Problem

5. A plant hangs from a 3.2-cm diameter suction cup affixed to a smooth horizontal surface (Fig. 18-42). What is the maximum weight that can be suspended (a) at sea level and (b) in Denver, where atmospheric pressure is about 0.80 atm?

FIGURE 18-42 Problem 5.

Solution

(a) The force exerted on the suction cup by the atmosphere is $F = PA = P_{\text{atm}}(\pi d^2/4) = (1.013\times 10^5\text{ Pa})\pi(0.016\text{ m})^2 = 81.5\text{ N}$ (perfect vacuum inside cup assumed). This is equal to the maximum weight. (b) At Denver, $P = 0.8P_{\text{atm}}$, so the maximum weight is 80% of that in part (a), or 65.2 N (a slight variation in g with altitude is neglected).

Problem

11. A paper clip is made from wire 1.5 mm in diameter. You unbend a paper clip and push the end against the wall. What force must you exert to give a pressure of 120 atm?

Solution

An average pressure of 120 atm over the cross-sectional area of the wire, $\frac{1}{4}\pi d^2$, results in a force of $F = PA = (120\times 101.3\text{ kPa})\frac{1}{4}\pi(1.5\times 10^{-3}\text{ m})^2 = 21.5\text{ N}$.

Problem

13. When a couple with a total mass of 120 kg lies on a water bed, the pressure in the bed increases by 4700 Pa. What surface area of the two bodies is in contact with the bed?

Solution

The pressure increase times the average horizontal contact surface area equals the weight of the couple, or $A_{\text{av}} = mg/\Delta P = (120\times 9.8\text{ N})/(4700\text{ Pa}) = 0.250\text{ m}^2$.

Problem

19. Scuba equipment provides the diver with air at the same pressure as the surrounding water. But at pressures greater than about 1 MPa, the nitrogen in air becomes dangerously narcotic. At what depth does nitrogen narcosis become a hazard?

Solution

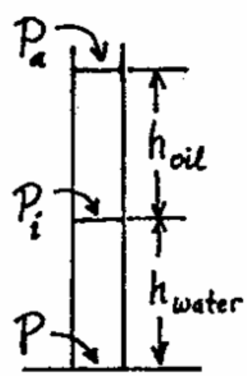
In fresh water ($\rho \simeq 10^3\text{ kg/m}^3$), the pressure is 1 MPa at a depth of $h = (P - P_0)/\rho g = (1\text{ MPa} - 0.103\text{ MPa})/(9.8\times 10^3\text{ N/m}^3) = 91.7\text{ m}$, where P_0 is atmospheric pressure at the surface. (See Equation 18-3.) The depth is a little less in salt water since its density is slightly greater.

Problem

21. A vertical tube open at the top contains 5.0 cm of oil (density 0.82 g/cm^3) floating on 5.0 cm of water. Find the *gauge* pressure at the bottom of the tube.

Solution

The pressure at the top of the tube is atmospheric pressure, P_a. The absolute pressure at the interface of the oil and water is $P_i = P_a + \rho_{\text{oil}} g h_{\text{oil}}$, and at the bottom is $P = P_i + \rho_{\text{water}} g h_{\text{water}} = P_a + \rho_{\text{oil}} g h_{\text{oil}} + \rho_{\text{water}} g h_{\text{water}}$ (see Equation 18-3). Therefore, the gauge pressure at the bottom is $P - P_a = (\rho_{\text{oil}} h_{\text{oil}} + \rho_{\text{water}} h_{\text{water}})g = (0.82 + 1.00)(10^3\text{ kg/m}^3)(0.05\text{ m})\times(9.8\text{ m/s}^2) = 892\text{ Pa}$ (gauge).



Problem 21 Solution.

Problem

25. A U-shaped tube open at both ends contains water and a quantity of oil occupying a 2.0-cm length of the tube, as shown in Fig. 18-45. If the oil's density is 0.82 times that of water, what is the height difference h?

Solution

From Equation 18-3, the pressure at points at the same level in the water is the same, $P_1 = P_2$. Now, $P_1 = P_{\text{atm}} + \rho_{H_2O} g(2\text{ cm} - h)$ and $P_2 = P_{\text{atm}} + \rho_{\text{oil}} g(2\text{ cm})$, so $h = (2\text{ cm})(1 - \rho_{\text{oil}}/\rho_{H_2O}) = (2\text{ cm})\times(1 - 0.82) = 3.6\text{ mm}$ (h is positive as shown).

Problem

29. A garage lift has a 45-cm diameter piston supporting the load. Compressed air with a maximum pressure of 500 kPa is applied to a small piston at the other end of the hydraulic system. What is the maximum mass the lift can support?

Solution

If we neglect the variation of pressure with height in the hydraulic system (which is usually small compared to the applied pressure), the fluid pressure is the same throughout, or $P_{\text{appl}} = F/A$ (for either the small or large cylinders). Thus, $F_{\text{max}} = (500 \text{ kPa})\frac{1}{4}\pi \times (0.45 \text{ m})^2 = 79.5 \text{ kN}$, which corresponds to a mass-load of $F_{\text{max}}/g = 8.11$ tonnes (metric tons).

31. On land, the most massive concrete block you can carry is 25 kg. How massive a block could you carry underwater, if the density of concrete is 2300 kg/m^3?

Solution

The 25×9.8 N force you exert underwater is equal to the apparent weight of the most massive block of concrete when submerged, $W_{\text{app}} = W - F_b = W(1 - \rho_w/\rho_c)$, where ρ_c/ρ_w is the ratio of the densities of concrete and water (also known as the specific gravity of concrete). (This relation is derived in Example 18-4, since the buoyant force on an object submerged in fluid is $F_b = W\rho_{\text{fluid}}/\rho$.) Thus, $W = W_{\text{app}}(1 - \rho_w/\rho_c)^{-1}$, or $m = W/g = (25 \text{ kg}) \times (1 - 1/2.3)^{-1} = 44.2$ kg.

Problem

35. A partially full beer bottle with interior diameter 52 mm is floating upright in water, as shown in Fig. 18-47. A drinker takes a swig and replaces the bottle in the water, where it now floats 28 mm higher than before. How much beer did the drinker drink?

Solution

Archimedes' principle implies that the weight of the beer swallowed equals the difference in the weight of water displaced by the bottle, before and after. Therefore $\Delta m_{\text{beer}} = \rho_{H_2O}\,\Delta V$, where "$g$" was canceled from both sides. The difference in the volume of water displaced equals the cross-sectional area of the bottle times 28 mm. If we ignore the thickness of the walls of the bottle, $\Delta m_{\text{beer}} = (1 \text{ g/cm}^3)\pi(\frac{1}{2} \times 5.2 \text{ cm})^2 \times (2.8 \text{ cm}) = 59.5$ g.

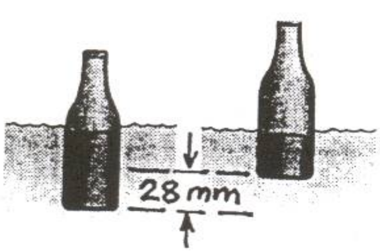


FIGURE 18-47 Problem 35 Solution.

Problem

39. (a) How much helium (density 0.18 kg/m^3) is needed to lift a balloon carrying two people in a basket, if the total mass of people, basket, and balloon (but not gas) is 280 kg? (b) Repeat for a hot air balloon, whose air density is 10% less than that of the surrounding atmosphere.

Solution

The buoyant force must exceed the weight of the load (mass M, including the balloon) plus the gas (mass m), $F_b \geq (M + m)g$. But $F_b = \rho_{\text{air}} gV$, and if we neglect the volume of the balloon's skin etc. compared to that of the gas it contains, $V = m/\rho_{\text{gas}}$, therefore $m = \rho_{\text{gas}} V = \rho_{\text{gas}}(F_b/\rho_{\text{air}} g) \geq (\rho_{\text{gas}}/\rho_{\text{air}})(M + m)$ or $m \geq M\rho_{\text{gas}}/(\rho_{\text{air}} - \rho_{\text{gas}})$. (a) When the gas is helium, $\rho_{\text{air}}/\rho_{\text{He}} = 1.2/0.18$, and $m \geq (280 \text{ kg})(6.67 - 1)^{-1} = 49.4$ kg. (b) For hot air, $\rho_{\text{gas}} = 0.9\rho_{\text{air}}$, and $m \geq (280 \text{ kg})(0.9/0.1) = 2520$ kg. (Note: these masses correspond to gas volumes of 275 m^3 for helium and 2330 m^3 for hot air.)

Problem

43. A typical mass flow rate for the Mississippi River is 1.8×10^7 kg/s. Find (a) the volume flow rate and (b) the flow speed in a region where the river is 2.0 km wide and an average of 6.1 m deep.

Solution

(a) The mass flow rate and the volume flow rate are related by Equations 18-4b and 5, namely $R_m = \rho v A = \rho R_V$. Therefore, $R_V = (1.8 \times 10^7 \text{ kg/s}) \div (10^3 \text{ kg/m}^3) = 1.8 \times 10^4 \text{ m}^3\text{/s}$ for the Mississippi.
(b) At a point in the river where the cross-sectional area is given, the average speed of flow is $v = R_V/A = (1.8 \times 10^4 \text{ m}^3\text{/s})/(2 \times 10^3 \times 6.1 \text{ m}^2) = 1.48$ m/s ($= 5.31$ km/h $= 3.30$ mph). The actual flow rate of any river varies with the season, local weather and vegetation conditions, and human water consumption.

47. In Fig. 18-48 a horizontal pipe of cross-sectional area A is joined to a lower pipe of cross-sectional area $\frac{1}{2}A$. The entire pipe is full of liquid with density ρ, and the left end is at atmospheric pressure P_a. A small open tube extends upward from the lower pipe. Find the height h_2 of liquid in the small tube (a) when the right end of the lower pipe is closed, so the liquid is in hydrostatic equilibrium, and (b) when the liquid flows with speed v in the upper pipe.

Solution

The continuity equation (Equation 18-5) and Bernoulli's equation (Equation 18-6) can be applied to

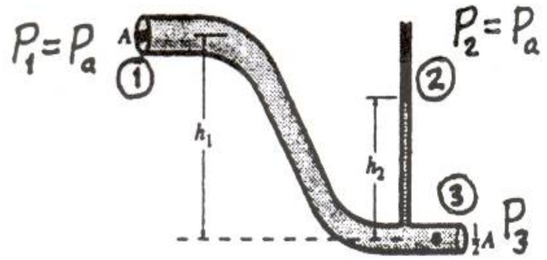


FIGURE 18-48 Problem 47.

an incompressible fluid whether it is at rest or flowing steadily. (a) In hydrostatic equilibrium, the flow speed is zero everywhere. Since the pressure is P_a at the left end of the upper horizontal pipe and at the top of the liquid in the small vertical tube, Equation 18-6a for these points gives $P_a + 0 + \rho g h_1 = P_a + 0 + \rho g h_2$, or $h_1 = h_2$, where we measured the heights y from the lower horizontal tube. (b) In steady flow, Equation 18-5 gives the flow speed in the lower pipe as $v' = v(A/\frac{1}{2}A) = 2v$, where v is the speed in the upper pipe and the cross-sectional areas are given. Then Equation 18-6a gives $P_a + \frac{1}{2}\rho v^2 + \rho g h_1 = P_3 + \frac{1}{2}\rho(2v)^2 + 0$, where P_3 is the pressure anywhere in the lower pipe. (Since the lower pipe is horizontal, $y = 0$, and uniform in cross-section, $v =$ constant, hence $P_3 =$ constant.) Now, even when liquid flows in the pipes, the liquid in the small vertical tube is stagnant. If we assume the pressure is constant over the cross-section of the lower pipe, then Equation 18-3 gives $P_3 = P_a + \rho g h_2$. Combining these results, we find $P_3 - P_a = -\frac{3}{2}\rho v^2 + \rho g h_1 = \rho g h_2$, or $h_2 = h_1 - 3v^2/2g$.

48. A can of height h is full of water. At what height y should a small hole be cut so the water initially goes as far horizontally as it does vertically, as shown in Fig. 18-49?

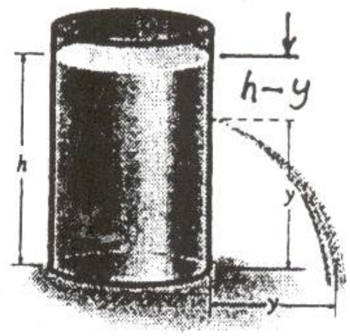


FIGURE 18-49 Problem 48.

Solution

In order for the initial horizontal distance to equal the height of the hole, the velocity of efflux (v_{hole} in Example 18-8) times the time of fall must equal y in Fig. 18-49. (The water is in free fall with initial velocity $v_{\text{hole}} = v_{\text{ox}}$.) Then $y = \frac{1}{2}gt^2 = v_{\text{hole}}t$, or $y = 2v_{\text{hole}}^2/g$. Using the approximate value of $v_{\text{hole}} = \sqrt{2g(h-y)}$ from Example 18-8, where $h - y$ has been substituted for the vertical distance between the height of the fluid and the hole, we find that $y = 2(2g)(h-y)/g = 4(h-y)$, or $y = 4h/5$. (The expression for v_{hole} in Example 18-8 is called Torricelli's theorem.)

Problem

51. The venturi flowmeter shown in Fig. 18-51 is used to measure the flow rate of water in a solar collector system. The flowmeter is inserted in a pipe with diameter 1.9 cm; at the venturi of the flowmeter the diameter is reduced to 0.64 cm. The manometer tube contains oil with density 0.82 times that of water. If the difference in oil levels on the two sides of the manometer tube is 1.4 cm, what is the volume flow rate?

Solution

If we apply Bernoulli's equation (Equation 18-6a) and the continuity equation (Equation 18-5) to points 1 and 2 in the flowmeter, we can calculate the volume rate of flow:

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2 \quad \text{and} \quad v_1 A_1 = V_2 A_2 \text{ imply}$$

$$P_1 - P_2 = \frac{1}{2}\rho(v_2^2 - v_1^2) = \frac{1}{2}\rho v_1^2 A_1^2 \left(\frac{1}{A_2^2} - \frac{1}{A_1^2}\right),$$

$$\text{or} \quad R_V = v_1 A_1 = \sqrt{\frac{2(P_1 - P_2)}{\rho(A_2^{-2} - A_1^{-2})}}.$$

(This is the same calculation as Example 18-9. Note that pressure variation with height in the flowmeter is assumed negligible.) The pressure difference is related to the difference in height and the density of oil in the manometer (where the fluid is assumed stagnant): $P_1 = P_3 + \rho g y_1$ and $P_2 = P_3 + \rho g y_2 + \rho_{\text{oil}} g h$ imply $P_1 - P_2 = (\rho - \rho_{\text{oil}})gh$, since $y_1 - y_2 = h$. If we use $A = \frac{1}{4}\pi d^2$ for each part of the flowmeter, we finally obtain $R_V = \frac{1}{4}\pi\sqrt{2gh(1 - \rho_{\text{oil}}/\rho)/(d_2^{-4} - d_1^{-4})} =$ $7.20 \text{ cm}^3/\text{s}$, when the given numerical values are substituted (we used h, d_1, d_2 in cm and $g =$ 980 cm/s^2).