CHAPTER 2 PROBLEMS

2-1

Let the true weight of the *NaCl* crystals be *x* kg.

Vol. of brass weight = $\dfrac{0.100\text{ kg}}{8400\text{ kg/m}^3}$ = 1.1905×10^{-5} m^3 = vol. of air displaced by brass weight.

Mass of displaced air = $(1.174\text{ kg m}^{-3})(1.1905\times10^{-5}\text{ m}^3) = 1.3976\times10^{-5}$ kg.

Therefore, buoyancy force acting upwards on brass weight = $mg = 1.3976\times10^{-5}g$

Vol. *NaCl* crystals = $\dfrac{x\text{ kg}}{2100\text{ kg/m}^3}$ = $4.7619\times10^{-4}x$ m^3 = vol. of air displaced by *NaCl* crystals.

Buoyancy force acting upwards on *NaCl* crystals = $(1.174)(4.7619\times10^{-4}x)\text{g} = 5.5905\times10^{-4}xg$

If the volume of the *NaCl* crystals were the same as that of the brass weight, an equal buoyancy force would act on each, and would cancel out. However, since the volume of the *NaCl* crystals is *greater* than the volume of the brass weight, more air is displaced by the crystals than by the weight, and therefore there is a net buoyancy force acting upwards on the *NaCl* crystals which makes them appear less heavy than they actually are by an amount Δm.

The net buoyancy force is: $F_{buoyancy} = 5.5905\times10^{-4}xg - 1.3976\times10^{-5}g$ newtons.

Therefore, $\Delta m = \dfrac{F_{buoyancy}}{\text{g}} = \dfrac{5.5905\times10^{-4}xg - 1.3976\times10^{-5}g}{g} = 5.5905\times10^{-4}x - 1.3976\times10^{-5}$ kg.

$$\text{(true weight of } NaCl \text{ crystals)} = \text{(apparent weight)} + \Delta m$$

$$x = (0.1000000) + (5.5905\times10^{-4}x - 1.3976\times10^{-5})$$

$$x - 5.5905\times10^{-4}x = 0.1000000 - 1.3976\times10^{-5}$$

$$0.999441x = 0.09998602$$

$$x = 0.100041947\text{ kg}$$

The true weight of the *NaCl* crystals is 100.0419 g, which is $\left(\dfrac{100.0419 - 100.0000}{100.0419}\right)\times100\% =$ 0.042% heavier than indicated by the balance. For most work an error of this magnitude is insignificant; but for the most accurate analytical work—such as the determination of accurate molar masses of the elements—such buoyancy effects must be corrected for.

Ans: $\boxed{100.0419\text{ g}}$

2-2

(a) From Appendix 1, the density of copper is 8.96 g cm^{-3} = 8960 kg m^{-3}

The static pressure *P* is given by

$$P = \rho g \Delta z$$

$$101\ 325 = (8960)(9.806)\Delta z$$

$$\Delta z = 1.1535 \text{ m}$$

The stack would be 1.1535 m high.

Ans: $\boxed{1.153 \text{ m}}$

(b) The area of the face of a penny is $\pi r^2 = \pi\left(\dfrac{1.90\times10^{-2}}{2}\right)^2 = 2.8353\times10^{-4}\ \text{m}^2$

The mass of one penny is 2.2785×10^{-3} kg

Therefore the thickness *t* of one penny is

$$t = \frac{\text{volume}}{\text{area}} = \frac{\text{mass/density}}{\text{area}} = \frac{2.2785\times10^{-3}\ \text{kg}/8960\ \text{kg}\,\text{m}^{-3}}{2.8353\times10^{-4}\ \text{m}^2}$$

$$= 8.9690\times10^{-4}\ \text{m}\ (= 0.8969\ \text{mm})$$

and the number *N* of pennies required to form a stack that is 1.1535 m high is

$$N = \frac{1.1535\ \text{m}}{8.969\times10^{-4}\ \text{m / penny}} = 1286$$

The value of 1286 pennies is \$12.86.

Ans: $\boxed{\$12.86}$

2-3

Archimede's principle states that the mass of the fluid displaced is equal to the mass of the body doing the displacing.

If the volume of the man is *V*, then the volume of the water displaced also is *V*, which has a mass of

$$\rho_W V = \left(997\ \tfrac{\text{kg}}{\text{m}^3}\right)\left(V\ \text{m}^3\right) = 997V\ \text{kg}$$

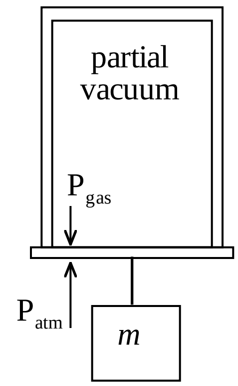
This must equal the mass of the man, which is 80.0 kg.

Therefore, $$997V = 80.0$$

and $$V = \frac{80}{997} = 0.08024 \text{ m}^3 = 80.24 \text{ L}$$

Ans: $\boxed{80.2 \text{ L}}$

2-4



At the point of breaking the suction the net external force pulling downward on the lid is equal to the net force upward exerted by the difference in pressure *ΔP* between the outside atmosphere and the pressure of the gas inside the container.

Thus, $$F\downarrow = F\uparrow$$

$$mg = (P_{atm} - P_{gas})A$$

Rearranging: $$P_{gas} = P_{atm} - \frac{mg}{A}$$

$$= 101\,325 - \frac{(50.0)(9.806)}{\pi(0.05)^2}$$

$$= 38\,898 \text{ Pa} = 38.898 \text{ kPa}$$

Ans: $\boxed{38.9 \text{ kPa}}$

2-5

At height *z* the pressure of the atmosphere is given by

$$P = P° - \rho g z$$

Differentiating: $$dP = -\rho g dz$$

$$\rho = \frac{\text{mass}}{\text{volume}} = \frac{m}{V} = \frac{nM}{V}$$

Since PV = nRT, then $$\frac{n}{V} = \frac{P}{RT}$$

and $$\rho = \frac{nM}{V} = \frac{PM}{RT}$$

Therefore: $$dP = -\rho g\, dz = -\left(\frac{PM}{RT}\right) g\, dz$$

Separating variables: $$\frac{dP}{P} = -\frac{Mg}{RT}dz$$

Integrating: $$\int_{P^o}^{P}\frac{dP}{P} = -\frac{Mg}{RT}\int_{0}^{z}dz$$

$$\ln\left(\frac{P}{P^o}\right) = -\frac{Mgz}{RT}$$

$$\frac{P}{P^o} = \exp\left[-\frac{Mgz}{RT}\right]$$

$$P = P^o \cdot \exp\left[-\frac{Mgz}{RT}\right]$$

At z = 5.00 km: $$P = (1.01325)\cdot\exp\left[-\frac{(0.0288)(9.806)(5000)}{(8.314)(273.15)}\right]$$

$$= (1.01325)(0.5370) = 0.5441 \text{ bar}$$

Ans: $\boxed{0.54 \text{ bar}}$

$\boxed{2\text{-}6}$

At height z the pressure of the atmosphere is given by

$$P = P^\circ - \rho g z$$

Differentiating: $$dP = -\rho g dz$$

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$$\ln\left(\frac{P}{P^o}\right) = -\frac{Mgz}{RT}$$

$$\frac{P}{P^o} = \exp\left[-\frac{Mgz}{RT}\right]$$

$$P = P^o \cdot \exp\left[-\frac{Mgz}{RT}\right] \qquad \text{[Already derived in Problem 2-4]}$$

At z = 1.00 km: $$P = (101\ 325)\cdot\exp\left[-\frac{(0.0288)(9.806)(1000)}{(8.314)(273.15)}\right]$$

$$= (101\ 325)(0.8831) = 89\ 476 \text{ Pa}$$

The pressure at a height of 1.0 km is generated by the weight of all the air in the column *above* z = 1.00 km. Thus the force acting on a cross-sectional area of 1.00 m^2 at a height of 1000 m is

$$F_{1000} = P_{1000}A = \left(89\ 476\ \frac{N}{m^2}\right)\left(1.00\ m^2\right) = 89\ 476\ N$$

At ground level (z = 0), the pressure is $P°$ = 101 325 Pa, and the force exerted by the column of air above z = 0 is

$$F_0 = P_0A = \left(101\ 325\ \frac{N}{m^2}\right)\left(1.00\ m^2\right) = 101\ 325\ N$$

The difference between these two forces is just the weight of the air between z = 0 m and z = 1000 m; namely,

$$\begin{aligned}\Delta F &= F_0 - F_1\\ &= 101\ 325 - 89\ 476\\ &= 11\ 849\ N\end{aligned}$$

This force corresponds to a mass of

$$m = \frac{\Delta F}{g} = \frac{11\ 849}{9.806} = 1208\ kg$$

The corresponding number of moles of air is

$$n = \frac{1208\ kg}{0.0288\ kg/mol} = 41\ 944\ mol$$

Ans: $\boxed{41.9\ \text{kmol}}$

2-7

Since the pressure is uniform throughout the fluid at the same height, then, at mechanical equilibrium the pressure P_2 acting on the larger piston face will be the same as the pressure P_1

acting on the smaller piston face:

$$P_1 = P_2$$

i.e.,
$$\frac{F_1}{A_1} = \frac{F_2}{A_2} = \frac{mg}{A_2}$$

from which
$$F_1 = mg\left(\frac{A_1}{A_2}\right) = (250)(9.806)\left(\frac{1.00}{300.0}\right) = 8.172 \text{ N}$$

Thus, a downward force of just *slightly greater* than F_1 = 8.172 N—which corresponds to the force of gravity on a mass of F_1/g = 8.172/9.806 = 0.833 kg—is able to lift a mass of 250 kg.

Ans: $\boxed{8.17 \text{ N}}$

2-8

(a) Her average blood pressure P_h at the level of her heart may be taken as

$$P_h = \tfrac{1}{2}(120 + 80) = 100 \text{ Torr} = (100 \text{ Torr}) \times \left(\frac{101325 \text{ Pa/atm}}{760 \text{ Torr/atm}}\right) = 13\,332 \text{ Pa}$$

When standing, the pressure P_b in her brain will be

$$P_b = P_h - \rho g \Delta z = 13\,332 - (1059.5)(9.806)(0.40)$$
$$= 13\,332 - 4156 = 9176 \text{ Pa} = 9.18 \text{ kPa}$$

Ans: $\boxed{9.18 \text{ kPa}}$

(b) When she bends over, her brain is 35 cm below her heart; therefore, the blood pressure P_b' in her brain now will be

$$P_b' = P_h + \rho g \Delta z = 13\,332 + (1059.5)(9.806)(0.35)$$
$$= 13\,332 + 3636 = 16\,968 \text{ Pa} = 16.97 \text{ kPa}$$

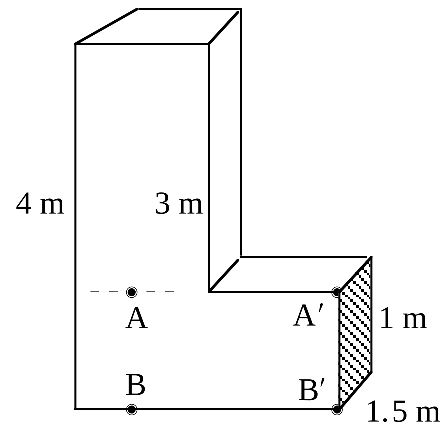
Ans: $\boxed{17.0 \text{ kPa}}$

From bending over to standing up the blood pressure in the brain decreases by 16.97 – 9.18 = 7.79 kPa! No wonder some people get dizzy if they stand up too fast.

2-9

The pressure at A' is the same as the pressure at A; similarly, the pressure at B' is the same as that at B.

Thus,



$$P_{A'} = P_A = P_{atm} + \rho_W g \Delta z_A$$
$$= 100\,000 + (1000)(9.806)(3)$$
$$= 129\,418 \text{ Pa}$$

Similarly,

$$P_{B'} = P_B = P_{atm} + \rho_W g \Delta z_B$$
$$= 100\,000 + (1000)(9.806)(4)$$
$$= 139\,224 \text{ Pa}$$

Thus, the pressure exerted on the cross-hatched area varies linearly downwards from a value of 129 418 Pa at the top of the face to a value of 139 224 Pa at the bottom.

The average pressure $\overline{P}$ acting on the face is thus

$$\overline{P} = \tfrac{1}{2}(129\,418 + 139\,224) = 134\,321 \text{ Pa}$$

and the net force acting on the face is

$$F = \overline{P}A = (134\,321)(1 \times 1.5)$$
$$= 201\,482 \text{ N} = 201 \text{ kN}$$

Ans: $\boxed{201 \text{ kN}}$

2-10

Let the densities of water, ice, and air be ρ_W, ρ_{ice}, and ρ_A, respectively. Let the total volume of the ice cube be V and the volume of that part of the ice cube floating *beneath* the surface of the water be V'.

Thus, according to Archimede's principle, the upward buoyant force $F_W\uparrow$ acting on the ice cube that is exerted by the displaced water is

$$F_W\uparrow = V'\rho_W g$$

Similarly, the upward buoyancy force $F_A\uparrow$ exerted upwards on the ice cube by the air that is displaced by that portion of the ice cube that is *above* the surface of the water is

$$F_A\uparrow = (V - V')\rho_A g$$

These upward forces are balanced by the downward force of gravity $F\downarrow$ acting on the mass m of the ice cube:

$$F\downarrow = mg = V\rho_{ice}\, g$$

For mechanical equilibrium (i.e., for the ice cube to float):

$$F\downarrow = F_W\uparrow + F_A\uparrow$$

i.e., $$V\rho_{ice}\, g = V'\rho_W g + (V - V')\rho_A g$$

Rearranging: $$V' = \left(\frac{\rho_{ice} - \rho_A}{\rho_W - \rho_A}\right) V \qquad \text{. . . [a]}$$

Let V_W be the volume of water formed when the ice cube melts.

Mass of ice cube = mass of melted water

i.e., $$V\rho_{ice} = V_W\rho_W$$

Rearranging: $$V_W = \left(\frac{\rho_{ice}}{\rho_W}\right) V \qquad \text{. . . [b]}$$

Dividing Eqn [b] by Eqn [a]: $$\frac{V_W}{V'} = \left(\frac{\rho_{ice}}{\rho_W}\right) \Bigg/ \left(\frac{\rho_{ice} - \rho_A}{\rho_W - \rho_A}\right) \qquad \text{. . . [c]}$$

Now consider the following:

$\rho_{ice} < \rho_W$, therefore $$\rho_{ice} = \rho_W - k$$

where k is a positive number.

Therefore: $$\frac{\rho_{ice}}{\rho_W} = \frac{\rho_W - k}{\rho_W} = 1 - \frac{k}{\rho_W} \qquad \text{. . . [d]}$$

Similarly, $$\frac{\rho_{ice} - \rho_A}{\rho_W - \rho_A} = \frac{(\rho_W - k) - \rho_A}{\rho_W - \rho_A} = 1 - \frac{k}{\rho_W - \rho_A} \qquad \text{. . . [e]}$$

But, since $(\rho_W - \rho_A) < \rho_W$

it follows that $$\frac{k}{\rho_W - \rho_A} > \frac{k}{\rho_W}$$

i.e., $$\frac{k}{\rho_W - \rho_A} = \frac{k}{\rho_W} + k'$$

where k' also is a positive number.

Therefore, $$1 - \frac{k}{\rho_W - \rho_A} = 1 - \left(\frac{k}{\rho_W} + k'\right) = \left(1 - \frac{k}{\rho_W}\right) - k' \qquad \ldots [f]$$

Substituting Eqn [f] into Eqn [e] gives

$$\frac{\rho_{ice} - \rho_A}{\rho_W - \rho_A} = \left(1 - \frac{k}{\rho_W}\right) - k' \qquad \ldots [g]$$

Comparing Eqns [e] and [g] shows that

$$\frac{\rho_{ice}}{\rho_W} > \frac{\rho_{ice} - \rho_A}{\rho_W - \rho_A}$$

and therefore, from Eqn [c], $$\frac{V_W}{V'} = \left(\frac{\rho_{ice}}{\rho_W}\right) \Big/ \left(\frac{\rho_{ice} - \rho_A}{\rho_W - \rho_A}\right) > 1$$

That is, $$V_W > V'$$

Therefore the volume V_W of the melted ice cube is slightly greater than the volume V' of the submerged ice; if it weren't for surface tension, when the ice melts the liquid would slightly overflow.

Ans: $\boxed{\text{Level rises}}$

$\boxed{\text{2-11}}$

Figs (a) and (b) show the situation before and after the rock is thrown overboard. Let the pond be of rectangular cross-section and have surface area A and initial depth y. Let the boat also be of rectangular cross-section of surface area A'. Initially the draft of the boat is x metres. After the rock has been thrown overboard the level of the pond is y' and the draft of the boat is x'.

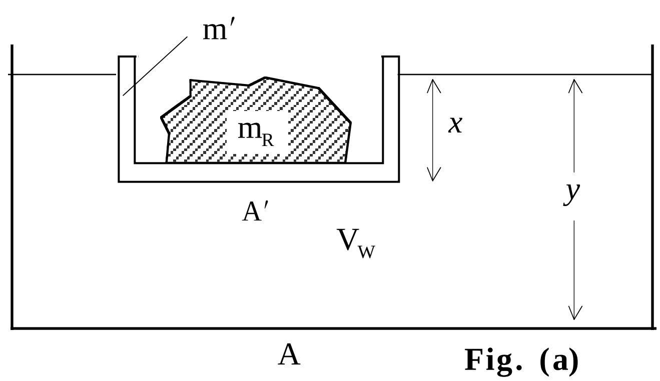


Fig. (a)

Using Archimede's principle, the force balance for the initial situation in Fig. (a) is

$$F\downarrow = (m_R + m')g$$

and $$F\uparrow = (A'x)\rho_W g$$

Force balance: $$F\downarrow = F\uparrow$$

$$\left(m_R + m'\right)g = \left(A'x\right)\rho_W g$$

Solving for x: $\quad x = \dfrac{m_R + m'}{A'\rho_W}$

The displacement volume $A'x$ of the boat in effect increases the volume of the pond from V_W to $(V_W + A'x)$. Therefore the effective depth of the pond in case (a) is

$$y = \frac{V_W + A'x}{A}$$

When the rock is thrown overboard—Fig. (b)—the new force balance is

$$F'\downarrow = F'\uparrow$$

$$m'g = \left(A'x'\right)\rho_W g$$

From which $\quad x' = \dfrac{m'g}{A'\rho_W g} = \dfrac{m'}{A'\rho_W}$

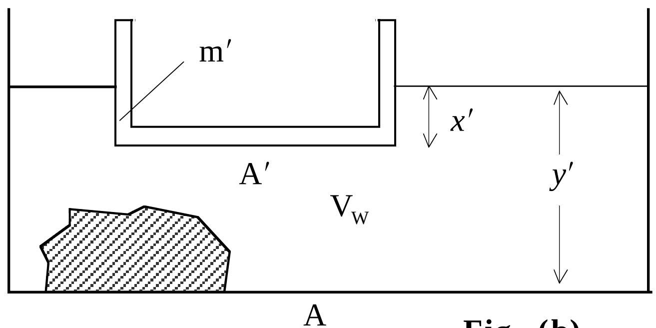


Fig. (b)

Now the new effective volume of the pond

is $(V_W + V_R + A'x')$ of effective depth

$$y' = \frac{V_W + V_R + A'x'}{A}$$

Let us assume that $y' < y$, i.e., the level of the pond goes *down* after the rock is dumped.

[If this doesn't work out, we could assume either of the other two cases.]

If this assumption is true, then

$$\frac{V_W + V_R + A'x'}{A} < \frac{V_W + A'x}{A}$$

i.e., $$V_W + V_R + A'x' < V_W + A'x$$

Subtracting V_W from each side: $$V_R + A'x' < A'x$$

i.e., $$\frac{m_R}{\rho_R} + A'\left(\frac{m'}{A'\rho_W}\right) < A'\left(\frac{m_R + m'}{A'\rho_W}\right)$$

$$\frac{m_R}{\rho_R} + \frac{m'}{\rho_W} < \frac{m_R}{\rho_W} + \frac{m'}{\rho_W}$$

Subtracting m'/ρ_W from each side: $$\frac{m_R}{\rho_R} < \frac{m_R}{\rho_W}$$

Dividing through by m_R: $$\frac{1}{\rho_R} < \frac{1}{\rho_W}$$

Inverting (this changes the direction of the inequality sign):

$$\rho_R > \rho_W$$

Yes!! This is true because the rock sinks!

Therefore $y' < y$ and the level of the pond *falls* when the rock is thrown overboard.

Ans: $\boxed{\text{Level falls}}$

$\boxed{\text{2-12}}$

Mass of helium: $$m_{He} = nM = \left(\frac{PV}{RT}\right)M = \left(\frac{(105\ 000)(5000)}{(8.314)(293.15)}\right)(0.00400) = 861.6 \text{ kg}$$

Density of surrounding air at 20°C and 1.00 bar pressure:

$$\rho_{air} = \frac{nM}{V} = \left(\frac{P}{RT}\right)M = \left(\frac{100\ 000}{(8.314)(293.15)}\right)(0.0288) = 1.1817 \text{ kg m}^{-3}$$

Total volume V of air displaced by airship is $V = 5000 + 30 = 5030 \text{ m}^3$

Mass of air displaced is $m_{air} = \rho_{air}V = (1.1817)(5030) = 5943.95 \text{ kg}$

Upward buoyancy force: $F\uparrow = m_{air}\, g = 5943.95\, g$

Total downward force:
$$\begin{aligned} F\downarrow &= (m_{He} + m_{blimp} + m')\, g \\ &= (861.6 + 4200 + m')\, g \\ &= (5061.6 + m')\, g \end{aligned}$$

Force balance for lift-off: $F\downarrow = F\uparrow$

$$(5061.6 + m')\, g = 5943.95\, g$$

$$m' = 5943.95 - 5061.6$$

$= 882.35$ kg

Ans: $\boxed{882 \text{ kg}}$

$\boxed{\text{2-13}}$

$$P_{gauge} = (50 \text{ psig})\left(\frac{1 \text{ atm}}{14.6959 \text{ psig}} \times \frac{101\,325 \text{ Pa}}{1 \text{ atm}}\right) = 344\,739 \text{ Pa}$$

$$P = P_{atm} + \rho g \Delta z$$

$$P - P_{atm} = P_{gauge} = \rho g \Delta z$$

$$344\,739 = (997)(9.806)\Delta z$$

$$\Delta z = \frac{344\,739}{(997)(9.806)} = 35.26 \text{ m}$$

This is about four stories high.

Ans: $\boxed{35.3 \text{ m}}$

$\boxed{\text{2-14}}$

The balance actually measures force (the force of gravity acting on the mass); the scale is calibrated, however, to give the readout in kilograms.

The density of the air is

$$\rho_{air} = \frac{nM}{V} = \left(\frac{P}{RT}\right)M = \left(\frac{100\,000}{(8.314)(298.15)}\right)(0.0288) = 1.1618 \text{ kg m}^{-3}$$

Let the volume of the object be V and the densities of water and of the unknown liquid be ρ_W and ρ, respectively.

In air the net downward force is: $(F\downarrow)_{net} = mg = 4.00g$

But $(F\downarrow)_{net} = F\downarrow - F\uparrow = mg - \rho_{air} gV$

Therefore: $mg - \rho_{air} gV = 4.00g$ . . . [a]

Similarly, in water: $(F\downarrow)_{net} = F\downarrow - F\uparrow = mg - \rho_W gV$

i.e., $$mg - \rho_W gV = 3.65g \qquad ...[b]$$

Finally, in the unknown liquid: $$mg - \rho gV = 3.72g \qquad ...[c]$$

Dividing Eqns [a], [b], and [c] by g: $$m - \rho_{air}V = 4.00 \qquad ...[d]$$

$$m - \rho_W V = 3.65 \qquad ...[e]$$

$$m - \rho V = 3.72 \qquad ...[f]$$

We now have three equations in three unknowns (m, V, and ρ).

Eqn [d] – Eqn [e]: $$V(\rho_W - \rho_{air}) = 0.35 \qquad ...[g]$$

Rearranging: $$V = \frac{0.35}{\rho_W - \rho_{air}} = \frac{0.35}{997 - 1.1618}$$
$$= 3.5146 \times 10^{-4}\ m^3 \qquad ...[h]$$

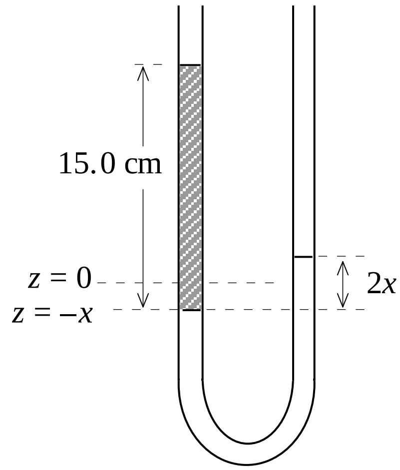
From Eqn [d]: $$m = 4.00 + \rho_{air}V$$
$$= 4.00 + (1.1618)(3.5146 \times 10^{-4})$$
$$= 4.00041\ kg$$

Finally, from Eqn [f]: $$\rho = \frac{m - 3.72}{V} = \frac{4.00041 - 3.72}{3.5146 \times 10^{-4}}$$
$$= 797.8\ kg\ m^{-3}$$

Ans: $\boxed{798\ kg\ m^{-3}}$

2-15

The 15.0 cm of water in the left arm pushes the mercury level down in the left arm by an amount x from its initial level at $z = 0$ and up in the right arm by an equal amount x.



For mechanical equilibrium, the total pressure in both arms at the level $z = -x$ must be the same.

Thus:

$$P_{left} = P_{right}$$

$$P_{atm} + (\rho g \Delta z)_{water} = P_{atm} + (\rho g \Delta z)_{Hg}$$

Subtracting P_{atm} from each side and dividing through by g:

$$\rho_W \Delta z_W = \rho_{Hg} \Delta z_{Hg}$$

$$(0.997)(15.0) = (13.55)(2x)$$

$$x = \frac{0.997 \times 15.0}{13.55 \times 2} = 0.5518 \text{ cm}$$

Ans: $\boxed{0.552 \text{ cm}}$

$\boxed{\text{2-16}}$

Basis: 100 cm^3 of wood.

Let the density of the wood be ρ_{wood} g cm^{-3}.

The wood displaces 60.0 cm^3 of oil; the mass of the displaced oil is

$$\left(60.0 \text{ cm}^3 \text{ oil}\right)\left(1.25 \frac{\text{g oil}}{\text{cm}^3 \text{ oil}}\right) = 75.0 \text{ grams of oil}$$

The downward force of gravity exerted on the wood is

$$F\downarrow = m_{wood}\, g = \left(100.0 \text{ cm}^3 \times \rho_{wood} \frac{\text{g}}{\text{cm}^3}\right) g = 100.0\, \rho_{wood}\, g$$

with the acceleration due to gravity g in appropriate units.

The upward buoyancy force exerted on the wood is

$$F\uparrow = m_{\text{oil displaced}}\, g = (75.0 \text{ grams})g$$

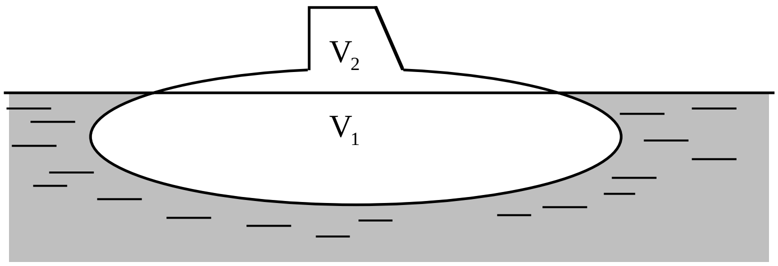
For mechanical equilibrium: $F\downarrow = F\uparrow$

i.e., $100.0\, \rho_{wood}\, g = 75.0g$

from which $\rho_{wood} = \dfrac{75.0g}{100.0g} = \dfrac{75.0}{100.0} = 0.750 \text{ g cm}^{-3} = 750 \text{ kg m}^{-3}$

Ans: $\boxed{750 \text{ kg m}^{-3}}$

2-17



When surfaced:

$$F\downarrow = F\uparrow$$

$$mg = V_1 \rho_{sea}\, g$$

$$V_1 = \frac{m}{\rho_{sea}} = \frac{3.40 \times 10^7}{1025} = 33\ 171\ m^3$$

10% of the total volume is above the surface;

therefore:

$$\frac{V_2}{V_1 + V_2} = 0.10$$

$$V_2 = 0.10V_1 + 0.10V_2$$

$$0.90V_2 = 0.10V_1$$

$$V_2 = \frac{0.10V_1}{0.90} = \frac{(0.10)(33171)}{0.90} = 3687\ m^3$$

Let the mass of seawater that must be taken aboard to submerge be m' kg.

When submerged:

$$F\downarrow = F\uparrow$$

$$(m + m')g = (V_1 + V_2)\rho_{sea}\, g$$

Therefore

$$m' = (V_1 + V_2)\rho_{sea} - m$$

$$= (33\ 171 + 3687)(1025) - 3.40 \times 10^7$$

$$= 37\ 779\ 450 - 34\ 000\ 000$$

$$= 3\ 779\ 450\ kg$$

Ans: $\boxed{3.78 \times 10^6\ kg}$