Figure 16 Freely floating droplets of liquid naturally assume a spherical shape. Here astronaut Dr. Joseph P. Allen, in Earth orbit on Space Shuttle *Columbia,* watches a ball of orange juice he created using a beverage dispenser.

in a nucleus experience short-range forces exerted by their neighbors. The nucleus experiences a surface tension that is similar to that of a liquid drop. In the case of the nucleus, the outward force originates with the electrostatic repulsion of the charged protons. For many nuclei, the equilibrium shape is determined by the balance between the surface and electrostatic forces, and it should therefore not be surprising that for these nuclei the preferred shape is spherical. The calculation of the binding energy of nuclei must include a term corresponding to the surface energy, which typically accounts for 30% of the total binding energy.

Considering the nucleus to behave like a charged liquid drop provides great insight in understanding many properties of the nucleus, especially nuclear fission, in which the nucleus splits into two parts of comparable size. Such a procedure is called *modeling,* in which we try to understand a complex system whose properties often cannot be calculated or understood directly, on the basis of a simpler physical system of relatively similar behavior, whose properties can be calculated and then tested against experiment. The *liquid drop model of the nucleus* has played an important role in our understanding of atomic nuclei, as we discuss in Chapters 54 and 55 of the extended text.

Sample Problem 5 In the experiment shown in Fig. 15*a*, it is found that the movable wire is in equilibrium when the upward force P is 3.45×10^{-3} N. The wire has a length d of 4.85 cm and a linear mass density μ of 1.75×10^{-3} kg/m. Find the surface tension of the liquid.

Solution From the equilibrium condition of Fig. 15*b*, we have

$$\sum F_y = P - F - mg = 0,$$

or

$$F = P - mg.$$

With $F = 2d\gamma$ and $m = \mu d$, we obtain

$$2d\gamma = P - \mu d g$$

or

$$\gamma = \frac{P - \mu d g}{2d}$$

$$= \frac{3.45 \times 10^{-3}\ \text{N} - (1.75 \times 10^{-3}\ \text{kg/m})(0.0485\ \text{m})(9.80\ \text{m/s}^2)}{2(0.0485\ \text{m})}$$

$$= 0.027\ \text{N/m}.$$ ■

QUESTIONS

1. Explain how it can be that pressure is a scalar quantity when forces, which are vectors, can be produced by the action of pressures.
2. Make an estimate of the average density of your body. Explain a way in which you could get an accurate value using ideas in this chapter.
3. In Chapter 20, we shall learn that an overpressure of only 20 Pa corresponds to the threshold of pain for intense sound. Yet a diver 2 m below the surface of water experiences a much greater pressure than this (how much?) and feels no pain. Why this difference?
4. Persons confined to bed are less likely to develop sores on their bodies if they use a water bed rather than an ordinary mattress. Explain.
5. Explain why one could lie on a bed of nails without pain.
6. Explain the statement "water seeks its own level."
7. Water is poured to the same level in each of the vessels shown, all having the same base area (Fig. 17). If the pressure is the same at the bottom of each vessel, the force experienced by the base of each vessel is the same. Why then do the three vessels have different weights when put on a

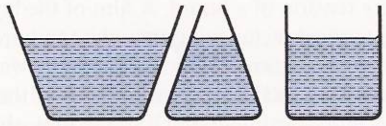

Figure 17 Question 7.

scale? This apparently contradictory result is commonly known as the *hydrostatic paradox.*

8. Does Archimedes' principle hold in a vessel in free fall or in a satellite moving in a circular orbit?

9. A spherical bob made of cork floats half submerged in a pot of tea at rest on the Earth. Will the cork float or sink aboard a spaceship (*a*) coasting in free space and (*b*) on the surface of Mars?

10. How does a suction cup work?

11. Is the buoyant force acting on a submerged submarine the same at all depths?

12. Explain how a submarine rises, falls, and maintains a fixed depth. Do fish use the same principles? (See "The Buoyancy of Marine Animals," by Eric Denton, *Scientific American,* July 1960, p. 118, and "Submarine Physics," by G. P. Harnwell, *American Journal of Physics,* March 1948, p. 127.)

13. A block of wood floats in a pail of water in an elevator. When the elevator starts from rest and accelerates down, does the block float higher above the water surface?

14. Two identical buckets are filled to the rim with water, but one has a block of wood floating in the water. Which bucket, if either, is heavier?

15. Estimate with some care the buoyant force exerted by the atmosphere on you.

16. According to Sample Problem 3, 89.6% of an iceberg is submerged. Yet occasionally icebergs turn over, with possibly disastrous results to nearby shipping. How can this happen considering that so much of their mass is below sea level?

17. Can you sink an iron ship by siphoning seawater into it?

18. Scuba divers are warned not to hold their breath when swimming upward. Why?

19. A beaker is exactly full of liquid water at its freezing point and has an ice cube floating in it, also at its freezing point. As the cube melts, what happens to the water level in these three cases: (*a*) the cube is solid ice; (*b*) the cube contains some grains of sand; and (*c*) the cube contains some bubbles?

20. Although parachutes are supposed to brake your fall, they are often designed with a hole at the top. Explain why.

21. A ball floats on the surface of water in a container exposed to the atmosphere. Will the ball remain immersed at its former depth or will it sink or rise somewhat if (*a*) the container is covered and the air is removed or (*b*) the container is covered and the air is compressed?

22. Explain why an inflated balloon will only rise to a definite height once it starts to rise, whereas a submarine will always sink to the very bottom of the ocean once it starts to sink, if no changes are made.

23. Why does a balloon weigh the same when empty as when filled with air at atmospheric pressure? Would the weights be the same if measured in a vacuum?

24. Liquid containers tend to leak when taken aloft in an airplane. Why? Does it matter whether or not they are right-side up? Does it matter whether or not they are initially completely full?

25. During World War II, a damaged freighter that was barely able to float in the North Sea steamed up the Thames estuary toward the London docks. It sank before it could arrive. Why?

26. Is it true that a floating object will be in stable equilibrium only if its center of buoyancy lies above its center of gravity? Illustrate with examples.

27. Logs dropped upright into a pond do not remain upright, but float "flat" in the water. Explain.

28. Why will a sinking ship often turn over as it becomes immersed in water?

29. A barge filled with scrap iron is in a canal lock. If the iron is thrown overboard, what happens to the water level in the lock? What if it is thrown onto the land beside the canal?

30. A bucket of water is suspended from a spring balance. Does the balance reading change when a piece of iron suspended from a string is immersed in the water? When a piece of cork is put in the water?

31. If enough iron is added to one end of a uniform wooden stick or log, it will float vertically, rather than horizontally (see Question 27). Explain.

32. Although there are practical difficulties, it is possible in principle to float an ocean liner in a few barrels of water. How would you go about doing this?

33. An open bucket of water is on a frictionless plane inclined at an angle α to the horizontal. Find the equilibrium inclination to the horizontal of the free surface of the water when (*a*) the bucket is held at rest; (*b*) the bucket is allowed to slide down at constant speed ($a = 0$, $v =$ constant); and (*c*) the bucket slides down without restraint ($a =$ constant). If the plane is curved so that $a \neq$ constant, what will happen?

34. In a barometer, how important is it that the inner diameter of the barometer be uniform? That the barometer tube be absolutely vertical?

35. An open-tube manometer has one tube twice the diameter of the other. Explain how this would affect the operation of the manometer. Does it matter which end is connected to the chamber whose pressure is to be measured?

36. We have considered liquids under compression. Can liquids be put under tension? If so, will they tear under sufficient tension as do solids? (See "The Tensile Strength of Liquids," by Robert E. Apfel, *Scientific American,* December 1972, p. 58.)

37. Explain why two glass plates with a thin film of water between them are difficult to separate by a direct pull but can easily be separated by sliding.

38. Give a molecular explanation of why surface tension decreases with increasing temperature.

39. Soap films are much more stable than films of water. Why? (Consider how surface tension reacts to stretching.)

40. Explain why a soap film collapses if a small hole appears in it.

41. Explain these observations: (*a*) water forms globules on a greasy plate but not on a clean one; (*b*) small bubbles on the surface of water cluster together.

42. If soap reduces the surface tension of water, why do we blow soap bubbles instead of water bubbles?

43. Some water beetles can walk on water. Estimate the maximum weight such an insect can have and still be supported in this way.

44. What is the source of the energy that allows a fluid in a capillary (e.g., a thin, hollow, glass tube) to rise?

45. What does it mean to say that certain liquids can exert a small negative pressure?

PROBLEMS

Section 17-2 Pressure and Density

1. Find the pressure increase in the fluid in a syringe when a nurse applies a force of 42.3 N to the syringe's piston of diameter 1.12 cm.
2. Three liquids that will not mix are poured into a cylindrical container. The amounts and densities of the liquids are 0.50 L, 2.6 g/cm^3; 0.25 L, 1.0 g/cm^3; and 0.40 L, 0.80 g/cm^3 (L = liter). Find the total force on the bottom of the container. (Ignore the contribution due to the atmosphere.) Does it matter if the fluids mix?
3. An office window is 3.43 m by 2.08 m. As a result of the passage of a storm, the outside air pressure drops to 0.962 atm, but inside the pressure is held at 1.00 atm. What net force pushes out on the window?
4. A solid copper cube has an edge length of 85.5 cm. How much pressure must be applied to the cube to reduce the edge length to 85.0 cm? The bulk modulus of the copper is 140 GPa.
5. An airtight box having a lid with an area of 12 in.^{2} is partially evacuated. If a force of 108 lb is required to pull the lid off the box, and the outside atmospheric pressure is 15 lb/in.^{2}, what was the pressure in the box?
6. In 1654 Otto von Guericke, Bürgermeister of Magdeburg and inventor of the air pump, gave a demonstration before the Imperial Diet in which two teams of horses could not pull apart two evacuated brass hemispheres. (*a*) Show that the force F required to pull apart the hemispheres is $F = \pi R^2 \Delta p$, where R is the (outside) radius of the hemispheres and Δp is the difference in pressure outside and inside the sphere (Fig. 18). (*b*) Taking R equal to 0.305 m and the inside pressure as 0.100 atm, what force would the team of horses have had to exert to pull apart the hemispheres? (*c*) Why were two teams of horses used? Would not one team prove the point just as well?

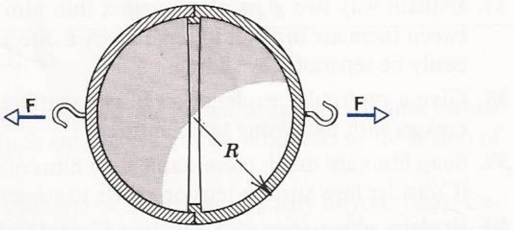

Figure 18 Problem 6.

Section 17-3 Variation of Pressure in a Fluid at Rest

7. The human lungs can operate against a pressure differential of less than 0.050 atm. How far below the water level can a diver, breathing through a snorkel (long tube), swim?
8. Calculate the hydrostatic difference in blood pressure in a person of height 1.83 m between the brain and the foot.
9. Find the total pressure, in pascal, 118 m below the surface of the ocean. The density of seawater is 1.024 g/cm^3 and the atmospheric pressure at sea level is 1.013×10^5 Pa.
10. The sewer outlets of a house constructed on a slope are 8.16 m below street level. If the sewer is 2.08 m below street level, find the minimum pressure differential that must be created by the sewage pump to transfer waste of average density 926 kg/m^3.
11. Figure 19 displays the phase diagram of carbon, showing the ranges of temperature and pressure in which carbon will crystallize either as diamond or graphite. What is the minimum depth at which diamonds can form if the local temperature is 1000°C and the subsurface rocks have density 3.1 g/cm^3? Assume that, as in a fluid, the pressure is due to the weight of material lying above.

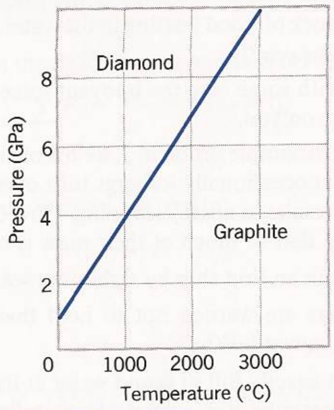

Figure 19 Problem 11.

12. According to the constant temperature model of the Earth's atmosphere, (*a*) what is the pressure (in atm) at an altitude of 5.00 km, and (*b*) at what altitude is the pressure equal to 0.500 atm? Compare your answers with Fig. 5.
13. A simple U-tube contains mercury. When 11.2 cm of water is poured into the right arm, how high does the mercury rise in the left arm from its initial level?
14. Water stands at a depth D behind the vertical upstream face of a dam, as shown in Fig. 20. Let W be the width of the dam. (*a*) Find the resultant horizontal force exerted on the

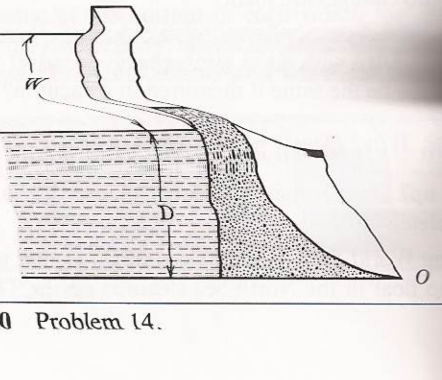

Figure 20 Problem 14.

dam by the gauge pressure of the water and (*b*) the net torque due to the gauge pressure of the water exerted about a line through *O* parallel to the width of the dam. (*c*) Where is the line of action of the equivalent resultant force?

15. A swimming pool has the dimensions 80 ft × 30 ft × 8.0 ft. (*a*) When it is filled with water, what is the force (due to the water alone) on the bottom? On the ends? On the sides? (*b*) If you are concerned with whether or not the concrete walls will collapse, is it appropriate to take the atmospheric pressure into account?

16. What would be the height of the atmosphere if the air density (*a*) were constant and (*b*) decreased linearly to zero with height? Assume a sea-level density of 1.21 kg/m³.

17. Crew members attempt to escape from a damaged submarine 112 m below the surface. How much force must they apply to a pop-out hatch, which is 1.22 m by 0.590 m, to push it out?

18. A cylindrical barrel has a narrow tube fixed to the top, as shown with dimensions in Fig. 21. The vessel is filled with water to the top of the tube. Calculate the ratio of the hydrostatic force exerted on the bottom of the barrel to the weight of the water contained inside. Why is the ratio not equal to one? (Ignore the presence of the atmosphere.)

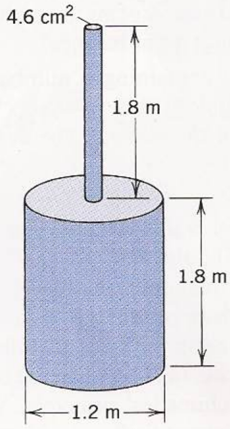

Figure 21 Problem 18.

19. In analyzing certain geological features of the Earth, it is often appropriate to assume that the pressure at some horizontal *level of compensation,* deep in the Earth, is the same over a large region and is equal to that exerted by the weight of the overlying material. That is, the pressure on the level of compensation is given by the hydrostatic (fluid) pressure formula. This requires, for example, that mountains have low-density *roots;* see Fig. 22. Consider a mountain 6.00 km high. The continental rocks have a density of 2.90 g/cm³; beneath the continent is the mantle, with a density of 3.30 g/cm³. Calculate the depth *D* of the root. (*Hint:* Set the pressure at points *a* and *b* equal; the depth *y* of the level of compensation will cancel out.)

20. (*a*) Show that the density ρ of water at a depth y in the ocean is related to the surface density ρ_s by

$$\rho \approx \rho_s[1 + (\rho_s g/B)y],$$

where $B = 2.2$ GPa is the bulk modulus of water. Ignore temperature variations. (*b*) By what fraction does the density at a depth of 4200 m exceed the surface density?

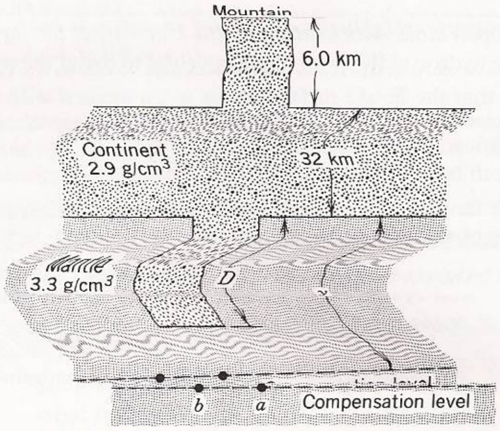

Figure 22 Problem 19.

21. A test tube 12.0 cm long is filled with water and set spinning in a horizontal plane in a centrifuge at 655 rev/s. Calculate the hydrostatic pressure on the outer base of the tube. The inner end of the tube is 5.30 cm from the axis of rotation.

22. The surface of contact of two fluids of different densities that are at rest and do not mix is horizontal. Prove this general result (*a*) from the fact that the potential energy of a system must be a minimum in stable equilibrium; (*b*) from the fact that at any two points in a horizontal plane in either fluid the pressures are equal.

23. Two identical cylindrical vessels with their bases at the same level each contain a liquid of density ρ. The area of either base is A, but in one vessel the liquid height is h_1 and in the other h_2. Find the work done by gravity in equalizing the levels when the two vessels are connected.

24. A U-tube is filled with a single homogeneous liquid. The liquid is temporarily depressed in one side by a piston. The piston is removed and the level of the liquid in each side oscillates. Show that the period of oscillation is $\pi\sqrt{2L/g}$, where L is the total length of the liquid in the tube.

25. (*a*) Show that Eq. 13, the variation of pressure with altitude in the atmosphere (temperature assumed to be uniform), can be written in terms of density ρ as

$$\rho = \rho_0 e^{-y/a},$$

where ρ_0 is the density at the ground ($y = 0$). (*b*) Assume that the drag force D due to the air on an object moving at speed v is given by $D = CA\rho v^2$, where C is a constant, A is the frontal cross-sectional area of the object, and ρ is the local air density. Find the altitude at which the drag force on a rocket is a maximum if the rocket is launched vertically and moves with constant upward acceleration a_r.

26. (*a*) Consider a container of fluid subject to a *vertical upward* acceleration a. Show that the pressure variation with depth in the fluid is given by

$$p = \rho h(g + a),$$

where h is the depth and ρ is the density. (*b*) Show also that if the fluid as a whole undergoes a *vertical downward* acceleration a, the pressure at a depth h is given by

$$p = \rho h(g - a).$$

(*c*) What is the state of affairs in free fall?

27. (*a*) Consider the horizontal acceleration of a mass of liquid in an open tank. Acceleration of this kind causes the liquid surface to drop at the front of the tank and to rise at the rear. Show that the liquid surface slopes at an angle θ with the horizontal, where $\tan\theta = a/g$, a being the horizontal acceleration. (*b*) How does the pressure vary with h, the *vertical* depth below the surface?

28. The tension in a string holding a solid block below the surface of a liquid (of density greater than the solid) is T_0 when the containing vessel (Fig. 23) is at rest. Show that the tension T, when the vessel has an upward vertical acceleration a, is given by $T_0(1 + a/g)$.

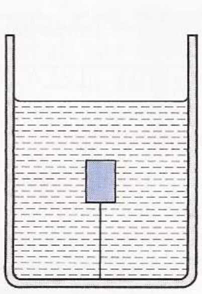

Figure 23 Problem 28.

29. (*a*) A fluid is rotating at constant angular velocity ω about the central vertical axis of a cylindrical container. Show that the variation of pressure in the radial direction is given by

$$\frac{dp}{dr} = \rho\omega^2 r.$$

(*b*) Take $p = p_c$ at the axis of rotation ($r = 0$) and show that the pressure p at any point r is

$$p = p_c + \tfrac{1}{2}\rho\omega^2 r^2.$$

(*c*) Show that the liquid surface is of paraboloidal form (Fig. 24); that is, a vertical cross section of the surface is the curve $y = \omega^2 r^2/2g$. (*d*) Show that the variation of pressure with depth is $p = \rho g h$.

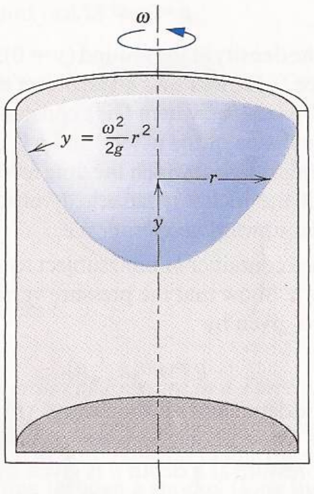

Figure 24 Problem 29.

Section 17-4 Pascal's Principle and Archimedes' Principle

30. (*a*) If the small piston of a hydraulic lever has a diamete 3.72 cm, and the large piston one of 51.3 cm, what weig on the small piston will support 18.6 kN (e.g., a car) on t large piston? (*b*) Through what distance must the small p ton move to raise the car 1.65 m?

31. A boat floating in fresh water displaces 35.6 kN of wat (*a*) What weight of water would this boat displace if it we floating in salt water of density 1024 kg/m^3? (*b*) Would t volume of water displaced change? If so, by how much?

32. A block of wood floats in water with 0.646 of its volu submerged. In oil it has 0.918 of its volume submerged. Fi the density of (*a*) the wood and (*b*) the oil.

33. A tin can has a total volume of 1200 cm^3 and a mass 130 g. How many grams of lead shot could it carry witho sinking in water? The density of lead is 11.4 g/cm^3.

34. About one-third of the body of a physicist swimming in t Dead Sea will be above the water line. Assuming that t human body density is 0.98 g/cm^3, find the density of t water in the Dead Sea. Why is it so much greater than 1 g/cm^3?

35. Assume the density of brass weights to be 8.0 g/cm^3 and th of air to be 0.0012 g/cm^3. What fractional error arises fro neglecting the buoyancy of air in weighing an object of de sity 3.4 g/cm^3 on a beam balance?

36. An iron casting containing a number of cavities weig 6130 N in air and 3970 N in water. What is the volu of the cavities in the casting? The density of iron is 78 kg/m^3.

37. A cubic object of dimensions $L = 0.608$ m on a side a weight $W = 4450$ N in a vacuum is suspended by a wire an open tank of liquid of density $\rho = 944$ kg/m^3, as in F 25. (*a*) Find the total downward force exerted by the liqu and the atmosphere on the top of the object. (*b*) Find t total upward force on the bottom of the object. (*c*) Find t tension in the wire. (*d*) Calculate the buoyant force on t object using Archimedes' principle. What relation exi among all these quantities?

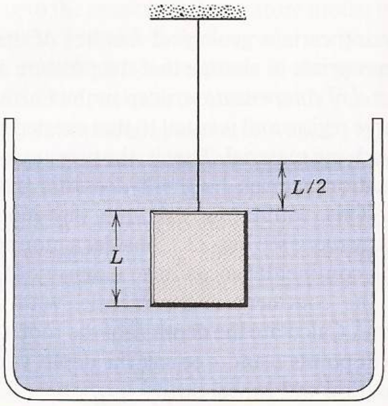

Figure 25 Problem 37.

38. A fish maintains its depth in seawater by adjusting the content of porous bone or air sacs to make its average de is the same as that of the water. Suppose that with its air sacs collapsed a fish has a density of 1.08 g/cm³. To what fraction of its expanded body volume must the fish inflate the air sacs to reduce its average density to that of the water? Assume that the air density is 0.00121 g/cm³.

39. It has been proposed to move natural gas from the North Sea gas fields in huge dirigibles, using the gas itself to provide lift. Calculate the force required to tether such an airship to the ground for off-loading when it arrives fully loaded with 1.17×10^6 m³ of gas at a density of 0.796 kg/m³. The density of the air is 1.21 kg/m³. (The weight of the airship is negligible by comparison.)

40. The Goodyear blimp *Columbia* (see Fig. 26) is cruising slowly at low altitude, filled as usual with helium gas. Its maximum useful payload, including crew and cargo, is 1280 kg. How much more payload could the *Columbia* carry if you replaced the helium with hydrogen? Why not do it? The volume of the helium-filled interior space is 5000 m³. The density of helium gas is 0.160 kg/m³ and the density of hydrogen is 0.0810 kg/m³.

Figure 26 Problem 40.

41. A hollow spherical iron shell floats almost completely submerged in water; see Fig. 27. The outer diameter is 58.7 cm and the density of iron is 7.87 g/cm³. Find the inner diameter of the shell.

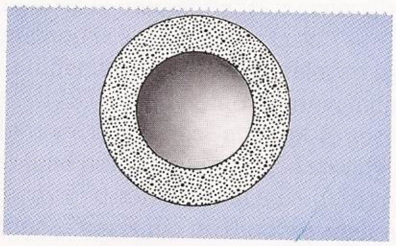

Figure 27 Problem 41.

42. A block of wood has a mass of 3.67 kg and a density of 594 kg/m³. It is to be loaded with lead so that it will float in water with 0.883 of its volume immersed. What mass of lead is needed (*a*) if the lead is on top of the wood and (*b*) if the lead is attached below the wood? The density of lead is 1.14×10^4 kg/m³.

43. Three children each of weight 82.4 lb make a log raft by lashing together logs of diameter 1.05 ft and length 5.80 ft. How many logs will be needed to keep them afloat? Take the density of the wood to be 47.3 lb/ft³.

44. (*a*) What is the minimum area of a block of ice 0.305 m thick floating on water that will hold up an automobile of mass 1120 kg? (*b*) Does it matter where the car is placed on the block of ice? The density of ice is 917 kg/m³.

45. An object floating in mercury has one-fourth of its volume submerged. If enough water is added to cover the object, what fraction of its volume will remain immersed in mercury?

46. A cylindrical wooden log is loaded with lead at one end so that it floats upright in water as in Fig. 28. The length of the submerged portion is $L = 2.56$ m. The log is set into vertical oscillation. (*a*) Show that the oscillation is simple harmonic. (*b*) Find the period of the oscillation. Neglect the fact that the water has a damping effect on the motion.

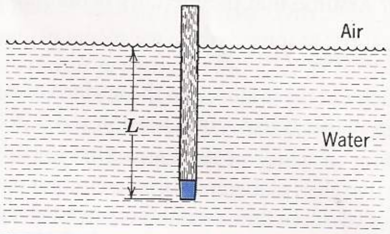

Figure 28 Problem 46.

47. A car has a total mass of 1820 kg. The volume of air space in the passenger compartment is 4.87 m³. The volume of the motor and front wheels is 0.750 m³, and the volume of the rear wheels, gas tank, and luggage is 0.810 m³. Water cannot enter these areas. The car is parked on a hill; the handbrake cable snaps and the car rolls down the hill into a lake; see Fig. 29. (*a*) At first, no water enters the passenger compartment. How much of the car, in cubic meters, is below the water surface with the car floating as shown? (*b*) As water slowly enters, the car sinks. How many cubic meters of water are in the car as it disappears below the water surface? (The car remains horizontal, owing to a heavy load in the trunk.)

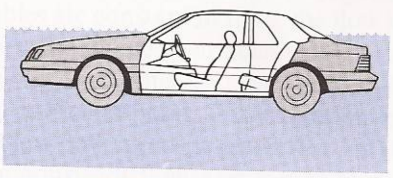

Figure 29 Problem 47.

48. You place a glass beaker, partially filled with water, in a sink (Fig. 30). It has a mass of 390 g and an interior volume of 500 cm³. You now start to fill the sink with water and you find, by experiment, that if the beaker is less than half full, it will float; but if it is more than half full, it remains on the

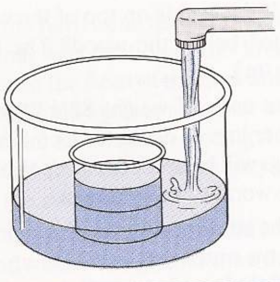

Figure 30 Problem 48.

bottom of the sink as the water rises to its rim. What is the density of the material of which the beaker is made?

Section 17-5 Measurement of Pressure

49. Estimate the density of the red wine that Pascal used in his 14-m-long barometer. Assume that the wine filled the tube.

50. The pressure at the surface of the planet Venus is 90 atm (i.e., 90 times the pressure at the surface of the Earth). How long would a mercury barometer have to be to measure this pressure? Assume that the mercury is maintained at 0°C.

Section 17-6 Surface Tension

51. How much energy is stored in the surface of a soap bubble 2.1 cm in radius if its surface tension is 4.5×10^{-2} N/m?

52. A thin film of water of thickness 80.0 μm is sandwiched between two glass plates and forms a circular patch of radius 12.0 cm. Calculate the normal force needed to separate the plates if the surface tension of water is 0.072 N/m.

53. Using a soap solution for which the surface tension is 0.025 N/m, a child blows a soap bubble of radius 1.40 cm. How much energy is expended in stretching the soap surface?

54. The surface tension of liquid ^{4}He is 0.35 mN/m and the liquid density is 145 kg/m^3. Estimate (*a*) the number of atoms/m^2 in the surface and (*b*) the energy per bond, in eV, in the liquid at this temperature. The mass of a helium atom is 6.64×10^{-27} kg. Picture each atom as a cube and assume that each atom interacts only with its four nearest neighbors.

55. Show that the pressure difference between the inside and the outside of a bubble of radius r is $4\gamma/r$, where γ is the surface tension of the liquid from which the bubble is blown.

56. A solid glass rod of radius $r = 1.3$ cm is placed inside and coaxial with a glass cylinder of internal radius $R = 1.7$ cm. Their bottom ends are aligned and placed in contact with, and perpendicular to, the surface of an open tank of water (see Fig. 31). To what height y will the water rise in the region between the rod and the cylinder? Assume that the angle of contact is 0° and use 72.8 mN/m for the surface tension of water.

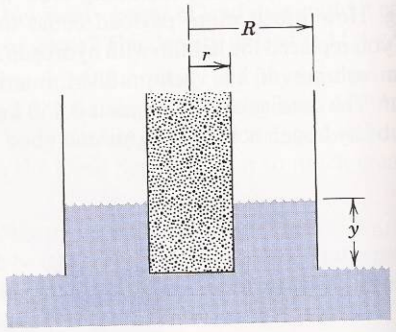

Figure 31 Problem 56.

57. A soap bubble in air has a radius of 3.20 cm. It is then blown up to a radius of 5.80 cm. Use 26.0 mN/m for the (constant) surface tension of the bubble. (*a*) What is the initial pressure difference across the bubble film? (*b*) Find the pressure difference across the film at the larger size. (*c*) How much work was done on the atmosphere in blowing up the bubble? (*d*) How much work was done in stretching the bubble surface?