Problems

Most of the problems herein are fairly straightforward. More difficult or open-ended assignments are indicated with an asterisk, as in Prob. 2.8. Problems labeled with an EES icon (for example, Prob. 2.62), will benefit from the use of the Engineering Equation Solver (EES), while problems labeled with a disk icon may require the use of a computer. The standard end-of-chapter problems 2.1 to 2.158 (categorized in the problem list below) are followed by word problems W2.1 to W2.8, fundamentals of engineering exam problems FE2.1 to FE2.10, comprehensive problems C2.1 to C2.4, and design projects D2.1 and D2.2.

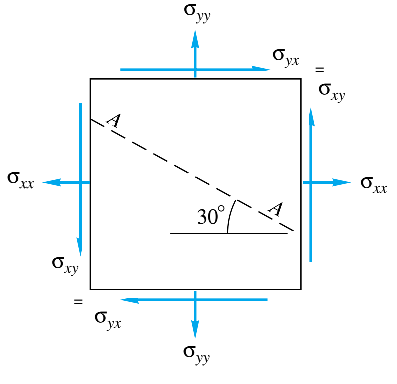
Problem Distribution

Section	Topic	Problems
2.1, 2.2	Stresses; pressure gradient; gage pressure	2.1–2.6
2.3	Hydrostatic pressure; barometers	2.7–2.23
2.3	The atmosphere	2.24–2.29
2.4	Manometers; multiple fluids	2.30–2.47
2.5	Forces on plane surfaces	2.48–2.81
2.6	Forces on curved surfaces	2.82–2.100
2.7	Forces in layered fluids	2.101–2.102
2.8	Buoyancy; Archimedes' principles	2.103–2.126
2.8	Stability of floating bodies	2.127–2.136
2.9	Uniform acceleration	2.137–2.151
2.9	Rigid-body rotation	2.152–2.158
2.10	Pressure measurements	None

P2.1 For the two-dimensional stress field shown in Fig. P2.1 it is found that

$$\sigma_{xx} = 3000 \text{ lbf/ft}^2 \quad \sigma_{yy} = 2000 \text{ lbf/ft}^2 \quad \sigma_{xy} = 500 \text{ lbf/ft}^2$$

Find the shear and normal stresses (in lbf/ft^2) acting on plane AA cutting through the element at a 30° angle as shown.



P2.1

P2.2 For the two-dimensional stress field shown in Fig. P2.1 suppose that

$$\sigma_{xx} = 2000 \text{ lbf/ft}^2 \quad \sigma_{yy} = 3000 \text{ lbf/ft}^2 \quad \sigma_n(AA) = 2500 \text{ lbf/ft}^2$$

Compute (*a*) the shear stress σ_{xy} and (*b*) the shear stress on plane AA.

P2.3 Derive Eq. (2.18) by using the differential element in Fig. 2.2 with z "up," no fluid motion, and pressure varying only in the z direction.

P2.4 In a certain two-dimensional fluid flow pattern the lines of constant pressure, or *isobars,* are defined by the expression $P_0 - Bz + Cx^2 =$ constant, where B and C are constants and p_0 is the (constant) pressure at the origin, $(x, z) = (0, 0)$. Find an expression $x = f(z)$ for the family of lines which are everywhere parallel to the local pressure gradient $\overline{V}_p$.

P2.5 Atlanta, Georgia, has an average altitude of 1100 ft. On a standard day (Table A.6), pressure gage A in a laboratory experiment reads 93 kPa and gage B reads 105 kPa. Express these readings in gage pressure or vacuum pressure (Pa), whichever is appropriate.

P2.6 Any pressure reading can be expressed as a length or *head*, $h = p/\rho g$. What is standard sea-level pressure expressed in (*a*) ft of ethylene glycol, (*b*) in Hg, (*c*) m of water, and (*d*) mm of methanol? Assume all fluids are at 20°C.

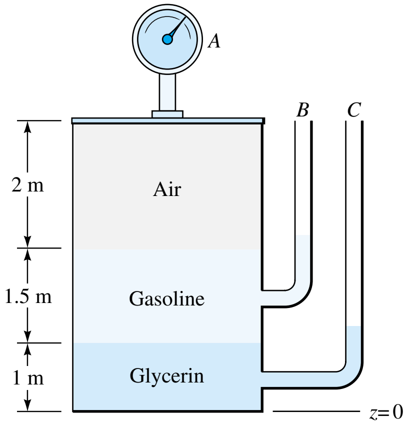
P2.7 The deepest known point in the ocean is 11,034 m in the Mariana Trench in the Pacific. At this depth the specific weight of seawater is approximately 10,520 N/m^3. At the surface, $\gamma \approx 10{,}050 \text{ N/m}^3$. Estimate the absolute pressure at this depth, in atm.

P2.8 *Dry adiabatic lapse rate* (DALR) is defined as the negative value of atmospheric temperature gradient, dT/dz, when temperature and pressure vary in an isentropic fashion. Assuming air is an ideal gas, DALR $= -dT/dz$ when $T = T_0(p/p_0)^a$, where exponent $a = (k-1)/k$, $k = c_p/c_v$ is the ratio of specific heats, and T_0 and p_0 are the temperature and pressure at sea level, respectively. (*a*) Assuming that hydrostatic conditions exist in the atmosphere, show that the dry adiabatic lapse rate is constant and is given by DALR $= g(k-1)/(kR)$, where R is the ideal gas constant for air. (*b*) Calculate the numerical value of DALR for air in units of °C/km.

***P2.9** For a liquid, integrate the hydrostatic relation, Eq. (2.18), by assuming that the *isentropic bulk modulus,* $B = \rho(\partial p/\partial \rho)_s$, is constant—see Eq. (9.18). Find an expression for $p(z)$ and apply the Mariana Trench data as in Prob. 2.7, using B_{seawater} from Table A.3.

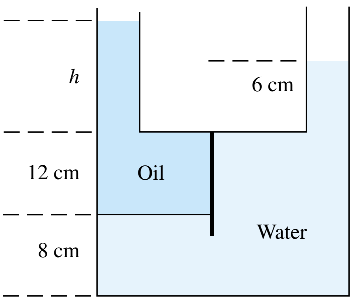
P2.10 A closed tank contains 1.5 m of SAE 30 oil, 1 m of water, 20 cm of mercury, and an air space on top, all at 20°C. The absolute pressure at the bottom of the tank is 60 kPa. What is the pressure in the air space?

P2.11 In Fig. P2.11, pressure gage A reads 1.5 kPa (gage). The fluids are at 20°C. Determine the elevations z, in meters, of the liquid levels in the open piezometer tubes B and C.



P2.11

P2.12 In Fig. P2.12 the tank contains water and immiscible oil at 20°C. What is h in cm if the density of the oil is 898 kg/m^3?

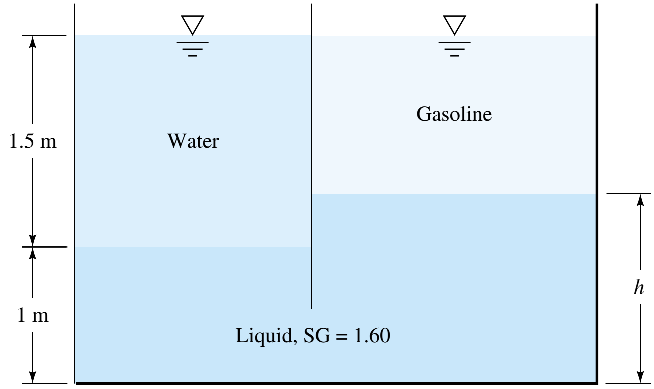


P2.12

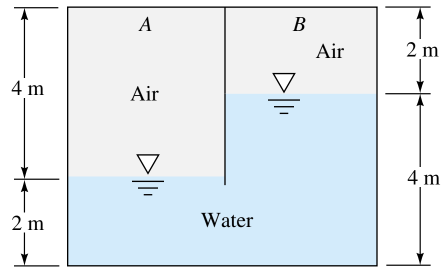
P2.13 In Fig. P2.13 the 20°C water and gasoline surfaces are open to the atmosphere and at the same elevation. What is the height h of the third liquid in the right leg?

P2.14 The closed tank in Fig. P2.14 is at 20°C. If the pressure at point A is 95 kPa absolute, what is the absolute pressure at point B in kPa? What percent error do you make by neglecting the specific weight of the air?

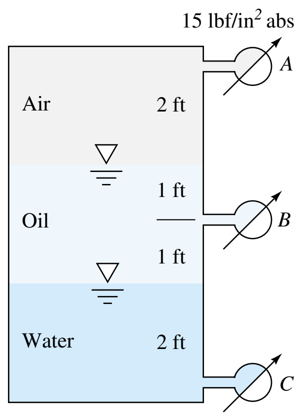
P2.15 The air-oil-water system in Fig. P2.15 is at 20°C. Knowing that gage A reads 15 lbf/in^2 absolute and gage B reads 1.25 lbf/in^2 less than gage C, compute (a) the specific weight of the oil in lbf/ft^3 and (b) the actual reading of gage C in lbf/in^2 absolute.



P2.13



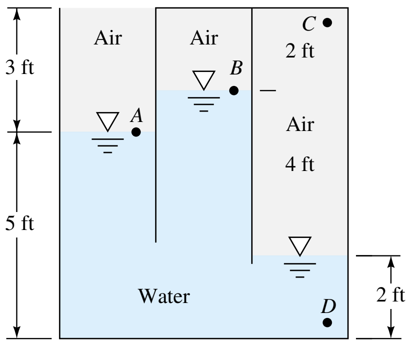
P2.14



P2.15

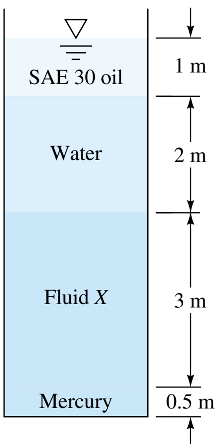
P2.16 A closed inverted cone, 100 cm high with diameter 60 cm at the top, is filled with air at 20°C and 1 atm. Water at 20°C is introduced at the bottom (the vertex) to compress the air isothermally until a gage at the top of the cone reads 30 kPa (gage). Estimate (a) the amount of water needed (cm^3) and (b) the resulting absolute pressure at the bottom of the cone (kPa).

P2.17 The system in Fig. P2.17 is at 20°C. If the pressure at point *A* is 1900 lbf/ft^2, determine the pressures at points *B*, *C*, and *D* in lbf/ft^2.



P2.17

P2.18 The system in Fig. P2.18 is at 20°C. If atmospheric pressure is 101.33 kPa and the pressure at the bottom of the tank is 242 kPa, what is the specific gravity of fluid *X*?

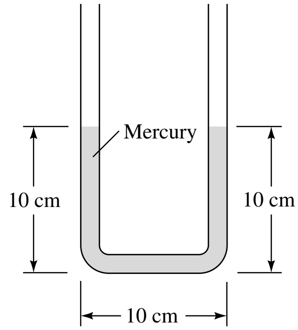


P2.18

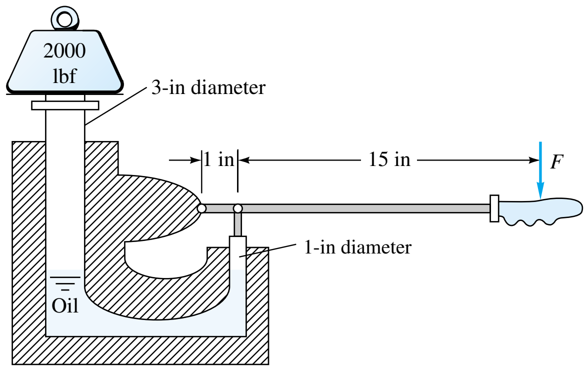
P2.19 The U-tube in Fig. P2.19 has a 1-cm ID and contains mercury as shown. If 20 cm^3 of water is poured into the right-hand leg, what will the free-surface height in each leg be after the sloshing has died down?

P2.20 The hydraulic jack in Fig. P2.20 is filled with oil at 56 lbf/ft^3. Neglecting the weight of the two pistons, what force *F* on the handle is required to support the 2000-lbf weight for this design?

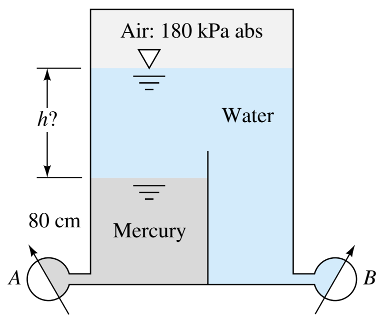
P2.21 At 20°C gage *A* reads 350 kPa absolute. What is the height *h* of the water in cm? What should gage *B* read in kPa absolute? See Fig. P2.21.



P2.19



P2.20

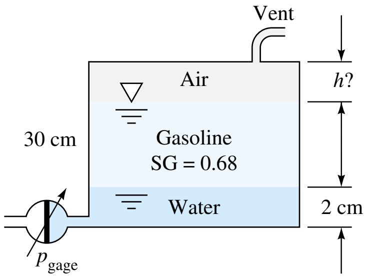


P2.21

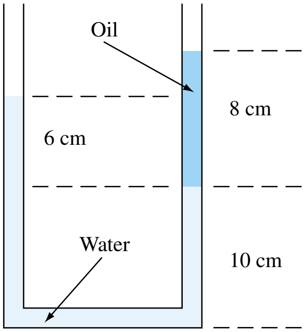
P2.22 The fuel gage for a gasoline tank in a car reads proportional to the bottom gage pressure as in Fig. P2.22. If the tank is 30 cm deep and accidentally contains 2 cm of water plus gasoline, how many centimeters of air remain at the top when the gage erroneously reads "full"?

P2.23 In Fig. P2.23 both fluids are at 20°C. If surface tension effects are negligible, what is the density of the oil, in kg/m^3?

P2.24 In Prob. 1.2 we made a crude integration of the density distribution $\rho(z)$ in Table A.6 and estimated the mass of the earth's atmosphere to be $m \approx 6$ E18 kg. Can this re-



P2.22



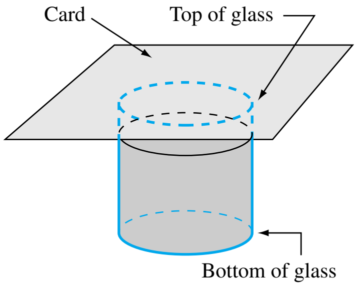
P2.23

sult be used to estimate sea-level pressure on the earth? Conversely, can the actual sea-level pressure of 101.35 kPa be used to make a more accurate estimate of the atmospheric mass?

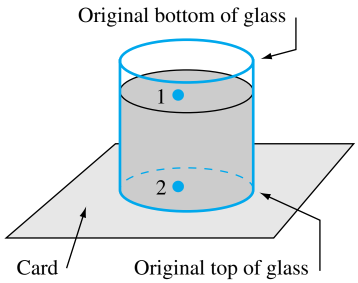
P2.25 Venus has a mass of 4.90 E24 kg and a radius of 6050 km. Its atmosphere is 96 percent CO_2, but let us assume it to be 100 percent. Its surface temperature averages 730 K, decreasing to 250 K at an altitude of 70 km. The average surface pressure is 9.1 MPa. Estimate the atmospheric pressure of Venus at an altitude of 5 km.

P2.26 Investigate the effect of doubling the lapse rate on atmospheric pressure. Compare the standard atmosphere (Table A.6) with a lapse rate twice as high, $B_2 = 0.0130$ K/m. Find the altitude at which the pressure deviation is (a) 1 percent and (b) 5 percent. What do you conclude?

P2.27 Conduct an experiment to illustrate atmospheric pressure. *Note:* Do this over a sink or you may get wet! Find a drinking glass with a very smooth, uniform rim at the top. Fill the glass nearly full with water. Place a smooth, light, flat plate on top of the glass such that the entire rim of the glass is covered. A glossy postcard works best. A small index card or one flap of a greeting card will also work. See Fig. P2.27*a*.
(*a*) Hold the card against the rim of the glass and turn the glass upside down. Slowly release pressure on the card. Does the water fall out of the glass? Record your experimental observations. (*b*) Find an expression for the pressure at points 1 and 2 in Fig. P2.27*b*. Note that the glass is now inverted, so the original top rim of the glass is at the bottom of the picture, and the original bottom of the glass is at the top of the picture. The weight of the card can be neglected.



P2.27a



P2.27b

(*c*) Estimate the theoretical maximum glass height such that this experiment could still work, i.e., such that the water would not fall out of the glass.

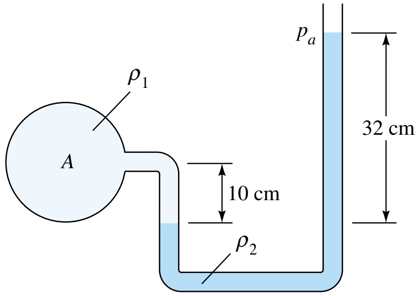
P2.28 Earth's atmospheric conditions vary somewhat. On a certain day the sea-level temperature is 45°F and the sea-level pressure is 28.9 inHg. An airplane overhead registers an air temperature of 23°F and a pressure of 12 lbf/in^2. Estimate the plane's altitude, in feet.

***P2.29** Under some conditions the atmosphere is *adiabatic*, $p \approx (\text{const})(\rho^k)$, where k is the specific heat ratio. Show that, for an adiabatic atmosphere, the pressure variation is given by

$$p = p_0\left[1 - \frac{(k-1)gz}{kRT_0}\right]^{k/(k-1)}$$

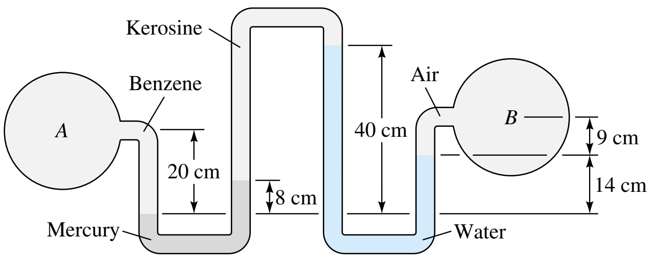
Compare this formula for air at $z = 5000$ m with the standard atmosphere in Table A.6.

P2.30 In Fig. P2.30 fluid 1 is oil (SG = 0.87) and fluid 2 is glycerin at 20°C. If $p_a = 98$ kPa, determine the absolute pressure at point A.



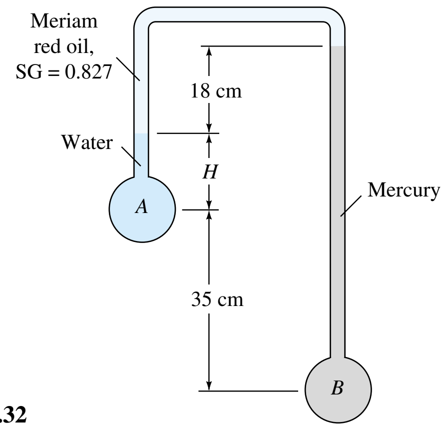
P2.30

P2.31 In Fig. P2.31 all fluids are at 20°C. Determine the pressure difference (Pa) between points A and B.



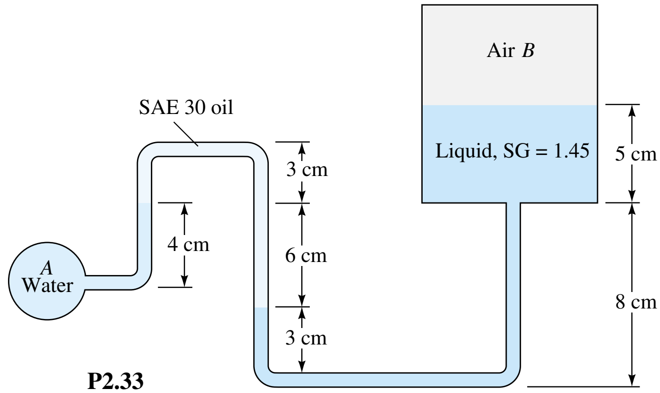
P2.31

P2.32 For the inverted manometer of Fig. P2.32, all fluids are at 20°C. If $p_B - p_A = 97$ kPa, what must the height H be in cm?



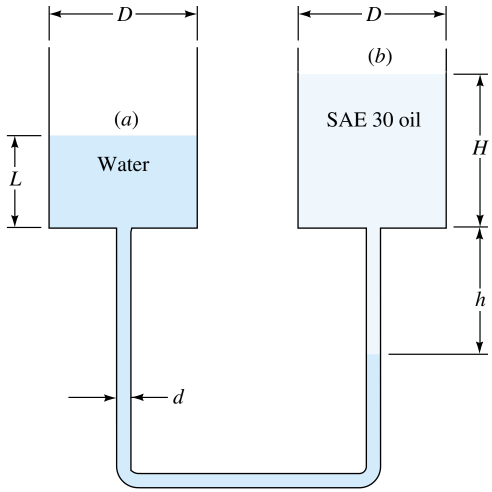
P2.32

P2.33 In Fig. P2.33 the pressure at point A is 25 lbf/in^2. All fluids are at 20°C. What is the air pressure in the closed chamber B, in Pa?



P2.33

***P2.34** Sometimes manometer dimensions have a significant effect. In Fig. P2.34 containers (a) and (b) are cylindrical and conditions are such that $p_a = p_b$. Derive a formula for the pressure difference $p_a - p_b$ when the oil-water interface on the right rises a distance $\Delta h < h$, for (a) $d \ll D$ and (b) $d = 0.15D$. What is the percent change in the value of Δp?

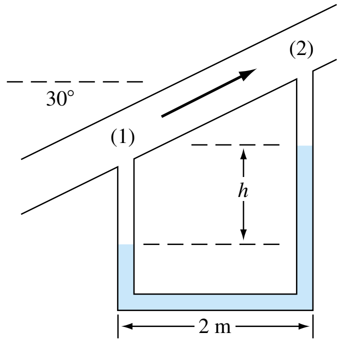


P2.34

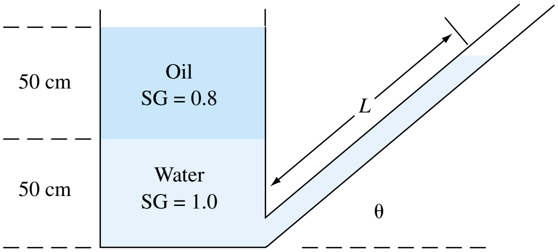
P2.35 Water flows upward in a pipe slanted at 30°, as in Fig. P2.35. The mercury manometer reads $h = 12$ cm. Both fluids are at 20°C. What is the pressure difference $p_1 - p_2$ in the pipe?

P2.36 In Fig. P2.36 both the tank and the tube are open to the atmosphere. If $L = 2.13$ m, what is the angle of tilt θ of the tube?

P2.37 The inclined manometer in Fig. P2.37 contains Meriam red manometer oil, SG = 0.827. Assume that the reservoir

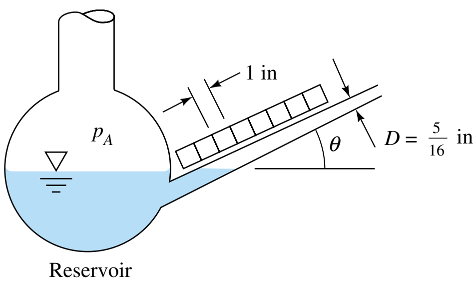


P2.35



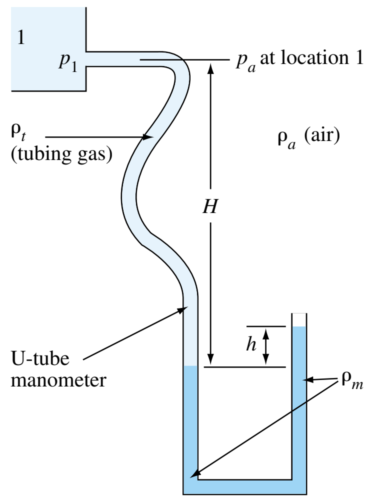
P2.36

is very large. If the inclined arm is fitted with graduations 1 in apart, what should the angle θ be if each graduation corresponds to 1 lbf/ft^2 gage pressure for p_A?



P2.37

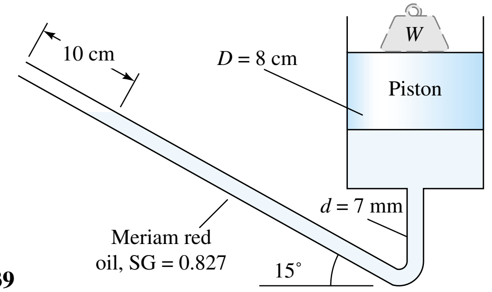
P2.38 An interesting article appeared in the *AIAA Journal* (vol. 30, no. 1, January 1992, pp. 279–280). The authors explain that the air inside fresh plastic tubing can be up to 25 percent more dense than that of the surroundings, due to outgassing or other contaminants introduced at the time of manufacture. Most researchers, however, assume that the tubing is filled with room air at standard air density, which can lead to significant errors when using this kind of tubing to measure pressures. To illustrate this, consider a U-tube manometer with manometer fluid ρ_m. One side of the manometer is open to the air, while the other is connected to new tubing which extends to pressure measurement location 1, some height H higher in elevation than the surface of the manometer liquid. For consistency, let ρ_a be the density of the air in the room, ρ_t be the density of the gas inside the tube, ρ_m be the density of the manometer liquid, and h be the height difference between the two sides of the manometer. See Fig. P2.38. (*a*) Find an expression for the gage pressure at the measurement point. *Note:* When calculating gage pressure, use the local atmospheric pressure at the elevation of the measurement point. You may assume that $h \ll H$; i.e., assume the gas in the entire left side of the manometer is of density ρ_t. (*b*) Write an expression for the error caused by assuming that the gas inside the tubing has the same density as that of the surrounding air. (*c*) How much error (in Pa) is caused by ignoring this density difference for the following conditions: $\rho_m = 860\ kg/m^3$, $\rho_a = 1.20\ kg/m^3$, $\rho_t = 1.50\ kg/m^3$, $H = 1.32$ m, and $h = 0.58$ cm? (*d*) Can you think of a simple way to avoid this error?



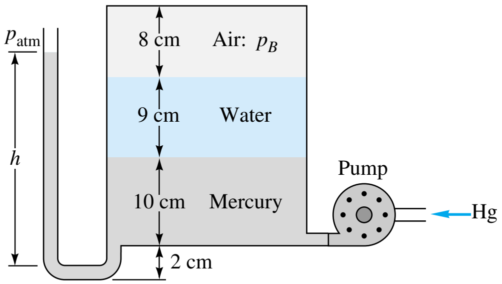
P2.38

P2.39 An 8-cm-diameter piston compresses manometer oil into an inclined 7-mm-diameter tube, as shown in Fig. P2.39. When a weight W is added to the top of the piston, the oil rises an additional distance of 10 cm up the tube, as shown. How large is the weight, in N?

P2.40 A pump slowly introduces mercury into the bottom of the closed tank in Fig. P2.40. At the instant shown, the air pressure p_B = 80 kPa. The pump stops when the air pressure rises to 110 kPa. All fluids remain at 20°C. What will be the manometer reading h at that time, in cm, if it is connected to standard sea-level ambient air p_{atm}?

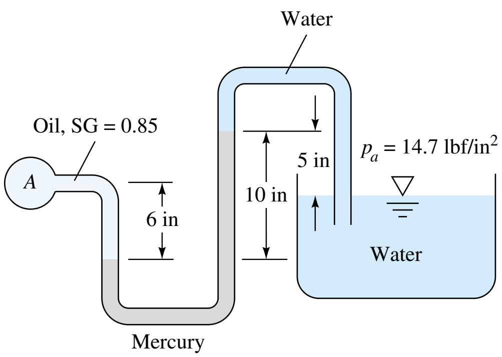


P2.39



P2.40

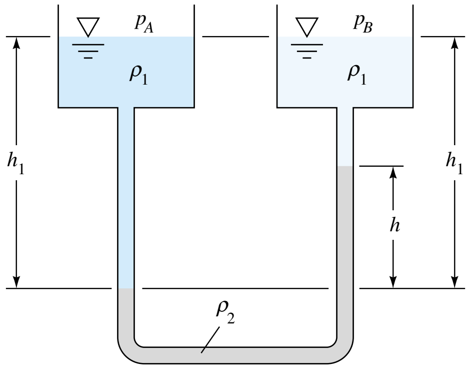
P2.41 The system in Fig. P2.41 is at 20°C. Compute the pressure at point A in lbf/ft^2 absolute.



P2.41

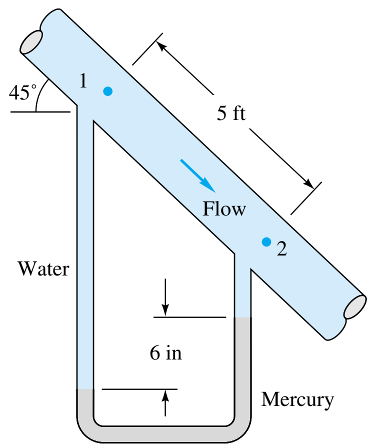
P2.42 Very small pressure differences $p_A - p_B$ can be measured accurately by the two-fluid differential manometer in Fig. P2.42. Density ρ_2 is only slightly larger than that of the upper fluid ρ_1. Derive an expression for the proportionality between h and $p_A - p_B$ if the reservoirs are very large.

***P2.43** A mercury manometer, similar to Fig. P2.35, records $h \approx$ 1.2, 4.9, and 11.0 mm when the water velocities in the pipe are V = 1.0, 2.0, and 3.0 m/s, respectively. Determine if these data can be correlated in the form $p_1 - p_2 \approx C_f \rho V^2$, where C_f is dimensionless.



P2.42

P2.44 Water flows downward in a pipe at 45°, as shown in Fig. P2.44. The pressure drop $p_1 - p_2$ is partly due to gravity and partly due to friction. The mercury manometer reads a 6-in height difference. What is the total pressure drop $p_1 - p_2$ in lbf/in^2? What is the pressure drop due to friction only between 1 and 2 in lbf/in^2? Does the manometer reading correspond only to friction drop? Why?



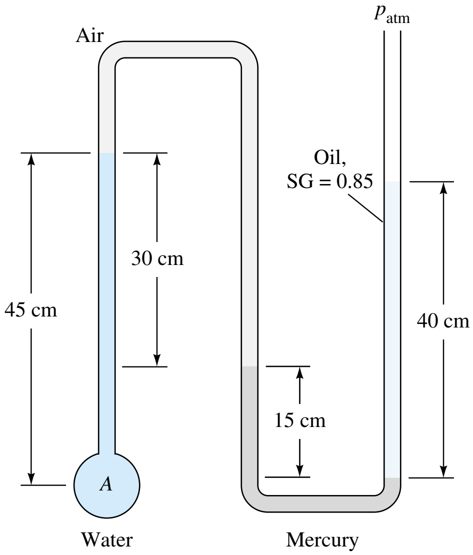
P2.44

P2.45 In Fig. P2.45, determine the gage pressure at point A in Pa. Is it higher or lower than atmospheric?

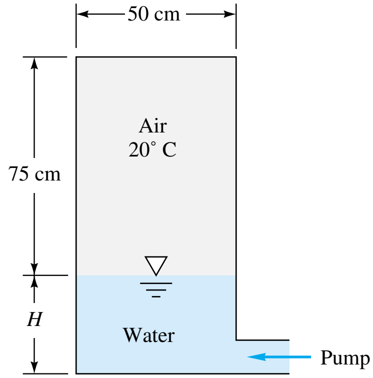
P2.46 In Fig. P2.46 both ends of the manometer are open to the atmosphere. Estimate the specific gravity of fluid X.

P2.47 EES The cylindrical tank in Fig. P2.47 is being filled with water at 20°C by a pump developing an exit pressure of 175 kPa. At the instant shown, the air pressure is 110 kPa and H = 35 cm. The pump stops when it can no longer raise the water pressure. For isothermal air compression, estimate H at that time.

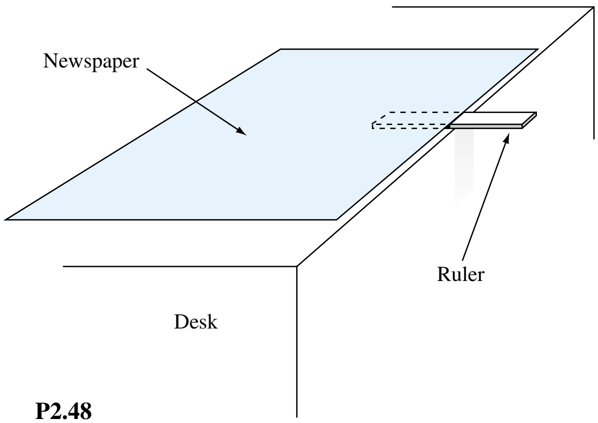
P2.48 Conduct the following experiment to illustrate air pressure. Find a thin wooden ruler (approximately 1 ft in



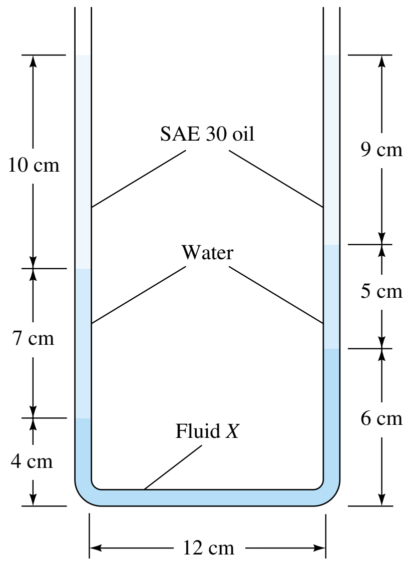
P2.45



P2.47



P2.48



P2.46

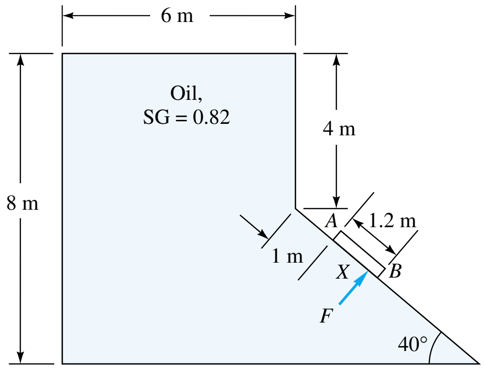
length) or a thin wooden paint stirrer. Place it on the edge of a desk or table with a little less than half of it hanging over the edge lengthwise. Get two full-size sheets of newspaper; open them up and place them on top of the ruler, covering only the portion of the ruler resting on the desk as illustrated in Fig. P2.48. (*a*) Estimate the total force on top of the newspaper due to air pressure in the room. (*b*) *Careful*! To avoid potential injury, make sure nobody is standing directly in front of the desk. Perform a karate chop on the portion of the ruler sticking out over the edge of the desk. Record your results. (*c*) Explain your results.

P2.49 A water tank has a circular panel in its vertical wall. The panel has a radius of 50 cm, and its center is 2 m below the surface. Neglecting atmospheric pressure, determine the water force on the panel and its line of action.

P2.50 A vat filled with oil (SG = 0.85) is 7 m long and 3 m deep and has a trapezoidal cross section 2 m wide at the bottom and 4 m wide at the top. Compute (*a*) the weight of oil in the vat, (*b*) the force on the vat bottom, and (*c*) the force on the trapezoidal end panel.

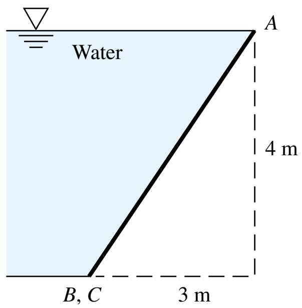
P2.51 Gate *AB* in Fig. P2.51 is 1.2 m long and 0.8 m into the paper. Neglecting atmospheric pressure, compute the force *F* on the gate and its center-of-pressure position *X*.

***P2.52** Suppose that the tank in Fig. P2.51 is filled with liquid *X*, not oil. Gate *AB* is 0.8 m wide into the paper. Suppose that liquid *X* causes a force *F* on gate *AB* and that the moment of this force about point *B* is 26,500 N · m. What is the specific gravity of liquid *X*?



P2.51

P2.53 Panel *ABC* in the slanted side of a water tank is an isosceles triangle with the vertex at *A* and the base *BC* = 2 m, as in Fig. P2.53. Find the water force on the panel and its line of action.



P2.53

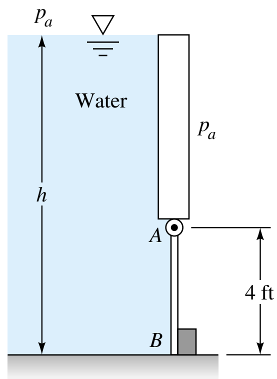
P2.54 If, instead of water, the tank in Fig. P2.53 is filled with liquid *X*, the liquid force on panel *ABC* is found to be 115 kN. What is the density of liquid *X*? The line of action is found to be the same as in Prob. 2.53. Why?

P2.55 Gate *AB* in Fig. P2.55 is 5 ft wide into the paper, hinged at *A*, and restrained by a stop at *B*. The water is at 20°C. Compute (*a*) the force on stop *B* and (*b*) the reactions at *A* if the water depth $h = 9.5$ ft.

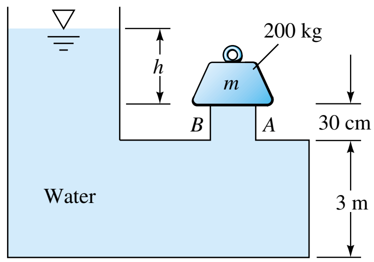
P2.56 In Fig. P2.55, gate *AB* is 5 ft wide into the paper, and stop *B* will break if the water force on it equals 9200 lbf. For what water depth *h* is this condition reached?

P2.57 In Fig. P2.55, gate *AB* is 5 ft wide into the paper. Suppose that the fluid is liquid *X*, not water. Hinge *A* breaks when its reaction is 7800 lbf, and the liquid depth is $h = 13$ ft. What is the specific gravity of liquid *X*?

P2.58 In Fig. P2.58, the cover gate *AB* closes a circular opening 80 cm in diameter. The gate is held closed by a 200-kg mass as shown. Assume standard gravity at 20°C. At what water level *h* will the gate be dislodged? Neglect the weight of the gate.

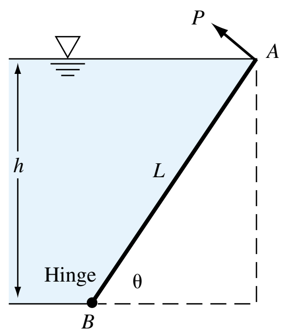


P2.55



P2.58

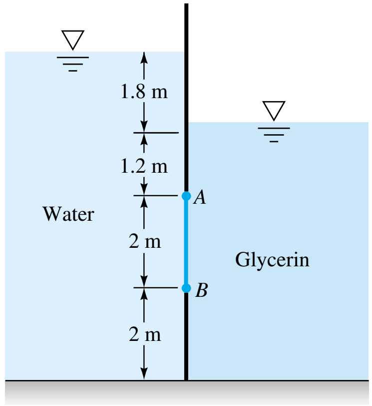
***P2.59** Gate AB has length *L*, width *b* into the paper, is hinged at B, and has negligible weight. The liquid level *h* remains at the top of the gate for any angle θ. Find an analytic expression for the force *P*, perpendicular to AB, required to keep the gate in equilibrium in Fig. P2.59.



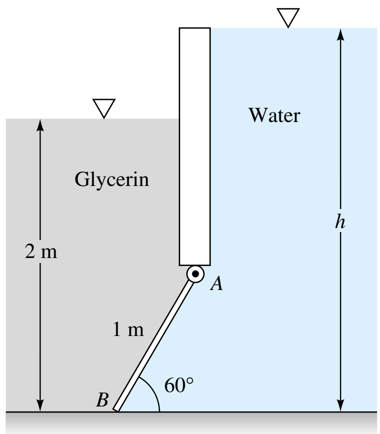
P2.59

***P2.60** Find the net hydrostatic force per unit width on the rectangular gate *AB* in Fig. P2.60 and its line of action.

***P2.61** Gate *AB* in Fig. P2.61 is a homogeneous mass of 180 kg, 1.2 m wide into the paper, hinged at *A*, and resting on a smooth bottom at *B*. All fluids are at 20°C. For what water depth *h* will the force at point *B* be zero?



P2.60



P2.61

P2.62 Gate *AB* in Fig. P2.62 is 15 ft long and 8 ft wide into the paper and is hinged at *B* with a stop at *A*. The water is at 20°C. The gate is 1-in-thick steel, SG = 7.85. Compute the water level *h* for which the gate will start to fall.

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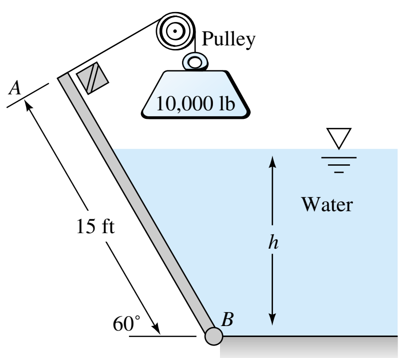
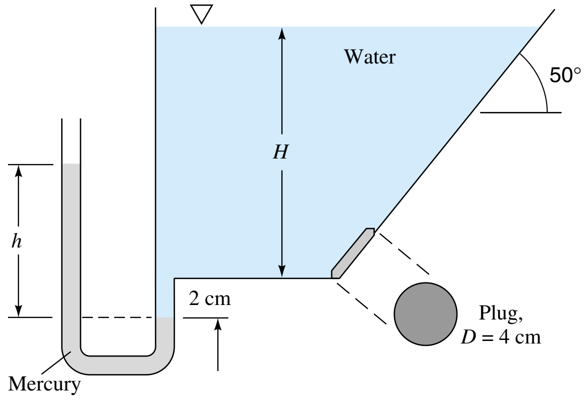


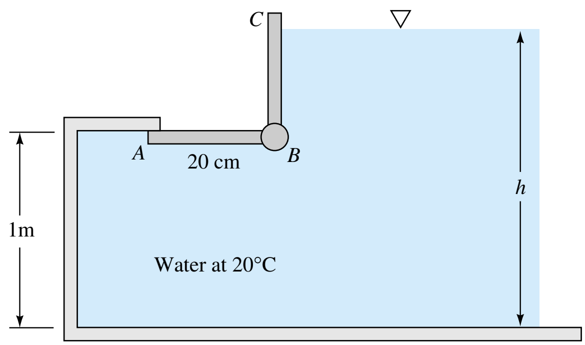
P2.62

P2.63 The tank in Fig. P2.63 has a 4-cm-diameter plug at the bottom on the right. All fluids are at 20°C. The plug will pop out if the hydrostatic force on it is 25 N. For this condition, what will be the reading *h* on the mercury manometer on the left side?



P2.63

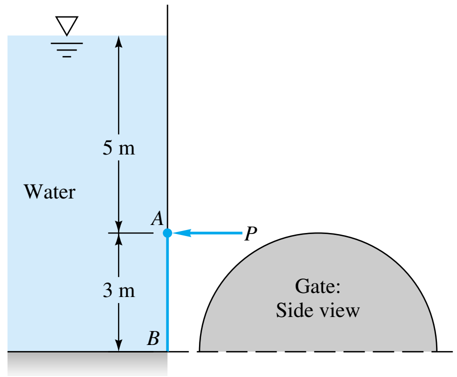
***P2.64** Gate *ABC* in Fig. P2.64 has a fixed hinge line at *B* and is 2 m wide into the paper. The gate will open at *A* to release water if the water depth is high enough. Compute the depth *h* for which the gate will begin to open.



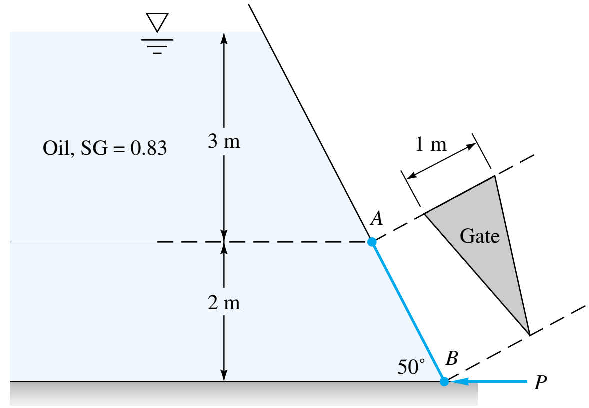
P2.64

***P2.65** Gate *AB* in Fig. P2.65 is semicircular, hinged at *B*, and held by a horizontal force *P* at *A*. What force *P* is required for equilibrium?

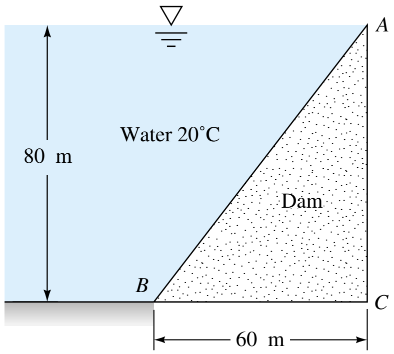
P2.66 Dam *ABC* in Fig. P2.66 is 30 m wide into the paper and made of concrete (SG = 2.4). Find the hydrostatic force on surface *AB* and its moment about *C*. Assuming no seepage of water under the dam, could this force tip the dam over? How does your argument change if there is seepage under the dam?



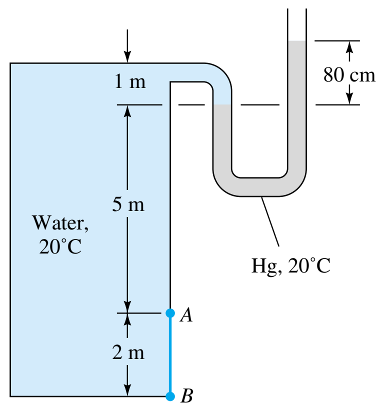
P2.65



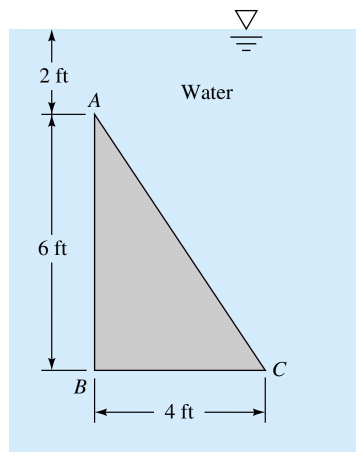
P2.68



P2.66



P2.69



P2.70

***P2.67** Generalize Prob. 2.66 as follows. Denote length *AB* as *H*, length *BC* as *L*, and angle *ABC* as θ. Let the dam material have specific gravity SG. The width of the dam is *b*. Assume no seepage of water under the dam. Find an analytic relation between SG and the critical angle θ_c for which the dam will just tip over to the right. Use your relation to compute θ_c for the special case SG = 2.4 (concrete).

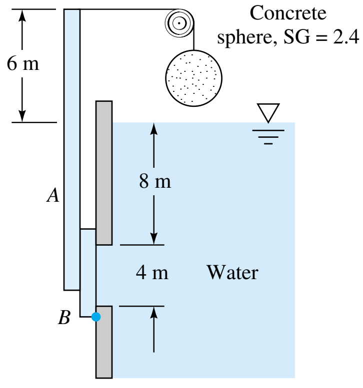
P2.68 Isosceles triangle gate *AB* in Fig. P2.68 is hinged at *A* and weighs 1500 N. What horizontal force *P* is required at point *B* for equilibrium?

***P2.69** The water tank in Fig. P2.69 is pressurized, as shown by the mercury-manometer reading. Determine the hydrostatic force per unit depth on gate *AB*.

P2.70 Calculate the force and center of pressure on one side of the vertical triangular panel *ABC* in Fig. P2.70. Neglect p_{atm}.

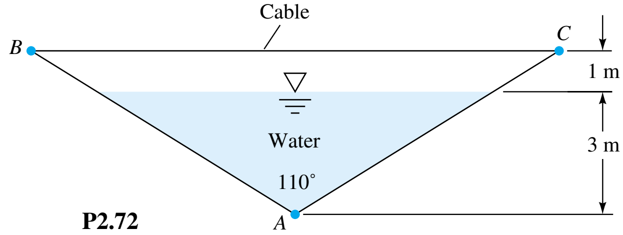
***P2.71** In Fig. P2.71 gate *AB* is 3 m wide into the paper and is connected by a rod and pulley to a concrete sphere (SG =

2.40). What diameter of the sphere is just sufficient to keep the gate closed?



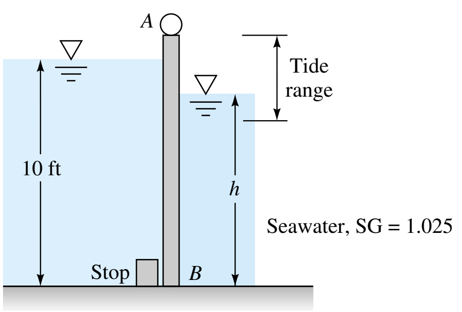
P2.71

P2.72 The V-shaped container in Fig. P2.72 is hinged at *A* and held together by cable *BC* at the top. If cable spacing is 1 m into the paper, what is the cable tension?



P2.72

P2.73 Gate *AB* is 5 ft wide into the paper and opens to let fresh water out when the ocean tide is dropping. The hinge at *A* is 2 ft above the freshwater level. At what ocean level *h* will the gate first open? Neglect the gate weight.



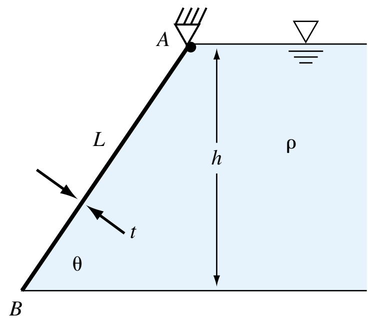
P2.73

***P2.74** In "soft" liquids (low bulk modulus β), it may be necessary to account for liquid compressibility in hydrostatic calculations. An approximate density relation would be

$$dp \approx \frac{\beta}{\rho}\, d\rho = a^2\, d\rho \qquad \text{or} \qquad p \approx p_0 + a^2(\rho - \rho_0)$$

where a is the speed of sound and (p_0, ρ_0) are the conditions at the liquid surface $z = 0$. Use this approximation to show that the density variation with depth in a soft liquid is $\rho = \rho_0 e^{-gz/a^2}$ where g is the acceleration of gravity and z is positive upward. Then consider a vertical wall of width b, extending from the surface ($z = 0$) down to depth $z = -h$. Find an analytic expression for the hydrostatic force F on this wall, and compare it with the incompressible result $F = \rho_0 g h^2 b/2$. Would the center of pressure be below the incompressible position $z = -2h/3$?

***P2.75** Gate *AB* in Fig. P2.75 is hinged at *A*, has width *b* into the paper, and makes smooth contact at *B*. The gate has density ρ_s and uniform thickness *t*. For what gate density ρ_s, expressed as a function of (h, t, ρ, θ), will the gate just begin to lift off the bottom? Why is your answer independent of gate length *L* and width *b*?



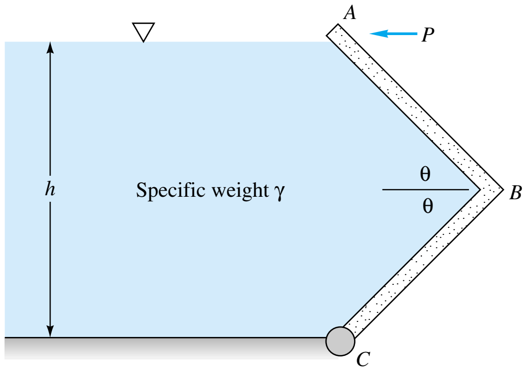
P2.75

***P2.76** Consider the angled gate *ABC* in Fig. P2.76, hinged at *C* and of width *b* into the paper. Derive an analytic formula for the horizontal force *P* required at the top for equilibrium, as a function of the angle θ.

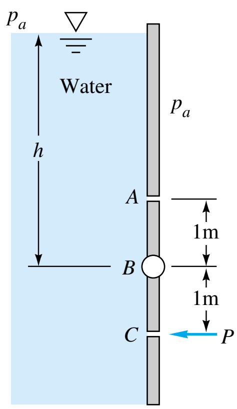
P2.77 The circular gate *ABC* in Fig. P2.77 has a 1-m radius and is hinged at *B*. Compute the force *P* just sufficient to keep the gate from opening when $h = 8$ m. Neglect atmospheric pressure.

P2.78 Repeat Prob. 2.77 to derive an analytic expression for *P* as a function of *h*. Is there anything unusual about your solution?

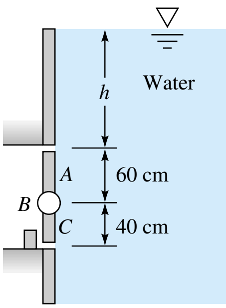
P2.79 Gate *ABC* in Fig. P2.79 is 1 m square and is hinged at *B*. It will open automatically when the water level *h* becomes high enough. Determine the lowest height for which the



P2.76



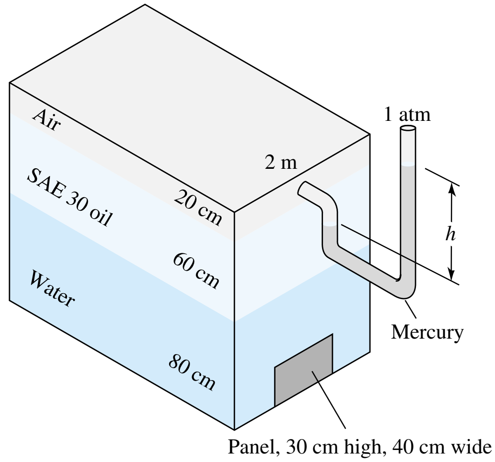
P2.77



P2.79

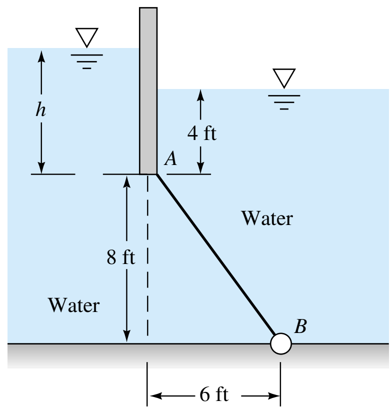
gate will open. Neglect atmospheric pressure. Is this result independent of the liquid density?

P2.80 For the closed tank in Fig. P2.80, all fluids are at 20°C, and the airspace is pressurized. It is found that the net outward hydrostatic force on the 30-by 40-cm panel at the bottom of the water layer is 8450 N. Estimate (*a*) the pressure in the airspace and (*b*) the reading *h* on the mercury manometer.



P2.80

P2.81 Gate *AB* in Fig. P2.81 is 7 ft into the paper and weighs 3000 lbf when submerged. It is hinged at *B* and rests against a smooth wall at *A*. Determine the water level *h* at the left which will just cause the gate to open.

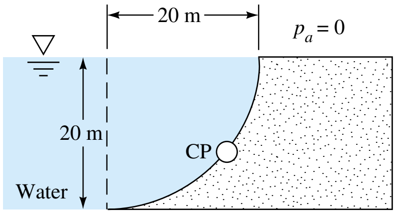


P2.81

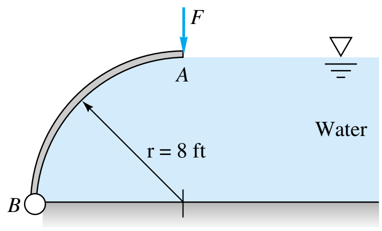
***P2.82** The dam in Fig. P2.82 is a quarter circle 50 m wide into the paper. Determine the horizontal and vertical components of the hydrostatic force against the dam and the point CP where the resultant strikes the dam.

***P2.83** Gate *AB* in Fig. P2.83 is a quarter circle 10 ft wide into the paper and hinged at *B*. Find the force *F* just sufficient to keep the gate from opening. The gate is uniform and weighs 3000 lbf.

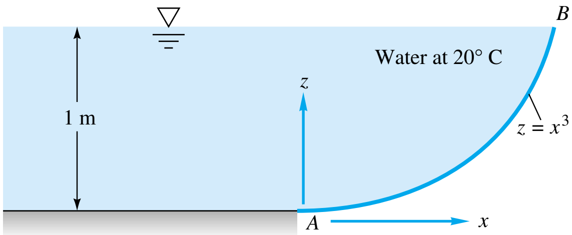
P2.84 Determine (*a*) the total hydrostatic force on the curved surface *AB* in Fig. P2.84 and (*b*) its line of action. Neglect atmospheric pressure, and let the surface have unit width.



P2.82

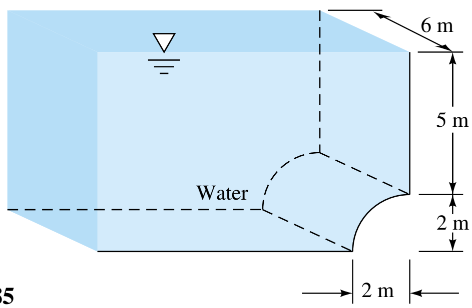


P2.83



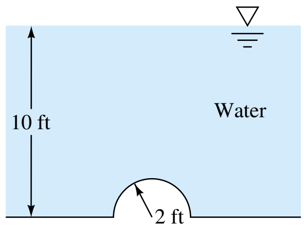
P2.84

P2.85 Compute the horizontal and vertical components of the hydrostatic force on the quarter-circle panel at the bottom of the water tank in Fig. P2.85.



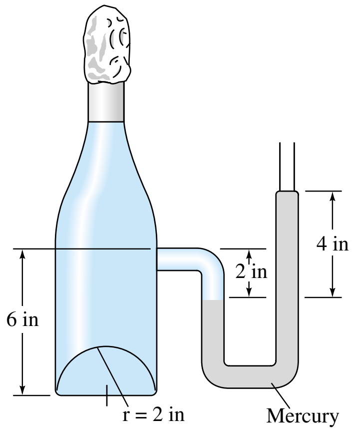
P2.85

P2.86 Compute the horizontal and vertical components of the hydrostatic force on the hemispherical bulge at the bottom of the tank in Fig. P2.86.



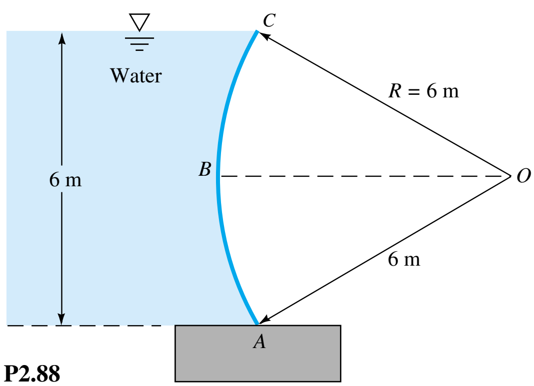
P2.86

P2.87 The bottle of champagne (SG = 0.96) in Fig. P2.87 is under pressure, as shown by the mercury-manometer reading. Compute the net force on the 2-in-radius hemispherical end cap at the bottom of the bottle.



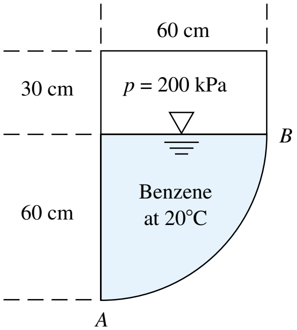
P2.87

***P2.88** Gate *ABC* is a circular arc, sometimes called a *Tainter gate*, which can be raised and lowered by pivoting about point *O*. See Fig. P2.88. For the position shown, determine (*a*) the hydrostatic force of the water on the gate and (*b*) its line of action. Does the force pass through point *O*?



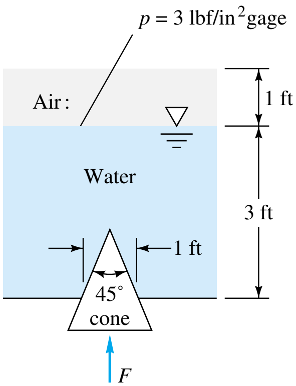
P2.88

P2.89 The tank in Fig. P2.89 contains benzene and is pressurized to 200 kPa (gage) in the air gap. Determine the vertical hydrostatic force on circular-arc section *AB* and its line of action.



P2.89

P2.90 A 1-ft-diameter hole in the bottom of the tank in Fig. P2.90 is closed by a conical 45° plug. Neglecting the weight of the plug, compute the force *F* required to keep the plug in the hole.

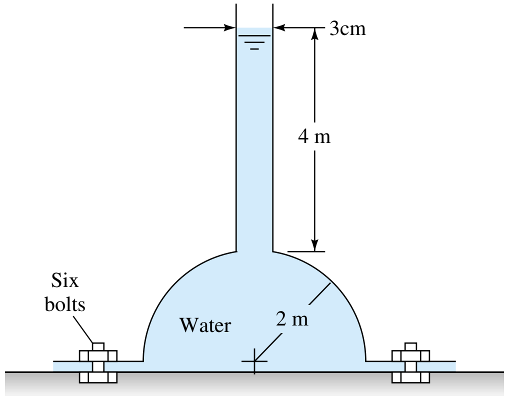


P2.90

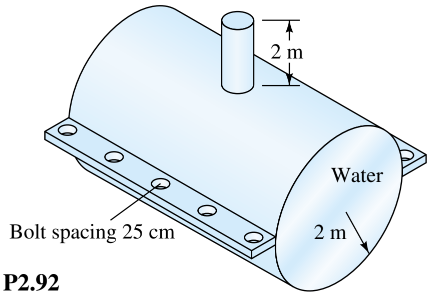
P2.91 The hemispherical dome in Fig. P2.91 weighs 30 kN and is filled with water and attached to the floor by six equally spaced bolts. What is the force in each bolt required to hold down the dome?

P2.92 A 4-m-diameter water tank consists of two half cylinders, each weighing 4.5 kN/m, bolted together as shown in Fig. P2.92. If the support of the end caps is neglected, determine the force induced in each bolt.

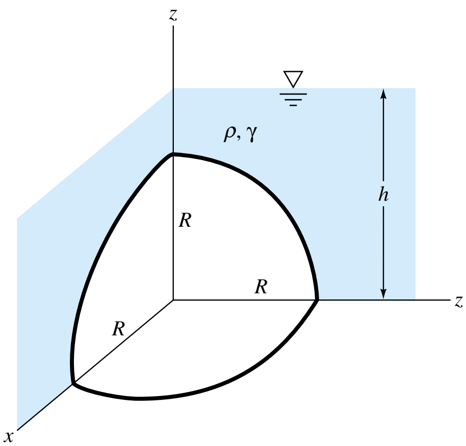
***P2.93** In Fig. P2.93, a one-quadrant spherical shell of radius *R* is submerged in liquid of specific gravity γ and depth $h > R$. Find an analytic expression for the resultant hydrostatic force, and its line of action, on the shell surface.



P2.91

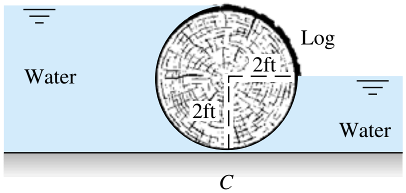


P2.92



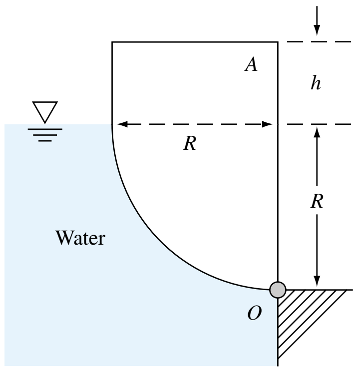
P2.93

P2.94 The 4-ft-diameter log (SG = 0.80) in Fig. P2.94 is 8 ft long into the paper and dams water as shown. Compute the net vertical and horizontal reactions at point *C*.



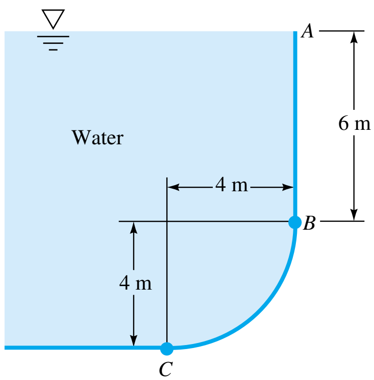
P2.94

***P2.95** The uniform body A in Fig. P2.95 has width b into the paper and is in static equilibrium when pivoted about hinge O. What is the specific gravity of this body if (*a*) $h = 0$ and (*b*) $h = R$?



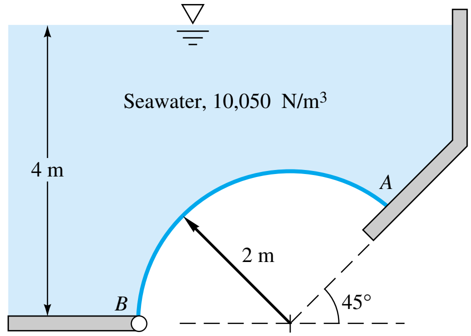
P2.95

P2.96 The tank in Fig. P2.96 is 3 m wide into the paper. Neglecting atmospheric pressure, compute the hydrostatic (*a*) horizontal force, (*b*) vertical force, and (*c*) resultant force on quarter-circle panel BC.



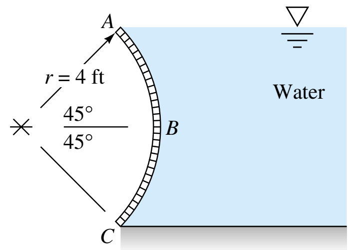
P2.96

P2.97 Gate AB in Fig. P2.97 is a three-eighths circle, 3 m wide into the paper, hinged at B, and resting against a smooth wall at A. Compute the reaction forces at points A and B.



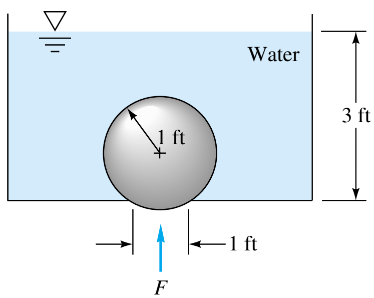
P2.97

P2.98 Gate ABC in Fig. P2.98 is a quarter circle 8 ft wide into the paper. Compute the horizontal and vertical hydrostatic forces on the gate and the line of action of the resultant force.



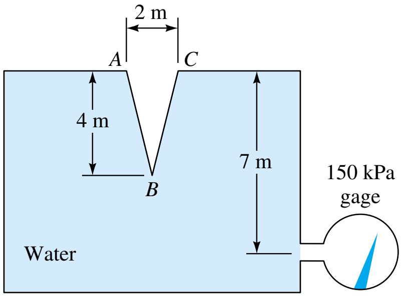
P2.98

P2.99 A 2-ft-diameter sphere weighing 400 lbf closes a 1-ft-diameter hole in the bottom of the tank in Fig. P2.99. Compute the force F required to dislodge the sphere from the hole.



P2.99

P2.100 Pressurized water fills the tank in Fig. P2.100. Compute the net hydrostatic force on the conical surface *ABC*.



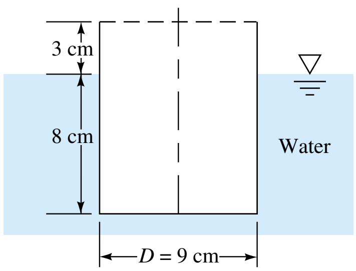
P2.100

P2.101 A fuel truck has a tank cross section which is approximately elliptical, with a 3-m horizontal major axis and a 2-m vertical minor axis. The top is vented to the atmosphere. If the tank is filled half with water and half with gasoline, what is the hydrostatic force on the flat elliptical end panel?

P2.102 In Fig. P2.80 suppose that the manometer reading is h = 25 cm. What will be the net hydrostatic force on the complete end wall, which is 160 cm high and 2 m wide?

P2.103 The hydrogen bubbles in Fig. 1.13 are very small, less than a millimeter in diameter, and rise slowly. Their drag in still fluid is approximated by the first term of Stokes' expression in Prob. 1.10: $F = 3\pi\mu VD$, where V is the rise velocity. Neglecting bubble weight and setting bubble buoyancy equal to drag, (*a*) derive a formula for the *terminal* (zero acceleration) rise velocity V_{term} of the bubble and (*b*) determine V_{term} in m/s for water at 20°C if D = 30 μm.

P2.104 The can in Fig. P2.104 floats in the position shown. What is its weight in N?



P2.104

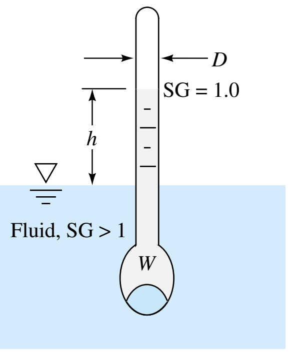
P2.105 It is said that Archimedes discovered the buoyancy laws when asked by King Hiero of Syracuse to determine whether his new crown was pure gold (SG = 19.3). Archimedes measured the weight of the crown in air to be 11.8 N and its weight in water to be 10.9 N. Was it pure gold?

P2.106 It is found that a 10-cm cube of aluminum (SG = 2.71) will remain neutral under water (neither rise nor fall) if it is tied by a string to a submerged 18-cm-diameter sphere of buoyant foam. What is the specific weight of the foam, in N/m^3?

P2.107 Repeat Prob. 2.62, assuming that the 10,000-lbf weight is aluminum (SG = 2.71) and is hanging submerged in the water.

P2.108 A piece of yellow pine wood (SG = 0.65) is 5 cm square and 2.2 m long. How many newtons of lead (SG = 11.4) should be attached to one end of the wood so that it will float vertically with 30 cm out of the water?

P2.109 A *hydrometer* floats at a level which is a measure of the specific gravity of the liquid. The stem is of constant diameter D, and a weight in the bottom stabilizes the body to float vertically, as shown in Fig. P2.109. If the position h = 0 is pure water (SG = 1.0), derive a formula for h as a function of total weight W, D, SG, and the specific weight γ_0 of water.

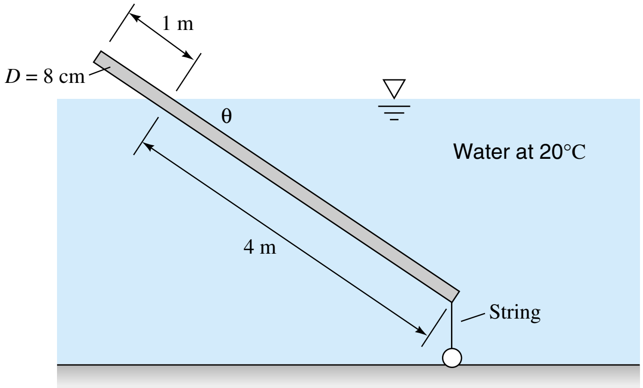


P2.109

P2.110 An average table tennis ball has a diameter of 3.81 cm and a mass of 2.6 g. Estimate the (small) depth at which this ball will float in water at 20°C and sea level standard air if air buoyancy is (*a*) neglected and (*b*) included.

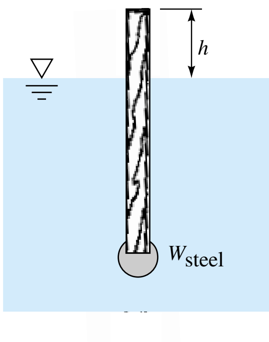
P2.111 A hot-air balloon must be designed to support basket, cords, and one person for a total weight of 1300 N. The balloon material has a mass of 60 g/m^2. Ambient air is at 25°C and 1 atm. The hot air inside the balloon is at 70°C and 1 atm. What diameter spherical balloon will just support the total weight? Neglect the size of the hot-air inlet vent.

P2.112 The uniform 5-m-long round wooden rod in Fig. P2.112 is tied to the bottom by a string. Determine (*a*) the tension in the string and (*b*) the specific gravity of the wood. Is it possible for the given information to determine the inclination angle θ? Explain.



P2.112

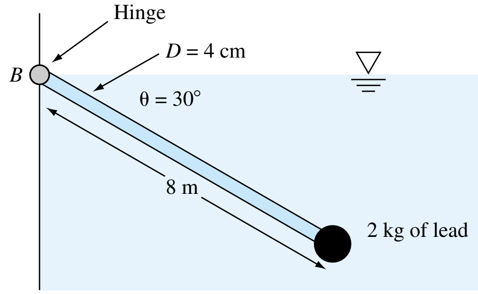
P2.113 A *spar buoy* is a buoyant rod weighted to float and protrude vertically, as in Fig. P2.113. It can be used for measurements or markers. Suppose that the buoy is maple wood (SG = 0.6), 2 in by 2 in by 12 ft, floating in seawater (SG = 1.025). How many pounds of steel (SG = 7.85) should be added to the bottom end so that h = 18 in?



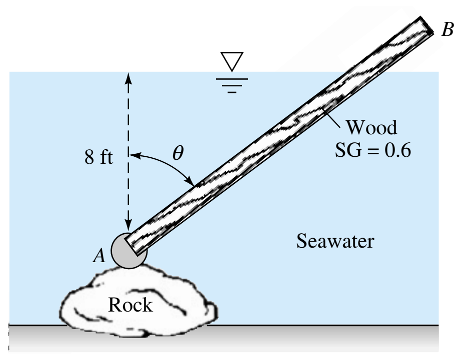
P2.113

P2.114 The uniform rod in Fig. P2.114 is hinged at point B on the waterline and is in static equilibrium as shown when 2 kg of lead (SG = 11.4) are attached to its end. What is the specific gravity of the rod material? What is peculiar about the rest angle θ = 30?

P2.115 The 2-in by 2-in by 12-ft spar buoy from Fig. P2.113 has 5 lbm of steel attached and has gone aground on a rock, as in Fig. P2.115. Compute the angle θ at which the buoy will lean, assuming that the rock exerts no moments on the spar.

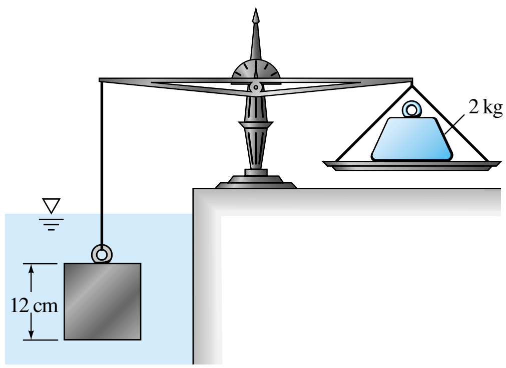


P2.114



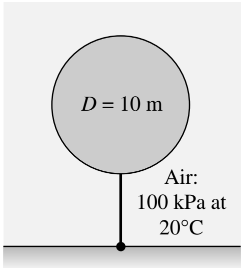
P2.115

P2.116 The homogeneous 12-cm cube in Fig. 2.116 is balanced by a 2-kg mass on the beam scale when the cube is immersed in 20°C ethanol. What is the specific gravity of the cube?



P2.116

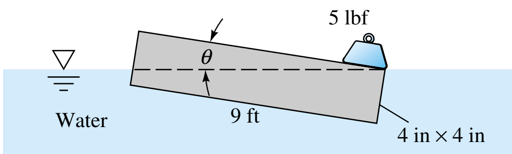
P2.117 The balloon in Fig. P2.117 is filled with helium and pressurized to 135 kPa and 20°C. The balloon material has a mass of 85 g/m^2. Estimate (*a*) the tension in the mooring line and (*b*) the height in the standard atmosphere to which the balloon will rise if the mooring line is cut.



P2.117

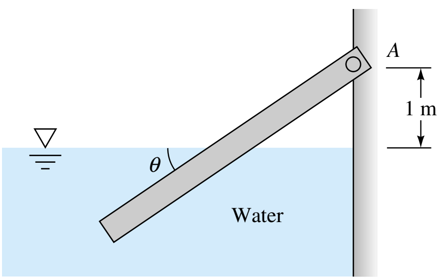
P2.118 A 14-in-diameter hollow sphere is made of steel (SG = 7.85) with 0.16-in wall thickness. How high will this sphere float in 20°C water? How much weight must be added inside to make the sphere neutrally buoyant?

P2.119 When a 5-lbf weight is placed on the end of the uniform floating wooden beam in Fig. P2.119, the beam tilts at an angle θ with its upper right corner at the surface, as shown. Determine (*a*) the angle θ and (*b*) the specific gravity of the wood. (*Hint:* Both the vertical forces and the moments about the beam centroid must be balanced.)



P2.119

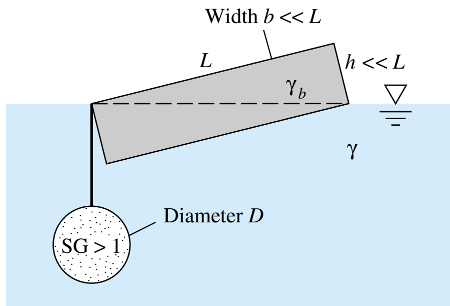
P2.120 A uniform wooden beam (SG = 0.65) is 10 cm by 10 cm by 3 m and is hinged at *A*, as in Fig. P2.120. At what angle θ will the beam float in the 20°C water?



P2.120

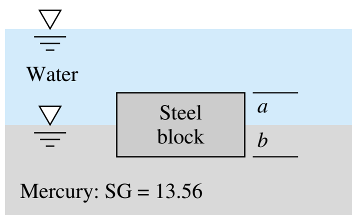
P2.121 The uniform beam in Fig. P2.121, of size *L* by *h* by *b* and with specific weight γ_b, floats exactly on its diagonal when a heavy uniform sphere is tied to the left corner, as shown. Show that this can only happen (*a*) when $\gamma_b = \gamma/3$ and (*b*) when the sphere has size

$$D = \left[\frac{Lhb}{\pi(\mathrm{SG} - 1)}\right]^{1/3}$$



P2.121

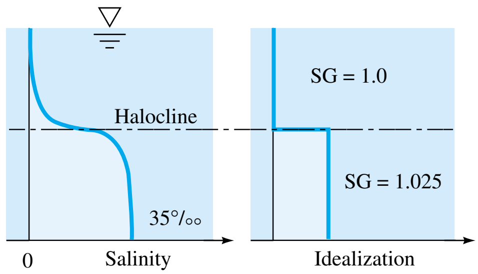
P2.122 A uniform block of steel (SG = 7.85) will "float" at a mercury-water interface as in Fig. P2.122. What is the ratio of the distances *a* and *b* for this condition?



P2.122

P2.123 In an estuary where fresh water meets and mixes with seawater, there often occurs a stratified salinity condition with fresh water on top and salt water on the bottom, as in Fig. P2.123. The interface is called a *halocline*. An idealization of this would be constant density on each side of the halocline as shown. A 35-cm-diameter sphere weighing 50 lbf would "float" near such a halocline. Compute the sphere position for the idealization in Fig. P2.123.

P2.124 A balloon weighing 3.5 lbf is 6 ft in diameter. It is filled with hydrogen at 18 lbf/in^2 absolute and 60°F and is released. At what altitude in the U.S. standard atmosphere will this balloon be neutrally buoyant?



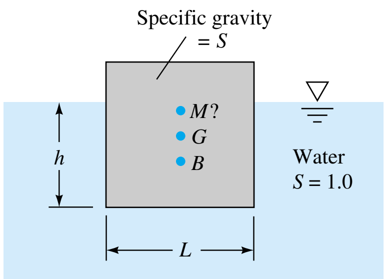
P2.123

P2.125 Suppose that the balloon in Prob. 2.111 is constructed to have a diameter of 14 m, is filled at sea level with hot air at 70°C and 1 atm, and is released. If the air inside the balloon remains constant and the heater maintains it at 70°C, at what altitude in the U.S. standard atmosphere will this balloon be neutrally buoyant?

***P2.126** A cylindrical can of weight W, radius R, and height H is open at one end. With its open end down, and while filled with atmospheric air (p_{atm}, T_{atm}), the can is eased down vertically into liquid, of density ρ, which enters and compresses the air isothermally. Derive a formula for the height h to which the liquid rises when the can is submerged with its top (closed) end a distance d from the surface.

***P2.127** Consider the 2-in by 2-in by 10-ft spar buoy of Prob. 2.113. How many pounds of steel (SG = 7.85) should be added at the bottom to ensure vertical floating with a metacentric height $\overline{MG}$ of (*a*) zero (neutral stability) or (*b*) 1 ft (reasonably stable)?

P2.128 An iceberg can be idealized as a cube of side length L, as in Fig. P2.128. If seawater is denoted by $S = 1.0$, then glacier ice (which forms icebergs) has $S = 0.88$. Determine if this "cubic" iceberg is stable for the position shown in Fig. P2.128.



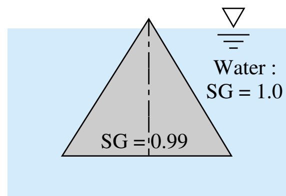
P2.128

P2.129 The iceberg idealization in Prob. 2.128 may become unstable if its sides melt and its height exceeds its width. In Fig. P2.128 suppose that the height is L and the depth into the paper is L, but the width in the plane of the paper is $H < L$. Assuming $S = 0.88$ for the iceberg, find the ratio H/L for which it becomes neutrally stable, i.e., about to overturn.

P2.130 Consider a wooden cylinder (SG = 0.6) 1 m in diameter and 0.8 m long. Would this cylinder be stable if placed to float with its axis vertical in oil (SG = 0.8)?

P2.131 A barge is 15 ft wide and 40 ft long and floats with a draft of 4 ft. It is piled so high with gravel that its center of gravity is 2 ft above the waterline. Is it stable?

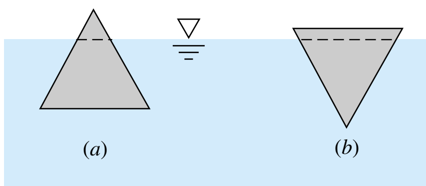
P2.132 A solid right circular cone has SG = 0.99 and floats vertically as in Fig. P2.132. Is this a stable position for the cone?



P2.132

P2.133 Consider a uniform right circular cone of specific gravity $S < 1$, floating with its vertex *down* in water ($S = 1$). The base radius is R and the cone height is H. Calculate and plot the stability $\overline{MG}$ of this cone, in dimensionless form, versus H/R for a range of $S < 1$.

P2.134 When floating in water (SG = 1.0), an equilateral triangular body (SG = 0.9) might take one of the two positions shown in Fig. P2.134. Which is the more stable position? Assume large width into the paper.



P2.134

P2.135 Consider a homogeneous right circular cylinder of length L, radius R, and specific gravity SG, floating in water (SG = 1). Show that the body will be stable with its axis vertical if

$$\frac{R}{L} > [2\text{SG}(1 - \text{SG})]^{1/2}$$

P2.136 Consider a homogeneous right circular cylinder of length L, radius R, and specific gravity SG = 0.5, floating in water (SG = 1). Show that the body will be stable with its axis horizontal if $L/R > 2.0$.

P2.137 A tank of water 4 m deep receives a constant upward acceleration a_z. Determine (*a*) the gage pressure at the tank bottom if $a_z = 5\ \text{m}^2/\text{s}$ and (*b*) the value of a_z which causes the gage pressure at the tank bottom to be 1 atm.

P2.138 A 12-fl-oz glass, of 3-in diameter, partly full of water, is attached to the edge of an 8-ft-diameter merry-go-round which is rotated at 12 r/min. How full can the glass be before water spills? (*Hint:* Assume that the glass is much smaller than the radius of the merry-go-round.)

P2.139 The tank of liquid in Fig. P2.139 accelerates to the right with the fluid in rigid-body motion. (*a*) Compute a_x in m/s^2. (*b*) Why doesn't the solution to part (*a*) depend upon the density of the fluid? (*c*) Determine the gage pressure at point A if the fluid is glycerin at 20°C.

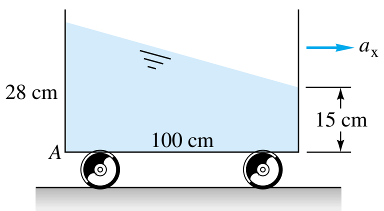


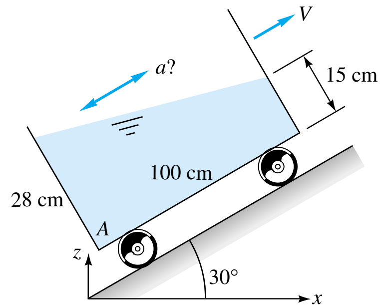
Fig. P2.139

P2.140 Suppose that the elliptical-end fuel tank in Prob. 2.101 is 10 m long and filled completely with fuel oil (ρ = 890 kg/m^3). Let the tank be pulled along a horizontal road. For rigid-body motion, find the acceleration, and its direction, for which (*a*) a constant-pressure surface extends from the top of the front end wall to the bottom of the back end and (*b*) the top of the back end is at a pressure 0.5 atm lower than the top of the front end.

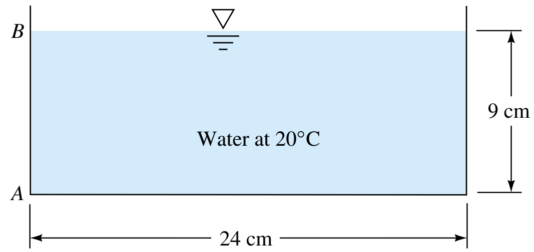
P2.141 The same tank from Prob. 2.139 is now moving with constant acceleration up a 30° inclined plane, as in Fig. P2.141. Assuming rigid-body motion, compute (*a*) the value of the acceleration a, (*b*) whether the acceleration is up or down, and (*c*) the gage pressure at point A if the fluid is mercury at 20°C.

P2.142 The tank of water in Fig. P2.142 is 12 cm wide into the paper. If the tank is accelerated to the right in rigid-body motion at 6.0 m/s^2, compute (*a*) the water depth on side AB and (*b*) the water-pressure force on panel AB. Assume no spilling.

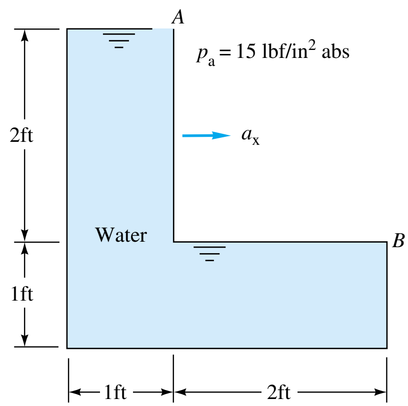
P2.143 The tank of water in Fig. P2.143 is full and open to the atmosphere at point A. For what acceleration a_x in ft/s^2 will the pressure at point B be (*a*) atmospheric and (*b*) zero absolute?



P2.141



P2.142

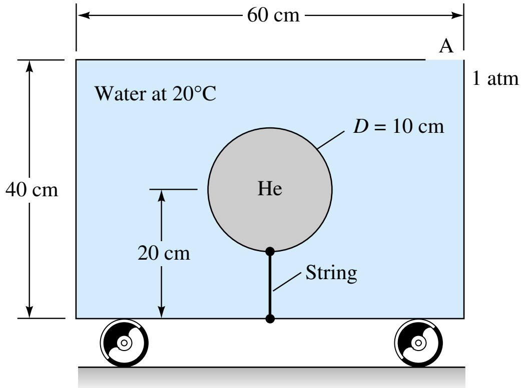


P2.143

P2.144 Consider a hollow cube of side length 22 cm, filled completely with water at 20°C. The top surface of the cube is horizontal. One top corner, point A, is open through a small hole to a pressure of 1 atm. Diagonally opposite to point A is top corner B. Determine and discuss the various rigid-body accelerations for which the water at point B begins to cavitate, for (*a*) horizontal motion and (*b*) vertical motion.

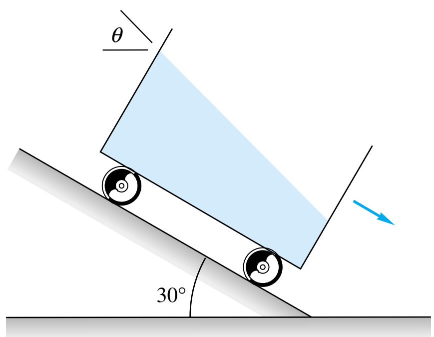
P2.145 A fish tank 14 in deep by 16 by 27 in is to be carried in a car which may experience accelerations as high as 6 m/s^2. What is the maximum water depth which will avoid spilling in rigid-body motion? What is the proper alignment of the tank with respect to the car motion?

P2.146 The tank in Fig. P2.146 is filled with water and has a vent hole at point *A*. The tank is 1 m wide into the paper. Inside the tank, a 10-cm balloon, filled with helium at 130 kPa, is tethered centrally by a string. If the tank accelerates to the right at 5 m/s^2 in rigid-body motion, at what angle will the balloon lean? Will it lean to the right or to the left?



P2.146

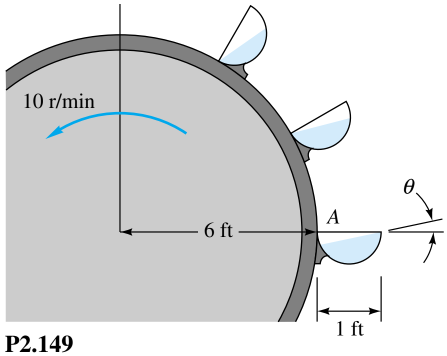
P2.147 The tank of water in Fig. P2.147 accelerates uniformly by freely rolling down a 30° incline. If the wheels are frictionless, what is the angle θ? Can you explain this interesting result?



P2.147

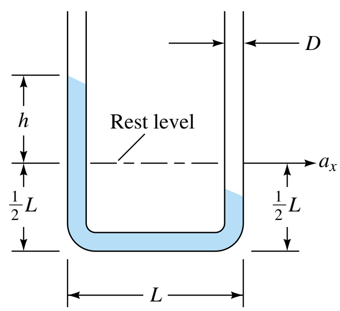
P2.148 A child is holding a string onto which is attached a helium-filled balloon. (*a*) The child is standing still and suddenly accelerates forward. In a frame of reference moving with the child, which way will the balloon tilt, forward or backward? Explain. (*b*) The child is now sitting in a car which is stopped at a red light. The helium-filled balloon is not in contact with any part of the car (seats, ceiling, etc.) but is held in place by the string, which is in turn held by the child. All the windows in the car are closed. When the traffic light turns green, the car accelerates forward. In a frame of reference moving with the car and child, which way will the balloon tilt, forward or backward? Explain. (*c*) Purchase or borrow a helium-filled balloon. Conduct a scientific experiment to see if your predictions in parts (*a*) and (*b*) above are correct. If not, explain.

P2.149 The 6-ft-radius waterwheel in Fig. P2.149 is being used to lift water with its 1-ft-diameter half-cylinder blades. If the wheel rotates at 10 r/min and rigid-body motion is assumed, what is the water surface angle θ at position *A*?



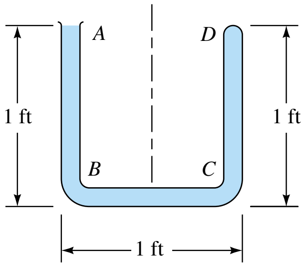
P2.149

P2.150 A cheap accelerometer, probably worth the price, can be made from a U-tube as in Fig. P2.150. If $L = 18$ cm and $D = 5$ mm, what will h be if $a_x = 6$ m/s^2? Can the scale markings on the tube be linear multiples of a_x?



P2.150

P2.151 The U-tube in Fig. P2.151 is open at *A* and closed at *D*. If accelerated to the right at uniform a_x, what acceleration will cause the pressure at point C to be atmospheric? The fluid is water (SG = 1.0).



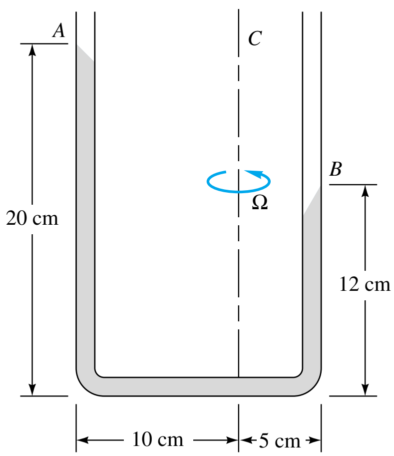
P2.151

P2.152 A 16-cm-diameter open cylinder 27 cm high is full of water. Compute the rigid-body rotation rate about its central axis, in r/min, (*a*) for which one-third of the water will spill out and (*b*) for which the bottom will be barely exposed.

P2.153 Suppose the U-tube in Fig. P2.150 is not translated but rather rotated about its right leg at 95 r/min. What will be the level h in the left leg if L = 18 cm and D = 5 mm?

P2.154 A very deep 18-cm-diameter can contains 12 cm of water overlaid with 10 cm of SAE 30 oil. If the can is rotated in rigid-body motion about its central axis at 150 r/min, what will be the shapes of the air-oil and oil-water interfaces? What will be the maximum fluid pressure in the can in Pa (gage)?

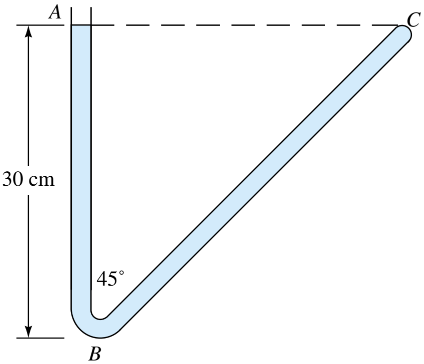
P2.155 EES For what uniform rotation rate in r/min about axis C will the U-tube in Fig. P2.155 take the configuration shown? The fluid is mercury at 20°C.



P2.155

P2.156 Suppose that the U-tube of Fig. P2.151 is rotated about axis DC. If the fluid is water at 122°F and atmospheric pressure is 2116 lbf/ft^2 absolute, at what rotation rate will the fluid within the tube begin to vaporize? At what point will this occur?

P2.157 The 45° V-tube in Fig. P2.157 contains water and is open at A and closed at C. What uniform rotation rate in r/min about axis AB will cause the pressure to be equal at points B and C? For this condition, at what point in leg BC will the pressure be a minimum?



P2.157

***P2.158** It is desired to make a 3-m-diameter parabolic telescope mirror by rotating molten glass in rigid-body motion until the desired shape is achieved and then cooling the glass to a solid. The focus of the mirror is to be 4 m from the mirror, measured along the centerline. What is the proper mirror rotation rate, in r/min, for this task?

Word Problems

W2.1 Consider a hollow cone with a vent hole in the vertex at the top, along with a hollow cylinder, open at the top, with the same base area as the cone. Fill both with water to the top. The *hydrostatic paradox* is that both containers have the same force on the bottom due to the water pressure, although the cone contains 67 percent less water. Can you explain the paradox?

W2.2 Can the temperature ever *rise* with altitude in the real atmosphere? Wouldn't this cause the air pressure to *increase* upward? Explain the physics of this situation.

W2.3 Consider a submerged curved surface which consists of a two-dimensional circular arc of arbitrary angle, arbitrary depth, and arbitrary orientation. Show that the resultant hydrostatic pressure force on this surface must pass through the center of curvature of the arc.

W2.4 Fill a glass approximately 80 percent with water, and add a large ice cube. Mark the water level. The ice cube, having SG $\approx$ 0.9, sticks up out of the water. Let the ice cube melt with negligible evaporation from the water surface. Will the water level be higher than, lower than, or the same as before?

W2.5 A ship, carrying a load of steel, is trapped while floating in a small closed lock. Members of the crew want to get out, but they can't quite reach the top wall of the lock. A crew member suggests throwing the steel overboard in the lock, claiming the ship will then rise and they can climb out. Will this plan work?

W2.6 Consider a balloon of mass m floating neutrally in the atmosphere, carrying a person/basket of mass $M > m$. Discuss the stability of this system to disturbances.

W2.7 Consider a helium balloon on a string tied to the seat of your stationary car. The windows are closed, so there is no air motion within the car. The car begins to accelerate forward. Which way will the balloon lean, forward or backward? (*Hint:* The acceleration sets up a horizontal pressure gradient in the air within the car.)

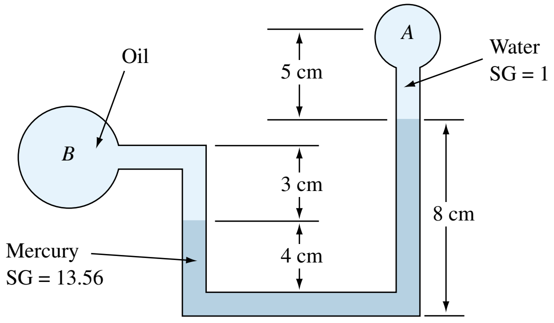
W2.8 Repeat your analysis of Prob. W2.7 to let the car move at constant velocity and go around a curve. Will the balloon lean in, toward the center of curvature, or out?

Fundamentals of Engineering Exam Problems

FE2.1 A gage attached to a pressurized nitrogen tank reads a gage pressure of 28 in of mercury. If atmospheric pressure is 14.4 psia, what is the absolute pressure in the tank?
(*a*) 95 kPa, (*b*) 99 kPa, (*c*) 101 kPa, (*d*) 194 kPa, (*e*) 203 kPa

FE2.2 On a sea-level standard day, a pressure gage, moored below the surface of the ocean (SG = 1.025), reads an absolute pressure of 1.4 MPa. How deep is the instrument?
(*a*) 4 m, (*b*) 129 m, (*c*) 133 m, (*d*) 140 m, (*e*) 2080 m

FE2.3 In Fig. FE2.3, if the oil in region *B* has SG = 0.8 and the absolute pressure at point A is 1 atm, what is the absolute pressure at point *B*?
(*a*) 5.6 kPa, (*b*) 10.9 kPa, (*c*) 106.9 kPa, (*d*) 112.2 kPa, (*e*) 157.0 kPa



FE2.3

FE2.4 In Fig. FE2.3, if the oil in region *B* has SG = 0.8 and the absolute pressure at point *B* is 14 psia, what is the absolute pressure at point *B*?
(*a*) 11 kPa, (*b*) 41 kPa, (*c*) 86 kPa, (*d*) 91 kPa, (*e*) 101 kPa

FE2.5 A tank of water (SG = 1,.0) has a gate in its vertical wall 5 m high and 3 m wide. The top edge of the gate is 2 m below the surface. What is the hydrostatic force on the gate?
(*a*) 147 kN, (*b*) 367 kN, (*c*) 490 kN, (*d*) 661 kN, (*e*) 1028 kN

FE2.6 In Prob. FE2.5 above, how far below the surface is the center of pressure of the hydrostatic force?
(*a*) 4.50 m, (*b*) 5.46 m, (*c*) 6.35 m, (*d*) 5.33 m, (*e*) 4.96 m

FE2.7 A solid 1-m-diameter sphere floats at the interface between water (SG = 1.0) and mercury (SG = 13.56) such that 40 percent is in the water. What is the specific gravity of the sphere?
(*a*) 6.02, (*b*) 7.28, (*c*) 7.78, (*d*) 8.54, (*e*) 12.56

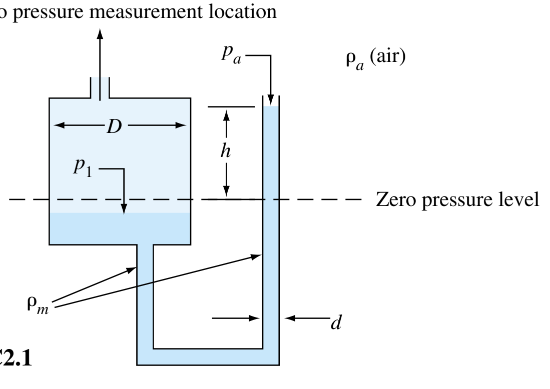
FE2.8 A 5-m-diameter balloon contains helium at 125 kPa absolute and 15°C, moored in sea-level standard air. If the gas constant of helium is 2077 $m^2/(s^2 \cdot K)$ and balloon material weight is neglected, what is the net lifting force of the balloon?
(*a*) 67 N, (*b*) 134 N, (*c*) 522 N, (*d*) 653 N, (*e*) 787 N

FE2.9 A square wooden (SG = 0.6) rod, 5 cm by 5 cm by 10 m long, floats vertically in water at 20°C when 6 kg of steel (SG = 7.84) are attached to one end. How high above the water surface does the wooden end of the rod protrude?
(*a*) 0.6 m, (*b*) 1.6 m, (*c*) 1.9 m, (*d*) 2.4 m, (*e*) 4.0 m

FE2.10 A floating body will be stable when its (*a*) center of gravity is above its center of buoyancy, (*b*) center of buoyancy is below the waterline, (*c*) center of buoyancy is above its metacenter, (*d*) metacenter is above its center of buoyancy, (*e*) metacenter is above its center of gravity

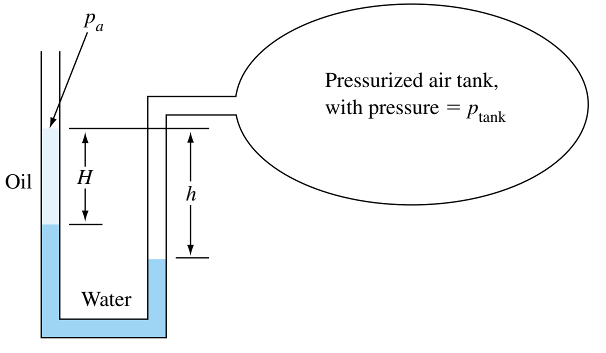
Comprehensive Problems

C2.1 Some manometers are constructed as in Fig. C2.1, where one side is a large reservoir (diameter D) and the other side is a small tube of diameter d, open to the atmosphere. In such a case, the height of manometer liquid on the reservoir side does not change appreciably. This has the advantage that only one height needs to be measured rather than two. The manometer liquid has density ρ_m while the air has density ρ_a. Ignore the effects of surface tension. When there is no pressure difference across the manometer, the elevations on both sides are the same, as indicated by the dashed line. Height h is measured from the zero pressure level as shown. (*a*) When a high pressure is applied to the left side, the manometer liquid in the large reservoir goes down, while that in the tube at the right goes up to conserve mass. Write an exact expression for $p_{1\text{gage}}$, taking into account the movement of the surface of the reservoir. Your equation should give $p_{1\text{gage}}$ as a function of h, ρ_m, and the physical parameters in the problem, h, d, D, and gravity constant g. (*b*) Write an approximate expression for $p_{1\text{gage}}$, neglecting the change in elevation of the surface of the reservoir liquid. (*c*) Suppose $h = 0.26$ m in a certain application. If $p_a = 101{,}000$ Pa and the manometer liquid has a density of 820 kg/m^3, estimate the ratio D/d required to keep the error of the approximation of part (*b*) within 1 percent of the exact measurement of part (*a*). Repeat for an error within 0.1 percent.



C2.1

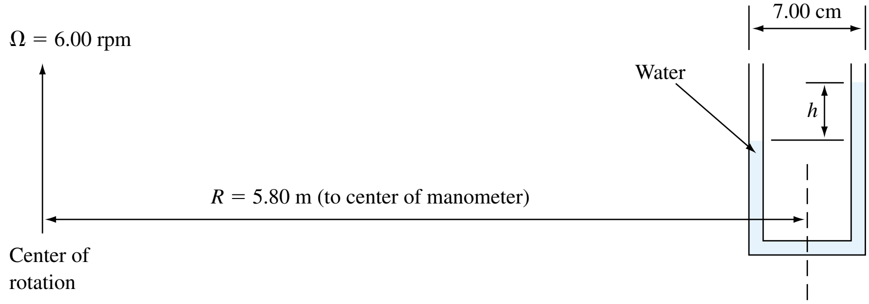
C2.2 A prankster has added oil, of specific gravity SG_0, to the left leg of the manometer in Fig. C2.2. Nevertheless, the U-tube is still useful as a pressure-measuring device. It is attached to a pressurized tank as shown in the figure. (*a*) Find an expression for h as a function of H and other parameters in the problem. (*b*) Find the special case of your result in (*a*) when $p_{tank} = p_a$. (*c*) Suppose $H = 5.0$ cm, p_a is 101.2kPa, p_{tank} is 1.82 kPa higher than p_a, and $SG_0 = 0.85$. Calculate h in cm, ignoring surface tension effects and neglecting air density effects.



C2.2

C2.3 Professor F. Dynamics, riding the merry-go-round with his son, has brought along his U-tube manometer. (You never know when a manometer might come in handy.) As shown in Fig. C2.3, the merry-go-round spins at constant angular velocity and the manometer legs are 7 cm apart. The manometer center is 5.8 m from the axis of rotation. Determine the height difference h in two ways: (*a*) approximately, by assuming rigid body translation with **a** equal to the average manometer acceleration; and (*b*) exactly, using rigid-body rotation theory. How good is the approximation?

C2.4 A student sneaks a glass of cola onto a roller coaster ride. The glass is cylindrical, twice as tall as it is wide, and filled to the brim. He wants to know what percent of the cola he should drink before the ride begins, so that none of it spills during the big drop, in which the roller coaster achieves 0.55-g acceleration at a 45° angle below the horizontal. Make the calculation for him, neglecting sloshing and assuming that the glass is vertical at all times.



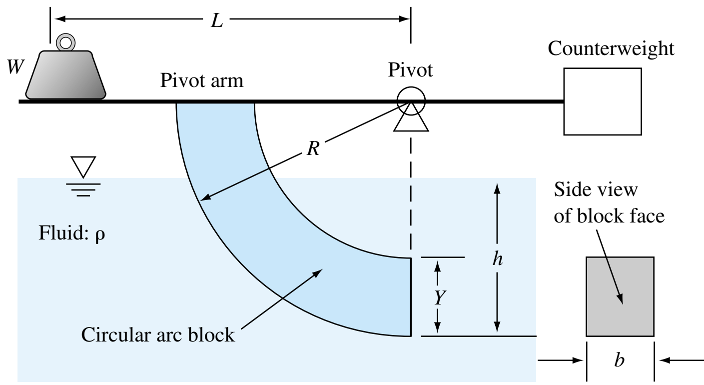
C2.3

Design Projects

D2.1 It is desired to have a bottom-moored, floating system which creates a nonlinear force in the mooring line as the water level rises. The design force F need only be accurate in the range of seawater depths h between 6 and 8 m, as shown in the accompanying table. Design a buoyant system which will provide this force distribution. The system should be practical, i.e., of inexpensive materials and simple construction.

h, m	F, N	h, m	F, N
6.00	400	7.25	554
6.25	437	7.50	573
6.50	471	7.75	589
6.75	502	8.00	600
7.00	530		

D2.2 A laboratory apparatus used in some universities is shown in Fig. D2.2. The purpose is to measure the hydrostatic force on the flat face of the circular-arc block and compare it with the theoretical value for given depth h. The counterweight is arranged so that the pivot arm is horizontal when the block is not submerged, whence the weight W can be correlated with the hydrostatic force when the submerged arm is again brought to horizontal. First show that the apparatus concept is valid in principle; then derive a formula for W as a function of h in terms of the system parameters. Finally, suggest some appropriate values of Y, L, etc., for a suitable appartus and plot theoretical W versus h for these values.



D2.2

References

1. *U.S. Standard Atmosphere*, 1976, Government Printing Office, Washington, DC, 1976.
2. G. Neumann and W. J. Pierson, Jr., *Principles of Physical Oceanography*, Prentice-Hall, Englewood Cliffs, NJ, 1966.
3. T. C. Gillmer and B. Johnson, *Introduction to Naval Architecture,* Naval Institute Press, Annapolis, MD, 1982.
4. D. T. Greenwood, *Principles of Dynamics*, 2d ed., Prentice-Hall, Englewood Cliffs, NJ, 1988.
5. R. I. Fletcher, "The Apparent Field of Gravity in a Rotating Fluid System," *Am. J. Phys.*, vol. 40, pp. 959–965, July 1972.
6. National Committee for Fluid Mechanics Films, *Illustrated Experiments in Fluid Mechanics*, M.I.T. Press, Cambridge, MA, 1972.
7. J. P. Holman, *Experimental Methods for Engineers*, 6th ed., McGraw-Hill, New York, 1993.
8. R. P. Benedict, *Fundamentals of Temperature, Pressure, and Flow Measurement*, 3d ed., Wiley, New York, 1984.
9. T. G. Beckwith and R. G. Marangoni, *Mechanical Measurements*, 4th ed., Addison-Wesley, Reading, MA, 1990.
10. J. W. Dally, W. F. Riley, and K. G. McConnell, *Instrumentation for Engineering Measurements*, Wiley, New York, 1984.
11. E. N. Gilbert, "How Things Float," *Am. Math. Monthly,* vol. 98, no. 3, pp. 201–216, 1991.
12. R. J. Figliola and D. E. Beasley, *Theory and Design for Mechanical Measurements,* 2d ed., Wiley, New York, 1994.
13. R. W. Miller, *Flow Measurement Engineering Handbook,* 3d ed., McGraw-Hill, New York, 1996.