# 13 Liquids

Photo 1 of the water tower was taken by my best friend, Paul Ryan. The tower provides pressure to the faucets of his neighborhood. Photo 2 is Tsing Bardin, who after retiring from doing nuclear physics and material science research in Lockheed and IBM, and teaching at San Jose State and City College of San Francisco, now devotes herself to upgrading math and science education in elementary and secondary schools. Photo 3 shows the impressive Falkirk Wheel, a most fascinating illustration of physics applied to liquids. The wheel turns independent of the weight of ships it carries, for their weight is the same as the volume of water they displace. This is treated in the chapter. Photo 4 is of my friend and neighbor Ray Serway, known to many physics students as the author of algebra and calculus-based physics textbooks.

The profile for this chapter is Blaise Pascal, for whom the unit of pressure is named.

The lovely young woman on the bed of nails in Figure 13.2 is Swedish physicist Sara Blomberg.

The depths of the ocean as well as the expanse of outer space are of current interest, yet liquids are seldom studied in introductory physics classes anymore. Perhaps this is because Archimedes' Principle and the like are too far from the frontiers of present research. Because much of the physics in this chapter is more than 2000 years old is no reason that it should not be in your physics course. Liquids are a very real part of your students' everyday world.

It is well known that falling from great heights into water has much the same effect as falling to solid ground. Less well known are the new "water saws," with pressures of about 5500 lb/in$^2$ used for cutting through armor-plate steel.

Regarding Figure 13.3, you may point out that the average mass of a giraffe's heart is about 40 kg. That's quite a pump.

The dedicated teacher walking on broken glass with bare feet in his classroom in Think and Discuss 99 is Marshall Ellenstein, profiled in Chapter 29. Marshall has been a contributor to this book for years and is the editor of the video and DVD series of my lectures in both San Francisco and Hawaii. He also posts my screencasts on YouTube.

Think and Discuss 112 is Bruce Novak's mom, Greta Novak. Bruce wonderfully tweaked the manuscript and all back matter for this edition. His photo is Figure 26.4. Bruce's knowledge of physics with his many suggestions makes the 12th a proud edition for me. And I hope you too!

In student laboratory exercises, it is more common to work with mass density than with weight density, and floating or submerged materials are more often described in units of mass rather than weight. Displaced liquid is also described in units of mass rather than weight. This is why buoyant force in this chapter is treated as "the weight of so many kilograms," rather than "so many newtons." The expression of buoyancy in terms of mass units should be compatible with what goes on in lab.

> DEMONSTRATION, an impressive one on buoyancy: Place about 8 grams of dry ice in a large (several cm) uninflated balloon. Tie the balloon. Immediately set it on a digital balance reading to the nearest milligram. As the balloon inflates (over a few minutes) the balance readout plummets at a rate of about 2 mg/sec. The scale will finally read about 2.4 grams less, assuming the balloon inflates to about 2 liters (density of air is about 1.2 g/L). I learned of this demo from my nephew John Suchocki.

Oceans tidbit: The Atlantic is getting wider, the Pacific narrower.

**Practicing Physics Book**:
- Archimedes' Principle I
- Archimedes' Principle II

**Problem Solving Book**: There is a good selection of problems for this chapter.

**Laboratory Manual**:
- Pool Cubes: *Density Simulations of density and flotation* (Tech Lab)
- Pool Cubes: *Buoyancy Simulations of buoyancy and flotation* (Tech Lab)
- Eureka! *Archimedes' Principle* (Activity)
- Sink or Swim: *What Makes an Object Sink or Float* (Activity)
- Boat Float: *Flotation* (Activity)

**Next-Time Questions**:
- Styrofoam Cargo
- Water's Own Level
- Fire Truck
- Boat with Scrap Iron
- Wood and Rock Float
- Floating Block
- Ice Cube on the Moon
- Deuterium Ice Cube
- Balance Stand
- Submerged Cube and Sphere
- Submerged Teabag

**Hewitt-Drew-it! Screencasts**: •*Liquid Pressure* •*Buoyancy* •*Archimedes* •*Buoyancy on a Submarine* •*More on Buoyancy* •*Buoyancy Problems* •*Pascal's Principle*

Prerequisite to this chapter is understanding of density, covered in the previous chapter. So if you skipped Chapter 12, discuss *density* here. This chapter is prerequisite to Chapter 14, but is not prerequisite to the remaining chapters of the textbook.

## SUGGESTED LECTURE PRESENTATION

### Force versus Pressure

Begin by distinguishing between force and pressure. Illustrate with examples: Somebody pushing on your back with a force of only 1 N—with a pin! Or as you're lying on the floor, a 400-N lady stands on your stomach—perched atop spike heels! Indian master lying on a bed of 1000 nails—apprentice being advised to start with one nail! The rounded corners on tables, sharp blades on cutting knives, and the absurdity of standing tall while pointing your toes downward when caught in quicksand.

Have students compare in their hands the weights of a small steel ball and a large Styrofoam ball, and after agreeing that the little ball is heavier (since density was treated in the previous chapter), weigh them and show the Styrofoam ball is heavier! Another example of pressure (on the nerve endings).

### Liquid Pressure

Liquid pressure = density × depth. After a few words about density, you may want to derive or call attention to the derivation of this relationship in the second footnote in the chapter.

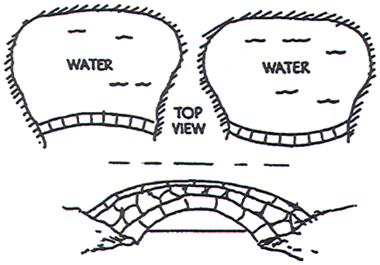
> DEMONSTRATION: Pascal's Vases (similar to Figure 13.5) are shown by Tsing Bardin in the chapter opener photo. Rationalize your results in terms of the supporting forces exerted by the

> sloping sides of the vases. [That is, in the wide sloping vase, the water pushes against the glass, and the glass reacts by pushing against the water. So the glass supports the extra water without the pressure below increasing. For the narrow vase that slopes outward near the bottom, the water pushes up against the sloping glass. By reaction, the glass pushes down on the water, so the pressure at the bottom is the same as if water were present all the way up to the surface.]

Discuss Figure 13.3 of the giraffes and why your heart gets more rest if you sleep in a prone position versus sitting up. Call attention to the fact that when swimming, the pressure one feels against one's eardrums is a function of only depth—that swimming 3 meters deep in a small pool has the same effect as swimming 3 meters deep in the middle of a huge lake.

> CHECK QUESTION: Would the pressure be greater swimming 3 m deep in the middle of the ocean? (Then compare the densities of fresh and salt water.)

Ask why dams are built thicker at the bottom, and after discussing Figure 13.4 sketch the top view of a couple of dams on the board and ask which design is best (Think and Explain 57, previous chapter). Then relate this to the shape of stone bridges (which actually need no mortar), and the arched shape of doorways in old stone structure (photo opener, previous chapter), and the aqueducts shown in Figure 13.6. Another illustration is the concave ends of large wine barrels (Think and Explain 58, previous chapter).



**Buoyant Force**

Show that the consequence of pressure being depth-dependent is the phenomenon of buoyancy. Sketch Figure 13.9 on the board. Follow up with a sketch and explanation of Figure 13.14.

> DEMONSTRATION: Show how an overflow can enables the measure of an object's volume. Ask how one could measure a quarter cup of butter in a liquid measuring cup using this method.

> DEMONSTRATION: Archimedes' Principle, as shown in Figure 13.13.

You may find that many students who have trouble with conceptualizing buoyant force are confused about the distinction between area and volume. Be sure to make this distinction clear, (as elementary as it seems). (If you didn't pour the contents of the spherical flask into the tall cylindrical flask of the same volume as described in the suggested lecture of the previous chapter, be sure to do so here.) Also, point out that because a liquid is incompressible (practically incompressible, as the volume of water decreases by only 50 one-millionths of its original volume for each atmosphere increase in pressure, or equivalently, for each addition 10.3 m in depth) its density is not depth-dependent. The density of water near the surface is practically the same as the density far beneath the surface. You may wish to acknowledge that some variation occurs due to temperature differences. Usually a student will inquire about waterlogged objects which lie submerged yet off the bottom of the body of water. Such objects are slightly denser than the warmer surface water and not quite as dense as the cooler water at the bottom. Stress that this is unusual and that objects appreciably denser than water always sink to the bottom, regardless of the depth of the water. Scuba divers do not encounter "floating" rocks near the bottoms of deep bodies of water!

> CHECK QUESTION: Two solid blocks of identical size are submerged in water. One block is lead and the other is aluminum. Upon which is the buoyant force greater? [Same, since volumes of water displaced are the same.]

After discussion, try this one:

> CHECK QUESTION: Two solid blocks of identical size, one of lead and the other of wood, are put in the same water. Upon which is the buoyant force greater? [This time the buoyant force is greater on the lead because it displaces more water than the wood that floats!]

> CHECK QUESTIONS: What is the buoyant force on a ten-ton ship floating in fresh water? In salt water? In a lake of mercury? [Same BF, but different *volumes* displaced.]

The unit "ton" is used in several places in this text. It may be taken to mean a metric tonne, the weight of 1000 kg, or the British ton, 2000 pounds. Either interpretation is sufficient in treating the concept involved.

**Flotation**
Discuss boats and rafts and the change of water lines when loaded.

> CHECK QUESTIONS: What is the approximate density of a fish? Of a person? What can you say of people who can't float?
>
> DEMONSTRATION: Cartesian diver (inverted partially filled small bottle submerged in a larger flexible plastic bottle that you squeeze to increase and decrease the weight of water in the small bottle to make it rise and fall).

Discuss the same weight of the flasks in Figure 13.18 carefully. This leads to the Falkirk Wheel, Figure 13.19, and how the water-filled caissons always weigh the same whether or not they carry boats, and that the weight of such boats makes no difference. To see the wheel in action, check Falkirk Wheel on the Internet! Most impressive, and some great physics!

Discuss the compressibility of the human body in swimming—how the density of most people a meter or two below the surface of the water is still less than the density of water, and that one need only relax and be buoyed to the surface. But that at greater depths, the greater pressure compresses one to densities greater than the density of water, and one must swim to the surface. Simply relaxing, one would sink to the bottom! Relate this to the Cartesian diver demonstration. Also state why one cannot snorkel with a tube that goes deeper than a half-meter or so.

Side point: Contrary to those old Tarzan movies, you cannot sink in quicksand. Quicksand is the name given to a mass of sand particles that are supported by circulating water rather than by each other. Its density is greater than the density of human bodies, so you can float on it. If you struggle, you'll unfortunately succeed in digging yourself deeper in. So if you're ever stuck in it, keep yourself still until you stop sinking (you will), and then use slow swimming motions to get yourself into a horizontal position and then roll onto the ground.

**Pascal's Principle**
Begin by pushing against the wall with a meterstick and state that the stick affords a means of applying pressure to the wall—then state that the same can be done with a confined fluid. Explain how any external pressure applied to a liquid that tightly fills a volume is transmitted to all parts of the liquid equally. Discuss Figures 13.21 and 13.22. If a hydraulic press is available, crush a block of wood with it. Point out that the pressure transmitted throughout a confined liquid is pressure over and above that already in the liquid. For example, the pressure in a hydraulic system at any point is equal to the applied pressure plus the density × depth. See the screencast *Pascal's Principle*.

**Surface Tension**
In the next chapter on gases we'll think of atoms as rigid balls that ricochet off one another. Here we think of atoms as sticky balls—capillarity. An interesting example of capillarity (not in the text) involves the tallness of trees. The cohesive forces of water explains the transport of water from roots to the top of tall trees. When a single water molecule evaporates from the cell membrane inside a leaf, it is replaced by the one immediately next to it due to the cohesive forces between water molecules. A pull is created on the column of water that is continuous from leaves to roots. Water can be lifted far higher than the 10.2-m height that atmospheric pressure would serve—even to 100 m in this way, the height of the largest trees.

## Answers and Solutions to Chapter 13

### Reading Check Questions

1. Pressure is force per area.
2. Pressure is due to the weight of water above (and total pressure, plus the weight of the atmosphere).
3. Liquid pressure is proportional to depth, and to weight density.
4. Greater pressure in salt water due to its greater density.
5. Pressures will be the same at the same depth.
6. Direction of water flow is at right angles to the container surface.
7. Buoyant force acts upward because there is more force beneath an object due to more pressure at greater depth.
8. Forces on opposite sides are equal and opposite and cancel.
9. Both volumes are the same.
10. Buoyant force equals the weight of water displaced.
11. A submerged body is completely immersed, completely beneath the surface.
12. 1 L of water has a mass of 1 kg, and a weight of 10 N (more precisely, 9.8 N).
13. Volume of displace water will be ½ L. Buoyant force will be 5 N.
14. Buoyant force equals the weight of fluid displaced.
15. Yes. When an object floats, buoyant force equals its weight.
16. Buoyant force depends on the volume of the submerged object.
17. Sink; float; neither sink nor float.
18. Density is controlled in a fish by expansion or contraction of an air sac; in a submarine by the weight of water blown in or out of ballast tanks.
19. Not a coincidence because in the case of floating the buoyant force equals both weight of the object as well as the weight of water displaced.
20. They have the same weight because when carrying a boat, the weight of the boat is the same as the weight of water that overflows (as in Figure 13.18).
21. If pressure in one part is increased, the same increase in pressure is transmitted to all parts.
22. 500 N will be supported by the output piston (10 N/cm$^2$ x 50 cm$^2$ = 500 N).
23. A sphere has the least surface area for a given volume.
24. Surface tension is caused by molecular attractions.
25. Adhesion is the attraction between unlike substances; cohesion is the attraction between like substances.
26. Height of water occurs when adhesive forces balance the weight of water lifted.

### Think and Do

27. An egg is denser than fresh water, but less dense than salted water. Therefore an egg will float in salt water, but sink in fresh water.

28. When the can is held still, pressure due to the weight of water in the can accounts for the spurt. But when dropped, the weight of water and the water pressure are nil, and no spurt occurs.

29. The wetted ball is pulled by surface tension beneath the surface when the system is weightless (dropping). When the can makes impact the submerged ball, much lighter than the water it displaces, is popped with great force out of the water.

30. Share this information about why soap cleans well with your friends.

31. The pepper grains float due to surface tension. When the surface tension is diminished by the addition of soap, the grains sink. Intriguing!

### Plug and Chug

32. Pressure = 10 N/50 cm$^2$ = 0.2 N/cm$^2$.
33. Pressure = weight density × depth = 10,000 N/m$^3$ × 1 m = 10,000 N/m$^2$ = 10 kPa.
34. Pressure = weight density × depth = 10,000 N/m$^3$ × 50 m = 500,000 N/m$^2$ = 500,000 Pa = 500 kPa.
35. Pressure = weight density × depth = 10,000 N/m$^3$ × 220 m = 2,200,000 N/m$^2$ = 2,200 kPa.
36. Pressure = weight density × depth = 10,000 N/m$^3$ × 20 m = 200,000 N/m$^2$ = 200 kPa.

### Think and Solve

**37.** Force per nail is 120 pounds/600 nails = 0.2 pounds per nail, which is quite tolerable.

**38.** A 5-kg ball weighs 50 N, so the pressure is 50 N/cm$^2$ = 500 kPa.

**39.** Density $= \dfrac{m}{V} = \dfrac{12\text{ kg}}{2\text{ L}} = 6\text{ kg/L}$ **.** (Since there are 1000 liters in 1 cubic meter, density may be expressed in units kg/m$^3$). Density $= \dfrac{6\text{ kg}}{1\text{ L}} \times \dfrac{1000\text{ L}}{\text{m}^3} = 6000\text{ kg/m}^3$. That's six times the density of water.

40. Pressure = weight density × depth = 10,000 N/m$^3$ × (5 + 1)m = 10,000 N/m$^3$ × 6 m = 60,000 N/m$^2$ = 60 kPa.

41. Yes. First find the pressure. It is weight density × depth = (10,000 N/m$^3$)(2 m) = 20,000 N/m$^2$, or 20,000 Pa. Force is pressure × area, and 1 cm$^2$ = 10$^{-4}$ m$^2$, so $F$ = (20,000 N/m$^2$)(10$^{-4}$ m$^2$) = 2 N. It would be easy for the boy to exert this force. It is about the weight of a notebook or a small box of cereal. (Note: Air pressure is not figured into this calculation because its effect in pushing down on the water from above is canceled by its effect in pushing from outside the hole against the leaking water.)

42. a. BF is 10 N – 8 N = 2 N.
b. The gain in scale reading is 2 N; total weight = 12 N.
c. Weight of the rock is 10 N, so total weight is 20 N.

43. From Table 12.1 the density of gold is 19.3 g/cm$^3$. Your gold has a mass of 1000 grams, so $\dfrac{1000\text{ g}}{V}$ = 19.3 g/cm$^3$. Solving for $V$,

$$V = \frac{1000\text{ g}}{19.3\text{ g/cm}^3} = 51.8\text{ cm}^3.$$

44. The relative areas are as the squares of the diameters; $6^2/2^2$ = 36/4 = 9. The large piston can lift 9 times the input force to the smaller piston.

45. Human density is about water's, 1000 kg/m$^3$. From density = $m/V$, $V = m$/density = (100 kg)/(1000 kg/m$^3$) = 0.1 m$^3$.

## Think and Rank

46. C, A, B
47. C, B, A
48. A, B, C

## Think and Explain

49. Water covers most of Earth and is essential to human life.

50. A sharp knife cuts better than a dull knife because it has a thinner cutting area which results in more cutting pressure for a given force.

51. Pressure would be appreciably greater by the woman because of the relatively small area of contact at the heel, which would hurt you more.

52. A woman with spike heels exerts considerably more pressure on the ground than an elephant! A 500-N lady with 1-cm$^2$ spike heels puts half her weight on each foot, distributed (let's say) half on her heel and half on her sole. So the pressure exerted by each heel will be (125 N/1 cm$^2$) = 125 N/cm$^2$. A 50,000-N elephant with 1000 cm$^2$ feet exerting $^1/4$ its weight on each foot produces (12,500N/1000 cm$^2$) = 12.5N/cm$^2$; about 10 times less pressure. (So a woman with spike heels will make greater dents in a new linoleum floor than an elephant will.)

53. There is less pressure with a waterbed due to the greater contact area.

54. Your upper arm is at the same level as your heart, so the blood pressure in your upper arms will be the same as the blood pressure in your heart.

55. Your body gets more rest when lying than when sitting or standing because when lying, the heart does not have to pump blood to the heights that correspond to standing or sitting.

56. No, in orbit where support is absent there are no pressure differences due to gravity.

57. More water will flow from open faucets downstairs because of the greater pressure. Since pressure depends on depth, a downstairs faucet is effectively "deeper" than an upstairs faucet. The pressure downstairs is greater by an amount = weight density × depth, where the depth is the vertical distance between faucets.

58. Both are the same, for pressure depends on depth.

59. (a) The reservoir is elevated so as to produce suitable water pressure in the faucets that it serves. (b) The hoops are closer together at the bottom because the water pressure is greater at the bottom. Closer to the top, the water pressure is not as great, so less reinforcement is needed there.

60. Both blocks have the same volume and therefore displace the same amount of water.

61. A one-kilogram block of aluminum is larger than a one-kilogram block of lead. The aluminum therefore displaces more water.

62. A 10-N block of aluminum is larger than a 10-N block of lead. The aluminum therefore displaces more water. Only in Question 60 were the block volumes equal. In this and the preceding exercise, the aluminum block is larger. (These questions serve only to emphasize the distinctions between volume, mass, and weight.)

63. The smaller the window area, the smaller the crushing force of water on it.

64. A typical plumbing design involves short sections of pipe bent at 45-degree angles between vertical sections two-stories long. The sewage therefore undergoes a succession of two-story falls which results in a moderate momentum upon reaching the basement level.

65. Water seeking its own level is a consequence of pressure depending on depth. In a bent U-tube full of water, for example, the water in one side of the tube tends to push water up the other side until the pressures at the same depth in each tube are equal. If the water levels were not the same, there would be more pressure at a given level in the fuller tube, which would move the water until the levels were equal.

66. In deep water, you are buoyed up by the water displaced and as a result, you don't exert as much pressure against the stones on the bottom. When you are up to your neck in water, you hardly feel the bottom at all.

67. Buoyant force is the result of differences in pressure; if there are no pressure differences, there is no buoyant force. This can be illustrated by the following example, Think and Do 29: A Ping-Pong ball pushed beneath the surface of water will normally float back to the surface when released. If the container of water is in free fall, however, a submerged Ping-Pong ball will fall with the container and make no attempt to reach the surface. In this case there is no buoyant force acting on the ball because there are no pressure differences—the local effects of gravity are absent.

68. Saltwater is denser than freshwater, which means you don't "sink" as far when displacing your weight. You'd float even higher in mercury (density 13.6 g/cm$^3$), and you'd sink completely in alcohol (density 0.8 g/cm$^3$).

69. A body floats higher in denser fluid because it does not have to sink as far to displace a weight of fluid equal to its own weight. A smaller volume of the displaced denser fluid is able to match the weight of the floating body.

70. The can of diet drink is less dense than water, whereas the can of regular drink is denser than water. (Water with dissolved sugar is denser than pure water.) Also, the weight of the can of diet drink is less than the buoyant force that would act on it if totally submerged. So it floats, where buoyant force equals the weight of the can.

71. Mercury is more dense (13.6 g/cm$^3$) than iron. A block of iron will displace its weight and still be partially above the mercury surface. Hence it floats in mercury. In water it sinks because it cannot displace its weight.

72. Mountain ranges are very similar to icebergs: Both float in a denser medium, and extend farther down into that medium than they extend above it. Mountains, like icebergs, are bigger than they appear to be. The concept of floating mountains is *isostacy*—Archimedes' principle for rocks.

73. A mostly-lead mountain would be more dense than the mantle and would sink in it. Guess where most of the iron in the world is. In the Earth's center!

74. The force needed will be the weight of 1 L of water, which is 9.8 N. If the weight of the carton is not negligible, then the force needed would be 9.8 N minus the carton's weight, for then the carton would be "helping" to push itself down.

75. When the ball is held beneath the surface, it displaces a greater weight of water.

76. The buoyant force on the ball beneath the surface is much greater than the force of gravity on the ball, producing a large net upward force and large acceleration.

77. Heavy objects may or may not sink, depending on their densities (a heavy log floats while a small rock sinks, or an ocean liner floats while a paper clip sinks, for example). People who say that heavy objects sink really mean that dense objects sink. Be careful to distinguish between how heavy an object is and how dense it is.

78. While floating, BF equals the weight of the submarine. When submerged, BF equals the submarine's weight *plus* the weight of water taken into its ballast tanks. Looked at another way, the submerged submarine displaces a greater weight of water than the same submarine floating.

79. Buoyant force will remain unchanged on the sinking rock because it displaces the same volume and weight of water at any depth.

80. Buoyant force on a sinking swimmer will decrease as she sinks. This is because her body, unlike the rock in the previous exercise, will be compressed by the greater pressure of greater depths.

81. You are compressible, whereas a rock is not, so when you are submerged, the water pressure tends to squeeze in on you and reduce your volume. This increases your density. (Be careful when swimming—at shallow depths you may still be less dense than water and be buoyed to the surface without effort, but at greater depths you may be pressed to a density greater than water and you'll have to swim to the surface.)

82. No, there does not have to actually be 14.5 N of fluid in the skull to supply a buoyant force of 14.5 N on the brain. To say that the buoyant force is 14.5 N is to say that the brain is taking up the space that 14.5 N of fluid would occupy if fluid instead of the brain were there. The amount of fluid in excess of the fluid that immediately surrounds the brain does not contribute to the buoyancy on the brain. (A ship floats the same in the middle of the ocean as it would if it were floating in a small lock just barely larger than the ship itself. As long as there is enough water to press against the hull of the ship, it will float. It is not important that the amount of water in this tight-fitting lock weigh as much as the ship—think about that, and don't let a literal word explanation "a floating object displaces a weight of fluid equal to its own weight" and the idea it represents confuse you.)

83. The buoyant force does not change. The buoyant force on a floating object is always equal to that object's weight, no matter what the fluid.

84. Ice cubes will float lower in a mixed drink because the mixture of alcohol and water is less dense than water. In a less dense liquid a greater volume of liquid must be displaced to equal the weight of the floating ice. In pure alcohol, the volume of alcohol equal to that of the ice cubes weighs less than the ice cubes, and buoyancy is less than weight and ice cubes will sink. Submerged ice cubes in a cocktail indicate that it contains a high percentage of alcohol.

85. When the ice cube melts the water level at the side of the glass is unchanged (neglecting temperature effects). To see this, suppose the ice cube is a 5-gram ice cube; then while floating it will displace 5

grams of water. But when melted it becomes the same 5 grams of water. Hence the water level is unchanged. The same occurs when the ice cube that contains air bubbles melts. Whether the ice cube is hollow or solid, it displaces as much water floating as when melted. If the ice cube contains grains of heavy sand, however, upon melting, the water level at the edge of the glass will drop (see Think and Discuss 107).

86. The total weight on the scale is the same either way, so the scale reading will be the same whether or not the wooden block is outside or floating in the beaker. Likewise for an iron block, where the scale reading shows the total weight of the system.

87. The gondolas weigh the same because they're brim full, and whatever the weight of a floating boat, that same weight of water was displaced when the boat entered the gondola.

88. The gondolas weigh the same because the floating boats have displaced a weight of water equal to their own weights, equaling the weight of the brim filled gondola with no boat.

89. If water doesn't overflow, the reading on the scale will increase by the ordinary weight of the fish. However, if the aquarium is brim filled so a volume of water equal to the volume of the fish overflows, then the reading will not change. We correctly assume that the fish and water have the same density.

90. Both you and the water would have the same weight density as on Earth, and you would float with the same proportion of your body above the water as on Earth.

91. Because of surface tension, which tends to minimize the surface of a blob of water, its shape without gravity and other distorting forces will be a *sphere*—the shape with the least surface area for a given volume.

92. A Ping-Pong ball in water in a zero-*g* environment would experience no buoyant force. This is because buoyancy depends on a pressure difference on different sides of a submerged body. In this weightless state, no pressure difference would exist because no water pressure exists.

93. Part of whatever pressure you add to the water is transmitted to the hungry crocodiles, via Pascal's principle. If the water were confined, that is, not open to the atmosphere, the crocs would receive every bit of pressure you exert. But even if you were able to slip into the pool to quietly float without exerting pressure via swimming strokes, your displacement of water raises the water level in the pool. This ever-so-slight rise, and accompanying ever-so-slight increase in pressure at the bottom of the pool, is an ever-so-welcome signal to the hungry crocodiles.

94. The strong man will be unsuccessful. He will have to push with 50 times the weight of the 10 kilograms. The hydraulic arrangement is arranged to his disadvantage. Ordinarily, the input force is applied against the smaller piston and the output force is exerted by the large piston—this arrangement is just the opposite.

95. In Figure 13.23, the increased pressure in the reservoir is a result of the applied force distributed over the input piston area. This increase in pressure is transmitted to the output piston. In Figure 13.22, however, the pressure increase is supplied by the mechanical pump, which has nothing to do with the area of fluid interface between the compressed air and the liquid. Many hydraulic devices have a single piston upon which pressure is exerted.

96. When water is hot, the molecules are moving more rapidly and do not cling to one another as well as when they are slower moving, so the surface tension is less. The lesser surface tension of hot water allows it to pass more readily through small openings.

97. A heavier clip would push deeper into the water surface, overcoming the small force of surface tension, whereupon it sinks.

98. Surface tension accounts for the "floating" of the razor blade. The weight of the blade is less than the restoring forces of the water surface that tends to resist stretching.

## Think and Discuss

99. The concept of pressure is being demonstrated. Marshall is careful that the pieces are small and numerous so that his weight is applied over a large area of contact. Then the sharp glass provides insufficient pressure to cut the feet.

100. The water can be no deeper than the spouts, which are at the same height, so both teapots hold the same amount of liquid.

101. From a physics point of view, the event was quite reasonable, for the force of the ocean on his finger would have been quite small. This is because the pressure on his finger has only to do with the depth of the water, specifically the distance of the leak below the sea level—not the weight of the ocean. For a numerical example, see Think and Solve 41.

102. This dramatically illustrates that water pressure depends on depth, which directly relates to Think and Solve 40.

103. The use of a water-filled garden hose as an elevation indicator is a practical example of water seeking its own level. The water surface at one end of the hose will be at the same elevation above sea level as the water surface at the other end of the hose.

104. The block of wood would float higher if the piece of iron is suspended below it rather than on top of it. By the law of flotation: The iron-and-wood unit displaces its combined weight and the same volume of water whether the iron is on top or the bottom. When the iron is on the top, more wood is in the water; when the iron is on the bottom, less wood is in the water. Or another explanation is that when the iron is below—submerged—buoyancy on it reduces its weight and less of the wood is pulled beneath the water line.

105. When a ship is empty its weight is least and it displaces the least water and floats highest. Carrying a load of anything increases its weight and makes it float lower. It will float as low carrying a few tons of Styrofoam as it will carrying the same number of tons of iron ore. So the ship floats lower in the water when loaded with Styrofoam than when empty. If the Styrofoam were outside the ship, below water line, then the ship would float higher as a person would with a life preserver.

106. A sinking submarine will continue to sink to the bottom so long as the density of the submarine is greater than the density of the surrounding water. If nothing is done to change the density of the submarine, it will continue to sink because the density of water is practically constant. In practice, water is sucked into or blown out of a submarine’s tanks to adjust its density to match the density of the surrounding water.

107. The water level will fall. This is because the iron will displace a greater amount of water while being supported than when submerged. A floating object displaces its weight of water, which is more than its own volume, while a submerged object displaces only its volume. (This may be illustrated in the kitchen sink with a dish floating in a dishpan full of water. Silverware in the dish takes the place of the scrap iron. Note the level of water at the side of the dishpan, and then throw the silverware overboard. The floating dish will float higher and the water level at the side of the dishpan will fall. Will the volume of the silverware displace enough water to bring the level to its starting point? No, not as long as it is denser than water.)

108. For the same reason as in the previous exercise, the water level will fall. (Try this one in your kitchen sink also. Note the water level at the side of the dishpan when a bowl floats in it. Tip the bowl so it fills and submerges, and you’ll see the water level at the side of the dishpan fall.)

109. The balloon will sink to the bottom because its density increases with depth. The balloon is compressible, so the increase in water pressure beneath the surface compresses it, squeezes and reduces its volume, thereby increasing its density. Density further increases as it sinks lower to regions of greater pressure and compression. Think buoyant force: As its volume is reduced by increasing pressure as it descends, the amount of water it displaces becomes less. So buoyant force decreases as it descends.

110. Since both preservers are the same size, they will displace the same amount of water when submerged and be buoyed up with equal forces. Effectiveness is another story. The amount of buoyant force exerted on the heavy gravel-filled preserver is much less than its weight. If you wear it, you’ll sink. The same amount of buoyant force exerted on the lighter Styrofoam preserver is greater

than its weight and it will keep you afloat. The *amount* of the force and the *effectiveness* of the force are two different things.

111. He's truthful. But what he doesn't tell you is that you'll drown! Your life preserver will submerge and displace more water than those of your friends who float at the surface. Although the buoyant force on you will be greater, your increased weight is greater still! Whether you float or sink depends on whether or not the buoyant force equals your weight.

112. A floating body displaces its own weight of water, any water! So the buoyant force on Greta is the same as when she floats in fresh water. What is different is the volume of water displaced in the two cases. In the very dense salt water less of her volume is needed to displace her weight, which is why she floats so high in the Dead Sea.

113. Buoyancy would not occur in the absence of weight. Buoyancy depends on pressure differences due to different weights of water beneath different depths of water. No pressure differences, no buoyancy. In the ISS, surface tension rather than buoyancy dictates the behavior of immersed objects.

114. When the ball is submerged (but not touching the bottom of the container), it is supported partly by the buoyant force on the left and partly by the string connected to the right side. So the left pan must increase its upward force to provide the buoyant force in addition to whatever force it provided before, and the right pan's upward force decreases by the same amount, since it now supports a ball lighter by the amount of the buoyant force. To bring the scale back to balance, the additional weight that must be put on the right side will equal twice the weight of water displaced by the submerged ball. Why twice? Half of the added weight makes up for the loss of upward force on the right, and the other half for the equal gain in upward force on the left. (If each side initially weighs 10 N and the left side gains 2 N to become 12 N, the right side loses 2 N to become 8 N. So an additional weight of 4 N, not 2 N, is required on the right side to restore balance.) Because the density of water is less than half the density of the iron ball, the restoring weight, equal to twice the buoyant force, will still be less than the weight of the ball.

115. If the gravitational field of the Earth increased, both water and fish would increase in weight and weight density by the same factor, so the fish would stay at its prior level in water.