisphere. To separate the hemispheres, the force applied along the axis must overcome the vector sum of all these small elements of force. This sum is equal to the force the gauge pressure exerts on a circular area, $A=\pi R^2$, which is the projection of the hemispherical surface onto a plane perpendicular to the axis. Therefore, the required force is

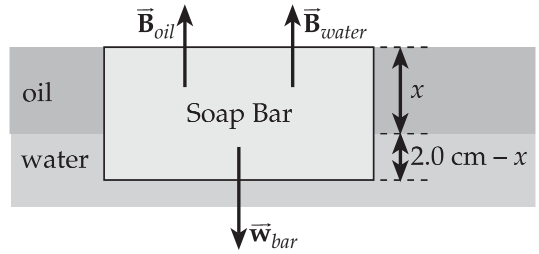
$$F=\left|P_{gauge}\right|A=\boxed{(P_o-P)\pi R^2}$$

(b) If $P=0.10P_o$ and $R=0.30\text{ m}$, the necessary force is

$$F=\left(P_0-0.10P_0\right)\pi R^2$$

$$=0.90\left(1.013\times10^5\text{ Pa}\right)\pi(0.30\text{ m})^2=2.6\times10^4\text{ N}=\boxed{26\text{ kN}}$$

9.85 The weight of the soap bar is equal to the buoyant force when it floats in water alone, or



$$w_{bar} = \rho_w\left[A\cdot(1.5\text{ cm})\right]g\,,$$

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

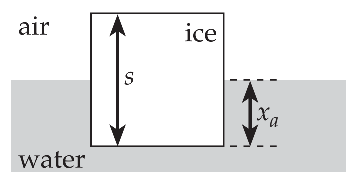
When both oil and water are present, the weight of the floating bar equals the total buoyant force, $B_{total} = B_{oil} + B_{water}$. Thus,

$$\rho_w\left[A\cdot(1.5\text{ cm})\right]g = \rho_{oil}\left[A\cdot x\right]g + \rho_w\left[A\cdot(2.0\text{ cm} - x)\right]g\,,$$

which reduces to $$x = \left(\frac{\rho_w}{\rho_w - \rho_{oil}}\right)(2.0\text{ cm} - 1.5\text{ cm})$$

Since $\rho_{oil} = 0.60\rho_w$, this gives $x = \left(\dfrac{1}{1-0.60}\right)(2.0\text{ cm} - 1.5\text{ cm}) = 1.3\text{ cm}$

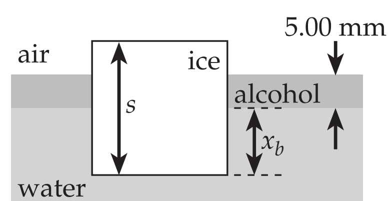
9.86 Let $s = 20.0\text{ mm}$ be the length of one edge of the ice cube. Then, the area of one face of the cube is s^2 and its volume is s^3. We shall ignore any buoyant force exerted by the air in comparison to those exerted by the more dense fluids in all cases.



(a) Since the ice cube is floating, the weight of the displaced water must equal the weight of the cube. Thus, $\rho_w\left(s^2\cdot x_a\right)g = \rho_{ice}s^3 g$, or

$$x_a = \left(\frac{\rho_{ice}}{\rho_w}\right)s = \left(\frac{917\ \text{kg/m}^3}{1\,000\ \text{kg/m}^3}\right)(20.0\text{ mm}) = \boxed{18.3\text{ mm}}$$

(b) Here, the sum of the buoyant forces exerted by the alcohol and the water must equal the weight of the floating ice cube. This gives



$$\rho_{al}\left[s^2(5.00\text{ mm})\right]g + \rho_w\left[s^2\cdot x_b\right]g = \rho_{ice}s^3 g\,,$$

or $$x_b = \frac{\rho_{ice}\cdot s - \rho_{al}(5.00\text{ mm})}{\rho_w}$$

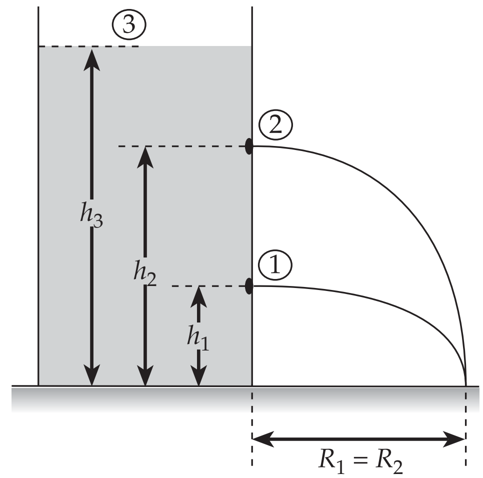
$$= \frac{(917)(20.0\text{ mm}) - (806)(5.00\text{ mm})}{1\,000} = \boxed{14.3\text{ mm}}$$

(c) Again the sum of the buoyant forces exerted by the alcohol and the water must equal the weight of the floating ice cube, so

$$\rho_{al}\left[s^2 \cdot x_c\right]g + \rho_w\left[s^2\left(s - x_c\right)\right]g = \rho_{ice}s^3 g \,.$$

This gives $x_c = \left(\dfrac{\rho_w - \rho_{ice}}{\rho_w - \rho_{al}}\right)s = \left(\dfrac{1\,000 - 917}{1\,000 - 806}\right)(20.0 \text{ mm}) = \boxed{8.56 \text{ mm}}$

9.87 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



$$t = \sqrt{\frac{2h}{g}}$$

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

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

$$v_1 = v_2\sqrt{\frac{h_2}{h_1}} = v_2\sqrt{\frac{12.0 \text{ cm}}{5.00 \text{ cm}}}, \text{ or } v_1 = v_2\sqrt{2.40} \qquad (1)$$

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, we obtain

$$P_{atm} + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_{atm} + 0 + \rho g h_3, \text{ or } v_1^2 = 2g\left(h_3 - h_1\right). \qquad (2)$$

Similarly, applying Bernoulli's equation to point 2 (the upper hole) and point 3 gives

$$P_{atm} + \frac{1}{2}\rho v_2^2 + \rho g h_2 = P_{atm} + 0 + \rho g h_3, \text{ or } v_2^2 = 2g\left(h_3 - h_2\right). \qquad (3)$$

Square equation (1) and substitute from equations (2) and (3) to obtain

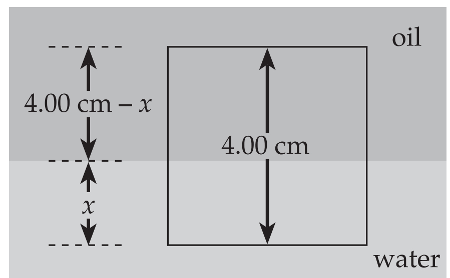
$$2g(h_3 - h_1) = 2.40[2g(h_3 - h_2)]$$

Solving for h_3 yields

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

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

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



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

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

Solving for the distance x gives

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

9.89 In order for the object to float fully submerged in the fluid, its average density must be the same as that of the fluid. Therefore, we must add ethanol to the water until the density of the mixture is $900 \text{ kg/m}^3 = 0.900 \text{ g/cm}^3$. The mass of the mixture will be $M = \rho V = (0.900 \text{ g/cm}^3)V$, where V is the total volume of the mixture.

The mass of water in the mixture is

$$m_w = \rho_w V_w = (1.00 \text{ g/cm}^3)(500 \text{ cm}^3) = 500 \text{ g},$$

and the mass of ethanol added is

$$m_e = \rho_e V_e = (0.806 \text{ g/cm}^3)V_e$$

where V_e is the volume of ethanol added.

The total mass is

$$M = m_w + m_e = 500\ \text{g} + \left(0.806\ \text{g/cm}^3\right)V_e$$

and the total volume is $V = V_w + V_e = 500\ \text{cm}^3 + V_e$

Substituting these into $M = \left(0.900\ \text{g/cm}^3\right)V$ from above gives

$$500\ \text{g} + \left(0.806\ \text{g/cm}^3\right)V_e = \left(0.900\ \text{g/cm}^3\right)\left(500\ \text{cm}^3 + V_e\right)$$

Solving for the volume of the added ethanol yields

$$V_e = \frac{500\ \text{g} - \left(0.900\ \text{g/cm}^3\right)\left(500\ \text{cm}^3\right)}{\left(0.900 - 0.806\right)\ \text{g/cm}^3} = \boxed{532\ \text{cm}^3}$$

9.90 When the section of walkway moves downward distance ΔL, the cable is stretched distance ΔL and the column is compressed distance ΔL. The tension force required to stretch the cable and the compression force required to compress the column this distance is

$$F_{cable} = \frac{Y_{steel}A_{cable}\Delta L}{L_{cable}} \qquad \text{and} \qquad F_{column} = \frac{Y_{Al}A_{column}\Delta L}{L_{column}}$$

Combined, these forces support the weight of the walkway section:

$$F_{cable} + F_{column} = F_g = 8\,500\ \text{N} \qquad \text{or} \qquad \frac{Y_{steel}A_{cable}\Delta L}{L_{cable}} + \frac{Y_{Al}A_{column}\Delta L}{L_{column}} = 8\,500\ \text{N}$$

giving $\Delta L = \dfrac{8\,500\ \text{N}}{\dfrac{Y_{steel}A_{cable}}{L_{cable}} + \dfrac{Y_{Al}A_{column}}{L_{column}}}$

The cross-sectional area of the cable is $A_{cable} = \dfrac{\pi D^2}{4} = \dfrac{\pi\left(1.27\times10^{-2}\ \text{m}\right)^2}{4}$

and the area of aluminum in the cross section of the column is

$$A_{cable} = \frac{\pi D_{outer}^2}{4} - \frac{\pi D_{inner}^2}{4} = \frac{\pi\left(D_{outer}^2 - D_{inner}^2\right)}{4} = \frac{\pi\left[\left(0.162\,4\ \text{m}\right)^2 - \left(0.161\,4\ \text{m}\right)^2\right]}{4}$$

Thus, the downward displacement of the walkway will be

$$\Delta L = \frac{8\,500\text{ N}}{\dfrac{\left(20\times10^{10}\text{ Pa}\right)\pi\left(1.27\times10^{-2}\text{ m}\right)^2}{4\left(5.75\text{ m}\right)}+\dfrac{\left(7.0\times10^{10}\text{ Pa}\right)\pi\left[\left(0.162\,4\text{ m}\right)^2-\left(0.161\,4\text{ m}\right)^2\right]}{4\left(3.25\text{ m}\right)}}$$

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