BRIDGING PROBLEM
How Long to Drain?

A large cylindrical tank with diameter $D$ is open to the air at the top. The tank contains water to a height $H$. A small circular hole with diameter $d$, where $d$ is very much less than $D$, is then opened at the bottom of the tank. Ignore any effects of viscosity. (a) Find $y$, the height of water in the tank a time $t$ after the hole is opened, as a function of $t$. (b) How long does it take to drain the tank completely? (c) If you double the initial height of water in the tank, by what factor does the time to drain the tank increase?

EXECUTE
4. Use your results from step 3 to write an equation for $dy/dt$.
5. Your result from step 4 is a relatively simple differential equation. With your knowledge of calculus, you can integrate it to find $y$ as a function of $t$. (Hint: Once you’ve done the integration, you’ll still have to do a little algebra.)
6. Use your result from step 5 to find the time when the tank is empty. How does your result depend on the initial height $H$?

EVALUATE
7. Check whether your answers are reasonable. A good check is to draw a graph of $y$ versus $t$. According to your graph, what is the algebraic sign of $dy/dt$ at different times? Does this make sense?

**SOLUTION GUIDE**

See MasteringPhysics® study area for a Video Tutor solution.

**IDENTIFY and SET UP**

1. Draw a sketch of the situation that shows all of the relevant dimensions.
2. Make a list of the unknown quantities, and decide which of these are the target variables.

**Problems**

- **Discussion Questions**

  **Q12.1** A cube of oak wood with very smooth faces normally floats in water. Suppose you submerge it completely and press one face flat against the bottom of a tank so that no water is under that face. Will the block float to the surface? Is there a buoyant force on it? Explain.

  **Q12.2** A rubber hose is attached to a funnel, and the free end is bent around to point upward. When water is poured into the funnel, it rises in the hose to the same level as in the funnel, even though the funnel has a lot more water in it than the hose does. Why? What supports the extra weight of the water in the funnel?

  **Q12.3** Comparing Example 12.1 (Section 12.1) and Example 12.2 (Section 12.2), it seems that 700 N of air is exerting a downward force of $2.0 \times 10^6$ N on the floor. How is this possible?

  **Q12.4** Equation (12.7) shows that an area ratio of 100 to 1 can give 100 times more output force than input force. Doesn’t this violate conservation of energy? Explain.

  **Q12.5** You have probably noticed that the lower the tire pressure, the larger the contact area between the tire and the road. Why?

  **Q12.6** In hot-air ballooning, a large balloon is filled with air heated by a gas burner at the bottom. Why must the air be heated? How does the balloonist control ascent and descent?

  **Q12.7** In describing the size of a large ship, one uses such expressions as “it displaces 20,000 tons.” What does this mean? Can the weight of the ship be obtained from this information?

  **Q12.8** You drop a solid sphere of aluminum in a bucket of water that sits on the ground. The buoyant force equals the weight of water displaced; this is less than the weight of the sphere, so the sphere sinks to the bottom. If you take the bucket with you on an elevator that accelerates upward, the apparent weight of the water increases and the buoyant force on the sphere increases. Could the acceleration of the elevator be great enough to make the sphere pop up out of the water? Explain.

  **Q12.9** A rigid, lighter-than-air dirigible filled with helium cannot continue to rise indefinitely. Why? What determines the maximum height it can attain?

  **Q12.10** Air pressure decreases with increasing altitude. So why is air near the surface not continuously drawn upward toward the lower-pressure regions above?

  **Q12.11** The purity of gold can be tested by weighing it in air and in water. How? Do you think you could get away with making a fake gold brick by gold-plating some cheaper material?

  **Q12.12** During the Great Mississippi Flood of 1993, the levees in St. Louis tended to rupture first at the bottom. Why?

  **Q12.13** A cargo ship travels from the Atlantic Ocean (salt water) to Lake Ontario (freshwater) via the St. Lawrence River. The ship rides several centimeters lower in the water in Lake Ontario than it did in the ocean. Explain why.

  **Q12.14** You push a piece of wood under the surface of a swimming pool. After it is completely submerged, you keep pushing it deeper and deeper. As you do this, what will happen to the buoyant force on it? Will the force keep increasing, stay the same, or decrease? Why?

  **Q12.15** An old question is “Which weighs more, a pound of feathers or a pound of lead?” If the weight in pounds is the gravitational force, will a pound of feathers balance a pound of lead on opposite pans of an equal-arm balance? Explain, taking into account buoyant forces.

  **Q12.16** Suppose the door of a room makes an airtight but frictionless fit in its frame. Do you think you could open the door if the air pressure on one side were standard atmospheric pressure and the air pressure on the other side differed from standard by 1%? Explain.
012.17 At a certain depth in an incompressible liquid, the absolute pressure is \( p \). At twice this depth, will the absolute pressure be equal to 2\( p \), greater than 2\( p \), or less than 2\( p \)? Justify your answer.

012.18 A piece of iron is glued to the top of a block of wood. When the block is placed in a bucket of water with the iron on top, the block floats. The block is now turned over so that the iron is submerged beneath the wood. Does the block float or sink? Does the water level in the bucket rise, drop, or stay the same? Explain your answers.

012.19 You take an empty glass jar and push it into a tank of water with the open mouth of the jar downward, so that the air inside the jar is trapped and cannot get out. If you push the jar deeper into the water, does the buoyant force on the jar stay the same? If not, does it increase or decrease? Explain your answer.

012.20 You are floating in a canoe in the middle of a swimming pool. Your friend is at the edge of the pool, carefully noting the level of the water on the side of the pool. You have a bowling ball with you in the canoe. If you carefully drop the bowling ball over the side of the canoe and it sinks to the bottom of the pool, does the water level in the pool rise or fall?

012.21 You are floating in a canoe in the middle of a swimming pool. A large bird flies up and lights on your shoulder. Does the water level in the pool rise or fall?

012.22 At a certain depth in the incompressible ocean the gauge pressure is \( p_g \). At three times this depth, will the gauge pressure be greater than 3\( p_g \), equal to 3\( p_g \), or less than 3\( p_g \)? Justify your answer.

012.23 An ice cube floats in a glass of water. When the ice melts, will the water level in the glass rise, fall, or remain unchanged? Explain.

012.24 You are told, “Bernoulli’s equation tells us that where there is higher fluid speed, there is lower fluid pressure, and vice versa.” Is this statement always true, even for an idealized fluid? Explain.

012.25 If the velocity at each point in space in steady-state fluid flow is constant, how can a fluid particle accelerate?

012.26 In a store-window vacuum cleaner display, a table-tennis ball is suspended in midair in a jet of air blown from the outlet hose of a tank-type vacuum cleaner. The ball bounces around a little but always moves back toward the center of the jet, even if the jet is tilted from the vertical. How does this behavior illustrate Bernoulli’s equation?

012.27 A tornado consists of a rapidly whirling air vortex. Why is the pressure always much lower in the center than at the outside? How does this condition account for the destructive power of a tornado?

012.28 Airports at high elevations have longer runways for take-offs and landings than do airports at sea level. One reason is that aircraft engines develop less power in the thin air well above sea level. What is another reason?

012.29 When a smooth-flowing stream of water comes out of a faucet, it narrows as it falls. Explain why this happens.

012.30 Identical-size lead and aluminum cubes are suspended at different depths by two wires in a large vat of water (Fig. Q12.30). (a) Which cube experiences a greater buoyant force? (b) For which cube is the tension in the wire greater? (c) Which cube experiences a greater force on its lower face? (d) For which cube is the difference in pressure between the upper and lower faces greater?

EXERCISES

Section 12.1 Density

12.1 • On a part-time job, you are asked to bring a cylindrical iron rod of length 85.8 cm and diameter 2.85 cm from a storage room to a machinist. Will you need a cart? (To answer, calculate the weight of the rod.)

12.2 • A cube 5.0 cm on each side is made of a metal alloy. After you drill a cylindrical hole 2.0 cm in diameter all the way through and perpendicular to one face, you find that the cube weighs 7.50 N. (a) What is the density of this metal? (b) What did the cube weigh before you drilled the hole in it?

12.3 • You purchase a rectangular piece of metal that has dimensions 5.0 \( \times \) 15.0 \( \times \) 30.0 mm and mass 0.0158 kg. The seller tells you that the metal is gold. To check this, you compute the average density of the piece. What value do you get? Were you cheated?

12.4 • Gold Brick. You win the lottery and decide to impress your friends by exhibiting a million-dollar cube of gold. At the time, gold is selling for $426.60 per troy ounce, and 1.0000 troy ounce equals 31.1035 g. How tall would your million-dollar cube be?

12.5 • A uniform lead sphere and a uniform aluminum sphere have the same mass. What is the ratio of the radius of the aluminum sphere to the radius of the lead sphere?

12.6 • (a) What is the average density of the sun? (b) What is the average density of a neutron star that has the same mass as the sun but a radius of only 20.0 km?

12.7 • A hollow cylindrical copper pipe is 1.50 m long and has an inside diameter of 3.50 cm and an inside diameter of 2.50 cm. How much does it weigh?

Section 12.2 Pressure in a Fluid

12.8 • Black Smokers. Black smokers are hot volcanic vents that emit smoke deep in the ocean floor. Many of them teem with exotic creatures, and some biologists think that life on earth may have begun around such vents. The vents range in depth from about 1500 m to 3200 m below the surface. What is the pressure at a 3200-m deep vent, assuming that the density of water does not vary? Express your answer in pascals and atmospheres.

12.9 • Oceans on Mars. Scientists have found evidence that Mars may once have had an ocean 0.500 km deep. The acceleration due to gravity on Mars is 3.71 m/s\(^2\). (a) What would be the gauge pressure at the bottom of such an ocean, assuming it was freshwater? (b) To what depth would you need to go in the earth’s ocean to experience the same gauge pressure?

12.10 • B10 (a) Calculate the difference in blood pressure between the feet and top of the head for a person who is 1.65 m tall. (b) Consider a cylindrical segment of a blood vessel 2.00 cm long and 1.50 mm in diameter. What additional outward force would such a vessel need to withstand in the person’s feet compared to a similar vessel in her head?

12.11 • B10 In intravenous feeding, a needle is inserted in a vein in the patient’s arm and a tube leads from the needle to a reservoir of fluid (density 1050 kg/m\(^3\)) located at height \( h \) above the arm. The top of the reservoir is open to the air. If the gauge pressure inside the vein is 5980 Pa, what is the minimum value of \( h \) that allows fluid to enter the vein? Assume the needle diameter is large enough that you can ignore the viscosity (see Section 12.6) of the fluid.
12.12 • A barrel contains a 0.120-m layer of oil floating on water that is 0.250 m deep. The density of the oil is 600 kg/m³. (a) What is the gauge pressure at the oil–water interface? (b) What is the gauge pressure at the bottom of the barrel?

12.13 • BIO Standing On Your Head. (a) What is the difference between the pressure of the blood in your brain when you stand on your head and the pressure when you stand on your feet? Assume that you are 1.85 m tall. The density of blood is 1060 kg/m³. (b) What effect does the increased pressure have on the blood vessels in your brain?

12.14 • You are designing a diving bell to withstand the pressure of seawater at a depth of 250 m. (a) What is the gauge pressure at this depth? (You can ignore changes in the density of the water with depth.) (b) At this depth, what is the net force due to the water outside and the air inside the bell on a circular glass window 30.0 cm in diameter if the pressure inside the diving bell equals the pressure at the surface of the water? (You can ignore the small variation of pressure over the surface of the window.)

12.15 • BIO Ear Damage from Diving. If the force on the tympanic membrane (eardrum) increases by about 1.5 N above atmospheric pressure, the membrane can be damaged. When you go scuba diving in the ocean, below what depth could damage to your eardrum start to occur? The eardrum is typically 8.2 mm in diameter. (Consult Table 12.1.)

12.16 • The liquid in the open-tube manometer in Fig. 12.8a is mercury, \( y_1 = 3.00 \text{ cm} \), and \( y_2 = 7.00 \text{ cm} \). Atmospheric pressure is 980 millibars. (a) What is the absolute pressure at the bottom of the U-shaped tube? (b) What is the absolute pressure in the open tube at a depth of 4.00 cm below the free surface? (c) What is the absolute pressure of the gas in the container? (d) What is the gauge pressure of the gas in pascals?

12.17 • BIO There is a maximum depth at which a diver can breathe through a snorkel tube (Fig. E12.17) because as the depth increases, so does the pressure difference, which tends to collapse the diver’s lungs. Since the snorkel connects the air in the lungs to the atmosphere at the surface, the pressure inside the lungs is atmospheric pressure. What is the external–internal pressure difference when the diver’s lungs are at a depth of 6.1 m (about 20 ft)? Assume that the diver is in freshwater. (A scuba diver breathing from compressed air tanks can operate at greater depths than can a snorkeler, since the pressure of the air inside the scuba diver’s lungs increases to match the external pressure of the water.)

12.18 • A tall cylinder with a cross-sectional area 12.0 cm² is partially filled with mercury; the surface of the mercury is 5.00 cm above the bottom of the cylinder. Water is slowly poured in on top of the mercury, and the two fluids don’t mix. What volume of water must be added to double the gauge pressure at the bottom of the cylinder?

12.19 • An electrical short cuts off all power to a submersible diving vehicle when it is 30 m below the surface of the ocean. The crew must push out a hatch of area 0.75 m² and weight 300 N on the bottom to escape. If the pressure inside is 1.0 atm, what downward force must the crew exert on the hatch to open it?

12.20 • A closed container is partially filled with water. Initially, the air above the water is at atmospheric pressure \( (1.01 \times 10^5 \text{ Pa}) \) and the gauge pressure at the bottom of the water is 2500 Pa. Then additional air is pumped in, increasing the pressure of the air above the water by 1500 Pa. (a) What is the gauge pressure at the bottom of the water? (b) By how much must the water level in the container be reduced, by drawing some water out through a valve at the bottom of the container, to return the gauge pressure at the bottom of the water to its original value of 2500 Pa? The pressure of the air above the water is maintained at 1500 Pa above atmospheric pressure.

12.21 • A cylindrical disk of wood weighing 45.0 N and having a diameter of 30.0 cm floats on a cylinder of oil of density 0.850 g/cm³ (Fig. E12.21). The cylinder of oil is 75.0 cm deep and has a diameter the same as that of the wood. (a) What is the gauge pressure at the top of the oil column? (b) Suppose now that someone puts a weight of 83.0 N on top of the wood, but no oil seeps around the edge of the wood. What is the change in pressure at the bottom of the oil and (ii) halfway down in the oil?

12.22 • Exploring Venus. The surface pressure on Venus is 92 atm, and the acceleration due to gravity there is 0.894g. In a future exploratory mission, an upright cylindrical tank of benzene is sealed at the top but still pressurized at 92 atm just above the benzene. The tank has a diameter of 1.72 m, and the benzene column is 11.50 m tall. Ignore any effects due to the very high temperature on Venus. (a) What total force is exerted on the inside surface of the bottom of the tank? (b) What force does the Venusian atmosphere exert on the outside surface of the bottom of the tank? (c) What total inward force does the atmosphere exert on the vertical walls of the tank?

12.23 • Hydraulic Lift I. For the hydraulic lift shown in Fig. 12.7, what must be the ratio of the diameter of the vessel at the car to the diameter of the vessel where the force \( F_1 \) is applied so that a 1520-kg car can be lifted with a force \( F_1 \) of just 125 N?

12.24 • Hydraulic Lift II. The piston of a hydraulic automobile lift is 0.30 m in diameter. What gauge pressure, in pascals, is required to lift a car with a mass of 1200 kg? Also express this pressure in atmospheres.

Section 12.3 Buoyancy

12.25 • A 950-kg cylindrical can buoy floats vertically in salt water. The diameter of the buoy is 0.900 m. Calculate the additional distance the buoy will sink when a 70.0-kg man stands on top of it.

12.26 • A slab of ice floats on a freshwater lake. What minimum volume must the slab have for a 45.0-kg woman to be able to stand on it without getting her feet wet?

12.27 • An ore sample weighs 17.50 N in air. When the sample is suspended by a light cord and totally immersed in water, the tension in the cord is 11.20 N. Find the total volume and the density of the sample.

12.28 • You are preparing some apparatus for a visit to a newly discovered planet Caasi having oceans of glycerine and a surface acceleration due to gravity of 4.15 m/s². If your apparatus floats in the oceans on earth with 25.0% of its volume
submerged, what percentage will be submerged in the glycerine oceans of Caasi?

12.29 ** An object of average density \( \rho \) floats at the surface of a fluid of density \( \rho_{\text{fluid}} \). (a) How must the two densities be related? (b) In view of the answer to part (a), how can steel ships float in water? (c) In terms of \( \rho \) and \( \rho_{\text{fluid}} \), what fraction of the object is submerged and what fraction is above the fluid? Check that your answers give the correct limiting behavior as \( \rho \to \rho_{\text{fluid}} \) and as \( \rho \to 0 \). (d) While on board your yacht, your cousin Throckmorton cuts a rectangular piece (dimensions \( 5.0 \times 4.0 \times 3.0 \) cm) out of a life preserver and throws it into the ocean. The piece has a mass of 42 g. As it floats in the ocean, what percentage of its volume is above the surface?

12.30 ** A hollow plastic sphere is held below the surface of a fresh-water lake by a cord anchored to the bottom of the lake. The sphere has a volume of 0.650 m\(^3\) and the tension in the cord is 900 N. (a) Calculate the buoyant force exerted by the water on the sphere. (b) What is the mass of the sphere? (c) The cord breaks and the sphere rises to the surface. When the sphere comes to rest, what fraction of its volume will be submerged?

12.31 ** A cubical block of wood, 10.0 cm on a side, floats at the interface between oil and water with its lower surface 1.50 cm below the interface (Fig. E12.31). The density of the oil is 790 kg/m\(^3\). (a) What is the gauge pressure at the upper face of the block? (b) What is the gauge pressure at the lower face of the block? (c) What are the mass and density of the block?

12.32 ** A solid aluminum ingot weighs 89 N in air. (a) What is its volume? (b) The ingot is suspended from a rope and totally immersed in water. What is the tension in the rope (the apparent weight of the ingot in water)?

12.33 ** A rock is suspended by a light string. When the rock is in air, the tension in the string is 39.2 N. When the rock is totally immersed in water, the tension is 28.4 N. When the rock is totally immersed in an unknown liquid, the tension is 18.6 N. What is the density of the unknown liquid?

Section 12.4 Fluid Flow

12.34 ** Water runs into a fountain, filling all the pipes, at a steady rate of 0.750 m\(^3\)/s. (a) How fast will it shoot out of a hole 4.50 cm in diameter? (b) At what speed will it shoot out if the diameter of the hole is three times as large?

12.35 ** A shower head has 20 circular openings, each with radius 1.0 mm. The shower head is connected to a pipe with radius 0.80 cm. If the speed of water in the pipe is 3.0 m/s, what is its speed as it exits the shower-head openings?

12.36 ** Water is flowing in a pipe with a varying cross-sectional area, and at all points the water completely fills the pipe. At point 1, the cross-sectional area of the pipe is 0.070 m\(^2\), and the magnitude of the fluid velocity is 3.50 m/s. (a) What is the fluid speed at points in the pipe where the cross-sectional area is (a) 0.105 m\(^2\) and (b) 0.047 m\(^2\)? (c) Calculate the volume of water discharged from the open end of the pipe in 1.00 hour.

12.37 ** Water is flowing in a pipe with a circular cross section but with varying cross-sectional area, and at all points the water completely fills the pipe. (a) At one point in the pipe the radius is 0.150 m. What is the speed of the water at this point if water is flowing into this pipe at a steady rate of 1.20 m\(^3\)/s? (b) At a second point in the pipe the water speed is 3.80 m/s. What is the radius of the pipe at this point?

12.38 ** Home Repair. You need to extend a 2.50-inch-diameter pipe, but you have only a 1.00-inch-diameter pipe on hand. You make a fitting to connect these pipes end to end. If the water is flowing at 6.00 cm/s in the wide pipe, how fast will it be flowing through the narrow one?

12.39 ** At a point where an irrigation canal having a rectangular cross section is 18.5 m wide and 3.75 m deep, the water flows at 2.50 cm/s. At a point downstream, but on the same level, the canal is 16.5 m wide, but the water flows at 11.0 cm/s. How deep is the canal at this point?

12.40 ** 1B Artery Blockage. A medical technician is trying to determine what percentage of a patient’s artery is blocked by plaque. To do this, she measures the blood pressure just before the region of blockage and finds that it is 1.20 \( \times 10^4 \) Pa, while in the region of blockage it is 1.15 \( \times 10^4 \) Pa. Furthermore, she knows that blood flowing through the normal artery just before the point of blockage is traveling at 30.0 cm/s, and the specific gravity of this patient’s blood is 1.06. What percentage of the cross-sectional area of the patient’s artery is blocked by the plaque?

Section 12.5 Bernoulli’s Equation

12.41 ** A sealed tank containing seawater to a height of 11.0 m also contains air above the water at a gauge pressure of 3.00 atm. Water flows out from the bottom through a small hole. How fast is this water moving?

12.42 ** A small circular hole 6.00 mm in diameter is cut in the side of a large water tank, 14.0 m below the water level in the tank. The top of the tank is open to the air. Find (a) the speed of efflux of the water and (b) the volume discharged per second.

12.43 ** What gauge pressure is required in the city water mains for a stream from a fire hose connected to the mains to reach a vertical height of 15.0 m? (Assume that the mains have a much larger diameter than the fire hose.)

12.44 ** At one point in a pipeline the water’s speed is 3.00 m/s and the gauge pressure is 5.00 \( \times 10^4 \) Pa. Find the gauge pressure at a second point in the line, 11.0 m lower than the first, if the pipe diameter at the second point is twice that at the first.

12.45 ** At a certain point in a horizontal pipeline, the water’s speed is 2.50 m/s and the gauge pressure is 1.80 \( \times 10^4 \) Pa. Find the gauge pressure at a second point in the line if the cross-sectional area at the second point is twice that at the first.

12.46 ** A soft drink (mostly water) flows in a pipe at a beverage plant with a mass flow rate that would fill 220 0.355-L cans per minute. At point 2 in the pipe, the gauge pressure is 152 kPa and the cross-sectional area is 8.00 cm\(^2\). At point 1, 1.35 m above point 2, the cross-sectional area is 2.00 cm\(^2\). Find the (a) mass flow rate; (b) volume flow rate; (c) flow speeds at points 1 and 2; (d) gauge pressure at point 1.

12.47 ** A golf course sprinkler system discharges water from a horizontal pipe at the rate of 7200 cm\(^3\)/s. At one point in the pipe, where the radius is 4.00 cm, the water’s absolute pressure is 2.40 \( \times 10^5 \) Pa. At a second point in the pipe, the water passes through a constriction where the radius is 2.00 cm. What is the water’s absolute pressure as it flows through this constriction?

Section 12.6 Viscosity and Turbulence

12.48 ** A pressure difference of 6.00 \( \times 10^4 \) Pa is required to maintain a volume flow rate of 0.800 m\(^3\)/s for a viscous fluid flowing through a section of cylindrical pipe that has radius 0.210 m.
What pressure difference is required to maintain the same volume flow rate if the radius of the pipe is decreased to 0.0700 m?

12.49 ** BIO Clogged Artery.** Viscous blood is flowing through an artery partially clogged by cholesterol. A surgeon wants to remove enough of the cholesterol to double the flow rate of blood through this artery. If the original diameter of the artery is \( D \), what should be the new diameter (in terms of \( D \)) to accomplish this for the same pressure gradient?

## PROBLEMS

12.50 ** CP** The deepest point known in any of the earth’s oceans is in the Marianas Trench, 10.92 km deep. (a) Assuming water is incompressible, what is the pressure at this depth? Use the density of seawater. (b) The actual pressure is \( 1.16 \times 10^8 \text{ Pa} \); your calculated value will be less because the density actually varies with depth. Using the compressibility of water and the actual pressure, find the density of the water at the bottom of the Marianas Trench. What is the percent change in the density of the water?

12.51 ** CP** In a lecture demonstration, a professor pulls apart two hemispherical steel shells (diameter \( D \)) with ease using their attached handles. She then places them together, pumps out the air to an absolute pressure of \( p \), and hands them to a bodybuilder in the back row to pull apart. (a) If atmospheric pressure is \( p_0 \), how much force must the bodybuilder exert on each shell? (b) Evaluate your answer for the case \( p = 0.025 \text{ atm}, D = 10.0 \text{ cm} \).

12.52 ** BIO Fish Navigation.** (a) As you can tell by watching them in an aquarium, fish are able to remain at any depth in water with no effort. What does this ability tell you about their density? (b) Fish are able to inflate themselves using a sac (called the swim bladder) located under their spinal column. These sacs can be filled with an oxygen–nitrogen mixture that comes from the blood. If a 2.75-kg fish in freshwater inflates itself and increases its volume by 10%, find the net force that the water exerts on it. (c) What is the net external force on it? Does the fish go up or down when it inflates itself?

12.53 ** CALC** A swimming pool is 5.0 m long, 4.0 m wide, and 3.0 m deep. Compute the force exerted by the water against (a) the bottom and (b) either end. (Hint: Calculate the force on a thin, horizontal strip at a depth \( h \), and integrate this over the end of the pool.) Do not include the force due to air pressure.

12.54 ** CP CALC** The upper edge of a gate in a dam runs along the water surface. The gate is 2.00 m high and 4.00 m wide and is hinged along a horizontal line through its center (Fig. P12.54). Calculate the torque about the hinge arising from the force due to the water. (Hint: Use a procedure similar to that used in Problem 12.53; calculate the torque on a thin, horizontal strip at a depth \( h \) and integrate this over the gate.)

12.55 ** CP CALC** Force and Torque on a Dam. A dam has the shape of a rectangular solid. The side facing the lake has area \( A \) and height \( H \). The surface of the freshwater lake behind the dam is at the top of the dam. (a) Show that the net horizontal force exerted by the water on the dam equals \( \frac{1}{2} \rho gHA \)—that is, the average gauge pressure across the face of the dam times the area (see Problem 12.53). (b) Show that the torque exerted by the water about an axis along the bottom of the dam is \( \rho gH^2A/6 \). (c) How do the force and torque depend on the size of the lake?

12.56 ** Ballooning on Mars.** It has been proposed that we could explore Mars using inflated balloons to hover just above the surface. The buoyancy of the atmosphere would keep the balloon aloft. The density of the Martian atmosphere is 0.0154 kg/m³ (although this varies with temperature). Suppose we construct these balloons of a thin but tough plastic having a density such that each square meter has a mass of 5.00 g. We inflate them with a very light gas whose mass we can neglect. (a) What should be the radius and mass of these balloons so they just hover above the surface of Mars? (b) If we released one of the balloons from part (a) on earth, where the atmospheric density is 1.20 kg/m³, what would be its initial acceleration assuming it was the same size as on Mars? Would it go up or down? (c) If on Mars these balloons have five times the radius found in part (a), how heavy an instrument package could they carry?

12.57 ** A 0.180-kg cube of ice (frozen water) is floating in glycerine. The glycerine is in a tall cylinder that has inside radius 3.50 cm. The level of the glycerine is well below the top of the cylinder. If the ice completely melts, by what distance does the height of liquid in the cylinder change? Does the level of liquid rise or fall? That is, is the surface of the water above or below the original level of the glycerine before the ice melted?

12.58 ** A narrow, U-shaped glass tube with open ends is filled with 25.0 cm of oil (of specific gravity 0.80) and 25.0 cm of water on opposite sides, with a barrier separating the liquids (Fig. P12.58). (a) Assume that the two liquids do not mix, and find the final heights of the columns of liquid in each side of the tube after the barrier is removed. (b) For the following cases, arrive at your answer by simple physical reasoning, not by calculations: (i) What would be the height on each side if the oil and water had equal densities? (ii) What would the heights be if the oil’s density were much less than that of water?

12.59 ** A U-shaped tube open to the air at both ends contains some mercury. A quantity of water is carefully poured into the left arm of the U-shaped tube until the vertical height of the water column is 15.0 cm (Fig. P12.59). (a) What is the gauge pressure at the water–mercury interface? (b) Calculate the vertical distance \( h \) from the top of the mercury in the right-hand arm of the tube to the top of the water in the left-hand arm.

12.60 ** CALC** The Great Molasses Flood. On the afternoon of January 15, 1919, an unusually warm day in Boston, a 17.7-m-high, 27.4-m-diameter cylindrical metal tank used for storing molasses ruptured. Molasses flooded into the streets in a 5-m-deep stream, killing pedestrians and horses and knocking down buildings. The molasses had a density of 1600 kg/m³. If the tank was full before the accident, what was the total outward force the molasses exerted on its sides? (Hint: Consider the outward force on a circular ring of the tank wall of width \( dy \) and at a depth \( y \) below the surface. Integrate to find the total outward force. Assume that before the tank ruptured, the pressure at the surface of the molasses was equal to the air pressure outside the tank.)
12.61 • An open barge has the dimensions shown in Fig. 12.61. If the barge is made out of 4.0-
cm-thick steel plate on each of its four sides and its bottom, what mass of coal can the barge
carry in freshwater without sinking? Is there enough room in the barge to hold this amount of coal?
(The density of coal is about 1500 kg/m³.)

12.62 • A hot-air balloon has a volume of 2200 m³. The bal-
loon fabric (the envelope) weighs 900 N. The basket with gear and full propane tanks weighs 1700 N. If the balloon can barely lift an additional 3200 N of passengers, breakfast, and champagne when the outside air density is 1.23 kg/m³, what is the average density
of the heated gases in the envelope?

12.63 • Advertisements for a certain small car claim that it floats
in water. (a) If the car’s mass is 900 kg and its interior volume is
3.0 m³, what fraction of the car is immersed when it floats? You
can ignore the volume of steel and other materials. (b) Water gradu-
ally leaks in and displaces the air in the car. What fraction of the
interior volume is filled with water when the car sinks?

12.64 • A single ice cube with mass 9.70 g floats in a glass com-
pletely full of 420 cm³ of water. You can ignore the water’s sur-
facing tension and its variation in density with temperature (as long
as it remains a liquid). (a) What volume of water does the ice cube
displace? (b) When the ice cube has completely melted, has any
water overflowed? If so, how much? If not, explain why this is so.
(c) Suppose the water in the glass had been very salty water of
density 1050 kg/m³. What volume of salt water would the 9.70-g
ice cube displace? (d) Redo part (b) for the freshwater ice cube in
the salty water.

12.65 • A piece of wood is 0.600 m long, 0.250 m wide, and
0.080 m thick. Its density is 700 kg/m³. What volume of lead must
be fastened underneath it to sink the wood in calm water so that its
top is just even with the water level? What is the mass of this vol-
ume of lead?

12.66 • A hydrometer consists of a spherical bulb and a cylin-
derical stem with a cross-sectional area of 0.400 cm² (see Fig. 12.12a).
The total volume of bulb and stem is 13.2 cm³. When immersed in
water, the hydrometer floats with 8.00 cm of the stem above the
water surface. When the hydrometer is immersed in an organic
fluid, 3.20 cm of the stem is above the surface. Find the density of
the organic fluid. (Note: This illustrates the precision of such a
hydrometer. Relatively small density differences give rise to rela-
tively large differences in hydrometer readings.)

12.67 • The densities of air, helium, and hydrogen (at
p = 1.0 atm and T = 20°C) are 1.20 kg/m³, 0.166 kg/m³, and
0.0899 kg/m³, respectively. (a) What is the volume in cubic
meters displaced by a hydrogen-filled airship that has a total “lift”
of 90.0 kN? (The “lift” is the amount by which the buoyant force
exceeds the weight of the gas that fills the airship.) (b) What would
be the “lift” if helium were used instead of hydrogen? In view of
your answer, why is helium used in modern airships like advertise-
ment blimps?

12.68 • When an open-faced boat has a mass of 5750 kg,
including its cargo and passengers, it floats with the water just
up to the top of its gunwales (sides) on a freshwater lake. (a)
What is the volume of this boat? (b) The captain decides that it
is too dangerous to float with his boat on the verge of sinking, so
he decides to throw some cargo overboard so that 20% of the
boat’s volume will be above water. How much mass should he
throw out?

12.69 • CP An open cylindrical tank of acid rests at the edge of a
table 1.4 m above the floor of the chemistry lab. If this tank springs
a small hole in the side at its base, how far from the foot of the
table will the acid hit the floor if the acid in the tank is 75 cm deep?

12.70 • CP A firehose must be able to shoot water to the top of a
building 28.0 m tall when aimed straight up. Water enters this hose
at a steady rate of 0.500 m³/s and shoots out of a round nozzle.
(a) What is the maximum diameter this nozzle can have? (b) If the
only nozzle available has a diameter twice as great, what is the
highest point the water can reach?

12.71 • CP You drill a small hole in the side of a vertical cylin-
derical water tank that is standing on the ground with its top open to
the air. (a) If the water level has a height H, at what height above
the base should you drill the hole for the water to reach its greatest
distance from the base of the cylinder when it hits the ground? (b)
What is the greatest distance the water will reach?

12.72 • CALC A closed and elevated vertical cylindrical tank
with diameter 2.00 m contains water to a depth of 0.800 m. A
worker accidentally pokes a circular hole with diameter 0.0200 m in
the bottom of the tank. As the water drains from the tank, com-
pressed air above the water in the tank maintains a gauge pressure
of 5.00 × 10³ Pa at the surface of the water. Ignore any effects of
viscosity. (a) Just after the hole is made, what is the speed of the
water as it emerges from the hole? What is the ratio of this speed to
the efflux speed if the top of the tank is open to the air? (b) How
much time does it take for all the water to drain from the tank?
What is the ratio of this time to the time it takes for the tank to
drain if the top of the tank is open to the air?

12.73 • A block of balsa wood placed in one scale pan of an equal-
arm balance is exactly balanced by a 0.115-kg brass mass in the
other scale pan. Find the true mass of the balsa wood if its density is
150 kg/m³. Explain why it is accurate to ignore the buoyancy in air
of the brass but not the buoyancy in air of the balsa wood.

12.74 • Block A in Fig. 12.74 hangs by a cord from spring bal-
ance D and is submerged in a liquid
C contained in beaker B. The mass
of the beaker is 1.00 kg; the mass
of the liquid is 1.80 kg. Balance
D reads 3.50 kg, and balance E reads
7.50 kg. The volume of block A is
3.80 × 10⁻³ m³. (a) What is the
density of the liquid? (b) What will
each balance read if block A is
pulled up out of the liquid?

12.75 • A hunk of aluminum is
completely covered with a gold
shell to form an ingot of weight
45.0 N. When you suspend the ingot from a spring balance and
submerge the ingot in water, the balance reads 39.0 N. What is the
weight of the gold in the shell?

12.76 • A plastic ball has radius 12.0 cm and floats in water with
24.0% of its volume submerged. (a) What force must you apply to
the ball to hold it at rest totally below the surface of the water?
(b) If you let go of the ball, what is its acceleration the instant you
release it?

12.77 • The weight of a king’s solid crown is w. When the crown
is suspended by a light rope and completely immersed in water,
the tension in the rope (the crown’s apparent weight) is f w. (a)
Prove that the crown’s relative density (specific gravity) is 1/(1 − f).
Discuss the meaning of the limits as f approaches 0 and 1. (b) If the
crown is solid gold and weighs 12.9 N in air, what is its apparent
weight when completely immersed in water? (c) Repeat part (b) if the crown is solid lead with a very thin gold plating, but still has a weight in air of 12.9 N.

12.78 A piece of steel has a weight \( w \), an apparent weight (see Problem 12.77) \( w_{\text{water}} \) when completely immersed in water, and an apparent weight \( w_{\text{fluid}} \) when completely immersed in an unknown fluid. (a) Prove that the fluid’s density relative to water (specific gravity) is \( (w - w_{\text{fluid}})/(w - w_{\text{water}}) \). (b) Is this result reasonable for the three cases of \( w_{\text{fluid}} \) greater than, equal to, or less than \( w_{\text{water}} \)? (c) The apparent weight of the piece of steel in water of density 1000 kg/m\(^3\) is 87.2% of its weight. What percentage of its weight will its apparent weight be in formic acid (density 1220 kg/m\(^3\))?}

12.79 You cast some metal of density \( \rho_m \) in a mold, but you are worried that there might be cavities within the casting. You measure the weight of the casting to be \( w \), and the buoyant force when it is completely surrounded by water to be \( B \). (a) Show that \( V_0 = B/(\rho_{\text{water}}g) - w/(\rho_{\text{mg}}g) \) is the total volume of any enclosed cavities. (b) If your metal is copper, the casting’s weight is 156 N, and the buoyant force is 20 N, what is the total volume of any enclosed cavities in your casting? What fraction is this of the total volume of the casting?

12.80 A cubical block of wood 0.100 m on a side and with a density of 550 kg/m\(^3\) floats in a jar of water. Oil with a density of 750 kg/m\(^3\) is poured on the water until the top of the oil layer is 0.035 m below the top of the block. (a) How deep is the oil layer? (b) What is the gauge pressure at the block’s lower face?

12.81 Dropping Anchor. An iron anchor with mass 35.0 kg and density 7860 kg/m\(^3\) lies on the deck of a small barge that has vertical sides and floats in a freshwater river. The area of the bottom of the barge is 8.00 m\(^2\). The anchor is thrown overboard but is suspended above the bottom of the river by a rope; the mass and volume of the rope are small enough to ignore. After the anchor is overboard and the barge has finally stopped bobbing up and down, has the barge risen or sunk down in the water? By what vertical distance?

12.82 Assume that crude oil from a supertanker has density 750 kg/m\(^3\). The tanker runs aground on a sandbar. To refloat the tanker, its oil cargo is pumped out into steel barrels, each of which has a mass of 15.0 kg when empty and holds 0.120 m\(^3\) of oil. You can ignore the volume occupied by the steel from which the barrel is made. (a) If a salvage worker accidentally drops a filled, sealed barrel overboard, will it float or sink in the seawater? (b) If the barrel floats, what fraction of its volume will be above the water surface? If it sinks, what minimum tension would have to be exerted by a rope to haul the barrel up from the ocean floor? (c) Repeat parts (a) and (b) if the density of the oil is 910 kg/m\(^3\) and the mass of each empty barrel is 32.0 kg.

12.83 A cubical block of density \( \rho_b \) and with sides of length \( L \) floats in a liquid of greater density \( \rho_l \). (a) What fraction of the block’s volume is above the surface of the liquid? (b) The liquid is denser than water (density \( \rho_w \)) and does not mix with it. If water is poured on the surface of the liquid, how deep must the water layer be so that the water surface just rises to the top of the block? Express your answer in terms of \( L, \rho_b, \rho_l, \) and \( \rho_w \). (c) Find the depth of the water layer in part (b) if the liquid is mercury, the block is made of iron, and the side length is 10.0 cm.

12.84 A barge is in a rectangular lock on a freshwater river. The lock is 60.0 m long and 20.0 m wide, and the steel doors on each end are closed. With the barge floating in the lock, a 2.50 \( \times \) 10\(^4\) N load of scrap metal is put onto the barge. The metal has density 9000 kg/m\(^3\). (a) When the load of scrap metal, initially on the bank, is placed onto the barge, what vertical distance does the water in the lock rise? (b) The scrap metal is now pushed overboard into the water. Does the water level in the lock rise, fall, or remain the same? If it rises or falls, by what vertical distance does it change?

12.85 CP CALC A U-shaped tube with a horizontal portion of length \( l \) (Fig. P12.85) contains a liquid. What is the difference in height between the liquid columns in the vertical arms (a) if the tube has an acceleration \( a \) toward the right and (b) if the tube is mounted on a horizontal turntable rotating with an angular speed \( \omega \) about one of the vertical arms on the axis of rotation? (c) Explain why the difference in height does not depend on the density of the liquid or on the cross-sectional area of the tube. Would it be the same if the vertical tubes did not have equal cross-sectional areas? Would it be the same if the horizontal portion were tapered from one end to the other? Explain.

12.86 CP CALC A cylindrical container of an incompressible liquid with density \( \rho \) rotates with constant angular speed \( \omega \) about its axis of symmetry, which we take to be the \( y \)-axis (Fig. P12.86). (a) Show that the pressure at a given height within the fluid increases in the radial direction (outward from the axis of rotation) according to \( \partial p/\partial r = \rho \omega^2 r \). (b) Integrate this partial differential equation to find the pressure as a function of distance from the axis of rotation along a horizontal line at \( y = 0 \). (c) Combine the result of part (b) with Eq. (12.5) to show that the surface of the rotating liquid has a parabolic shape; that is, the height of the liquid is given by \( h(r) = \frac{\omega^2 r^2}{2g} \). (This technique is used for making parabolic telescope mirrors; liquid glass is rotated and allowed to solidify while rotating.)

12.87 CP CALC An incompressible fluid with density \( \rho \) is in a horizontal test tube of inner cross-sectional area \( A \). The test tube spins in a horizontal circle in an ultracentrifuge at an angular speed \( \omega \). Gravitational forces are negligible. Consider a volume element of the fluid of area \( A \) and thickness \( dr \) a distance \( r \) from the rotation axis. The pressure on its inner surface is \( p \) and on its outer surface is \( p + dp \). (a) Apply Newton’s second law to the volume element to show that \( dp = \rho \omega^2 r^2 dr \'). (b) If the surface of the fluid is at a radius \( r_0 \) where the pressure is \( p_0 \), show that the pressure at a distance \( r \) \( \geq \) \( r_0 \) is \( p = p_0 + \rho \omega^2 (r^2 - r_0^2)/2 \). (c) An object of volume \( V \) and density \( \rho_b \) has its center of mass at a distance \( R_{\text{cmob}} \) from the axis. Show that the net horizontal force on the object is \( \rho V \omega^2 R_{\text{cmob}} \), where \( R_{\text{cm}} \) is the distance from the axis to the center of mass of the displaced fluid. (d) Explain why the object will move inward if \( \rho R_{\text{cm}} > \rho_b R_{\text{cmob}} \) and outward if \( \rho R_{\text{cm}} < \rho_b R_{\text{cmob}} \). (e) For small objects of uniform density, \( R_{\text{cm}} = R_{\text{cmob}} \). What happens to a mixture of small objects of this kind with different densities in an ultracentrifuge?

12.88 CALC Untethered helium balloons, floating in a car that has all the windows rolled up and outside air vents closed, move in the direction of the car’s acceleration, but loose balloons filled with air move in the opposite direction. To show why, consider only the horizontal forces acting on the balloons. Let \( a \) be the magnitude of the car’s forward acceleration. Consider a horizontal tube of air with a cross-sectional area \( A \) that extends from the
windshield, where \( x = 0 \) and \( p = p_0 \), back along the \( x \)-axis. Now consider a volume element of thickness \( dx \) in this tube. The pressure on its front surface is \( p \) and the pressure on its rear surface is \( p + dp \). Assume the air has a constant density \( \rho \). (a) Apply Newton’s second law to the volume element to show that \( dp = \rho dx \). (b) Integrate the result of part (a) to find the pressure at the front surface in terms of \( a \) and \( x \). (c) To show that considering \( \rho \) constant is reasonable, calculate the pressure difference in atm for a distance as long as 2.5 m and a large acceleration of 5.0 m/s\(^2\).

12.89 \( \clubsuit \) CP Water stands at a depth \( H \) in a large, open tank whose side walls are vertical (Fig. P12.89). A hole is made in one of the walls at a depth \( h \) below the water surface. (a) At what distance \( R \) from the foot of the wall does the emerging stream strike the floor? (b) How far above the bottom of the tank could a second hole be cut so that the stream emerging from it could have the same range as for the first hole?

Figure P12.89

12.90 \( \bullet \bullet \bullet \) A cylindrical bucket, open at the top, is 25.0 cm high and 10.0 cm in diameter. A circular hole with a cross-sectional area 1.50 cm\(^2\) is cut in the center of the bottom of the bucket. Water flows into the bucket from a tube above it at the rate of 2.40 \( \times \) 10\(^{-4} \) m\(^3\)/s. How high will the water in the bucket rise?

12.91 \( \bullet \) Water flows steadily from an open tank as in Fig. P12.91. The elevation of point 1 is 10.0 m, and the elevation of points 2 and 3 is 2.00 m. The cross-sectional area at point 2 is 0.0480 m\(^2\); at point 3 it is 0.0160 m\(^2\). The area of the tank is very large compared with the cross-sectional area of the pipe. Assuming that Bernoulli’s equation applies, compute (a) the discharge rate in cubic meters per second and (b) the gauge pressure at point 2.

Figure P12.91

12.92 \( \bullet \) CP In 1993 the radius of Hurricane Emily was about 350 km. The wind speed near the center (“eye”) of the hurricane, whose radius was about 30 km, reached about 200 km/h. As air swirled in from the rim of the hurricane toward the eye, its angular momentum remained roughly constant. (a) Estimate the wind speed at the rim of the hurricane. (b) Estimate the pressure difference at the earth’s surface between the eye and the rim. (Hint: See Table 12.1.) Where is the pressure greater? (c) If the kinetic energy of the swirling air in the eye could be converted completely to gravitational potential energy, how high would the air go? (d) In fact, the air in the eye is lifted to heights of several kilometers. How can you reconcile this with your answer to part (c)?

12.93 \( \bullet \bullet \) Two very large open tanks \( A \) and \( F \) (Fig. P12.93) contain the same liquid. A horizontal pipe \( BCD \), having a constriction at \( C \) and open to the air at \( D \), leads out of the bottom of tank \( A \), and a vertical pipe \( E \) opens into the constriction at \( C \) and dips into the liquid in tank \( F \). Assume streamline flow and no viscosity. If the cross-sectional area at \( C \) is one-half the area at \( D \) and if \( D \) is a distance \( h_1 \) below the level of the liquid in \( A \), to what height \( h_2 \) will liquid rise in pipe \( E \)? Express your answer in terms of \( h_1 \).

Figure P12.93

12.94 \( \bullet \bullet \) The horizontal pipe shown in Fig. P12.94 has a cross-sectional area of 40.0 cm\(^2\) at the wider portions and 10.0 cm\(^2\) at the constriction. Water is flowing in the pipe, and the discharge from the pipe is 6.00 \( \times \) 10\(^{-3} \) m\(^3\)/s (6.00 L/s). Find (a) the flow speeds at the wide and the narrow portions; (b) the pressure difference between these portions; (c) the difference in height between the mercury columns in the U-shaped tube.

12.95 \( \bullet \) A liquid flowing from a vertical pipe has a definite shape as it flows from the pipe. To get the equation for this shape, assume that the liquid is in free fall once it leaves the pipe. Just as it leaves the pipe, the liquid has speed \( v_0 \) and the radius of the stream of liquid is \( r_0 \). (a) Find an equation for the speed of the liquid as a function of the distance \( y \) it has fallen. Combining this with the equation of continuity, find an expression for the radius of the stream as a function of \( y \). (b) If water flows out of a vertical pipe at a speed of 1.20 m/s, how far below the outlet will the radius be one-half the original radius of the stream?

**Challenge Problems**

12.96 \( \bullet \bullet \bullet \) A rock with mass \( m = 3.00 \) kg is suspended from the roof of an elevator by a light cord. The rock is totally immersed in a bucket of water that sits on the floor of the elevator, but the rock doesn’t touch the bottom or sides of the bucket. (a) When the elevator is at rest, the tension in the cord is 21.0 N. Calculate the volume of the rock. (b) Derive an expression for the tension in the cord when the elevator is accelerating upward with an acceleration of magnitude \( a \). Calculate the tension when \( a = 2.50 \) m/s\(^2\).
upward. (c) Derive an expression for the tension in the cord when the elevator is accelerating downward with an acceleration of magnitude $a$. Calculate the tension when $a = 2.50 \text{ m/s}^2$ downward.

(d) What is the tension when the elevator is in free fall with a downward acceleration equal to $g$?

**12.97 CALC** Suppose a piece of styrofoam, $\rho = 180 \text{ kg/m}^3$, is held completely submerged in water (Fig. P12.97). (a) What is the tension in the cord? Find this using Archimedes’s principle. (b) Use $p = p_g + p_f \rho h$ to calculate directly the force exerted by the water on the two sloped sides and the bottom of the styrofoam; then show that the vector sum of these forces is the buoyant force.

![Figure P12.97](image)

**Answers**

**Chapter Opening Question**

The flesh of both the shark and the tropical fish is denser than seawater, so left to themselves they would sink. However, a tropical fish has a gas-filled body cavity called a swimbladder, so that the average density of the fish’s body is the same as that of seawater and the fish neither sinks nor rises. Sharks have no such cavity. Hence they must swim constantly to keep from sinking, using their pectoral fins to provide lift much like the wings of an airplane (see Section 12.5).

**Test Your Understanding Questions**

**12.1 Answer:** (ii), (iv), (i) and (iii) (tie), (v) In each case the average density equals the mass divided by the volume. Hence we have (i) $\rho = (4.00 \text{ kg})/(1.60 \times 10^{-3} \text{ m}^3) = 2.50 \times 10^3 \text{ kg/m}^3$; (ii) $\rho = (8.00 \text{ kg})/(1.60 \times 10^{-3} \text{ m}^3) = 5.00 \times 10^3 \text{ kg/m}^3$; (iii) $\rho = (8.00 \text{ kg})/(3.20 \times 10^{-3} \text{ m}^3) = 2.50 \times 10^3 \text{ kg/m}^3$; (iv) $\rho = (2560 \text{ kg})/(0.640 \text{ m}^3) = 4.00 \times 10^3 \text{ kg/m}^3$; (v) $\rho = (2560 \text{ kg})/(1.28 \text{ m}^3) = 2.00 \times 10^3 \text{ kg/m}^3$. Note that compared to object (i), object (ii) has double the mass but the same volume and so has double the average density. Object (iii) has double the mass and double the volume of object (i), so (i) and (iii) have the same average density. Finally, object (v) has the same mass as object (iv) but double the volume, so (v) has half the average density of (iv).

**12.2 Answer:** (ii) From Eq. (12.9), the pressure outside the barometer is equal to the product $p_f \rho_h$. When the barometer is taken out of the refrigerator, the density $\rho$ decreases while the height $h$ of the mercury column remains the same. Hence the air pressure must be lower outdoors than inside the refrigerator.

**12.3 Answer:** (i) Consider the water, the statue, and the container together as a system; the total weight of the system does not depend on whether the statue is immersed. The total supporting force, including the tension $T$ and the upward force $F$ of the scale on the container (equal to the scale reading), is the same in both cases. But we saw in Example 12.5 that $F$ decreases by $7.84 \text{ N}$ when the statue is immersed, so the scale reading $F$ must increase by $7.84 \text{ N}$. An alternative viewpoint is that the water exerts an upward buoyant force of $7.84 \text{ N}$ on the statue, so the statue must exert an equal downward force on the water, making the scale reading $7.84 \text{ N}$ greater than the weight of water and container.

**12.4 Answer:** (ii) A highway that narrows from three lanes to one is like a pipe whose cross-sectional area narrows to one-third of its value. If cars behaved like the molecules of an incompressible fluid, then as the cars encountered the one-lane section, the spacing between cars (the “density”) would stay the same but the cars would triple their speed. This would keep the “volume flow rate” (number of cars per second passing a point on the highway) the same. In real life cars behave like the molecules of a compressible fluid: They end up packed closer (the “density” increases) and fewer cars per second pass a point on the highway (the “volume flow rate” decreases).

**12.5 Answer:** (ii) Newton’s second law tells us that a body accelerates (its velocity changes) in response to a net force. In fluid flow, a pressure difference between two points means that fluid particles moving between those two points experience a force, and this force causes the fluid particles to accelerate and change speed.

**12.6 Answer:** (iv) The required pressure is proportional to $1/R^4$, where $R$ is the inside radius of the needle (half the inside diameter). With the smaller-diameter needle, the pressure is greater by a factor of $[(0.60 \text{ mm})/(0.30 \text{ mm})]^4 = 2^4 = 16$.

**Bridging Problem**

Answers: (a) $y = H - \left(\frac{d}{D}\right)^2 \sqrt{2gh} + \left(\frac{d}{D}\right)^2 \frac{gt^2}{2}$

(b) $T = \frac{\sqrt{2H}}{\sqrt{g}} \left(\frac{D}{d}\right)^2$

(c) $\sqrt{2}$