13

CHAPTER 13

Liquids

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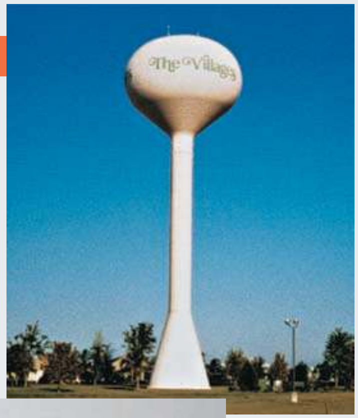

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1 The depth of water above ground level in the tower ensures substantial and reliable water pressure to the many homes it serves. 2 When showing Pascal's vases, Tsing Bardin asks her class how the same levels of colored water relate to the saying "Water seeks its own level." 3 The Falkirk Wheel in Scotland lifts boats 18 m from a lower body of water to a higher one with ease. While one water-filled gondola rotates upward, the other rotates downward, always balanced regardless of the weights of the boats it may or may not carry. 4 Physics textbook author Ray Serway plays around with surface tension.

Blaise Pascal was an outstanding 17th-century scientist, writer, and theologian. While investigating the physics of fluids, he invented the hydraulic press, which uses hydraulic pressure to multiply force. He also invented the syringe. Pascal's notoriety was fostered by his commentary on Evangelista Torricelli's experimentation with barometers. Pascal questioned what force kept some mercury in the tube and what filled the space above the mercury in the tube. Most scientists at the time, in the spirit of Aristotle, didn't believe a vacuum was possible and thought some invisible matter was present in the "empty space." Pascal conducted new experiments and contended that, indeed, a near-vacuum occupies the space above the column of liquid in a barometer tube.

Pascal, in poor health all his life, enlisted his brother-in-law to carry a barometer up the slope of a high mountain to investigate the effect on the mercury level in the tube. As Pascal hypothesized, the level of mercury dropped with increased altitude. Pascal conducted a more modest version of the experiment by carrying a barometer up to the top of a church bell tower, a height of about 50 meters. Again the mercury level dropped, but not as much. These and other experiments of Pascal were hailed throughout Europe as establishing the principle and value of the barometer.

To answer the contention that some invisible matter must exist in the empty space, Pascal called on the scientific method and replied: "In order to show that a hypothesis is evident, it does not suffice that all the phenomena follow from it; instead, if it leads to something contrary to a single one of the phenomena, that suffices to establish its falsity." His insistence on the existence of the vacuum also created conflict with other prominent scientists, including Descartes.

Pascal's work with hydraulics led him to what is now called Pascal's principle: A change in pressure at any point in an enclosed fluid at rest is transmitted undiminished to all points in the fluid. Ropes and pulleys have given way to this principle, as hydraulic devices multiply forces unimagined before the time of Pascal.

Although a devout theologian, Pascal took issue with some of the dogmas of the time. Some of his writings on religion were banned by the Church. As a scientist, he is remembered for the hydraulics that subsequently changed the technological landscape; as a theologian, he is remembered for his many assertions, one of which relates to centuries of the human landscape: "Men never do evil so cheerfully and completely as when they do so from religious convictions."

Today, in honor of his scientific contributions, the name Pascal has been given to the SI unit of pressure and to a computer programming language. In literature, Pascal is regarded as one of the most important authors of the mid-17th century. His use of satire and wit has influenced writers around the world.

13.1 Pressure

A liquid contained in a vessel exerts forces against the walls of the vessel. To discuss the interaction between the liquid and the walls, it is convenient to introduce the concept of pressure. **Pressure** is a force divided by the area over which the force is exerted:[1]

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

As an illustration of the distinction between pressure and force, consider the two blocks in Figure 13.1. The blocks are identical, but one stands on its end and the other rests on its side. Both blocks are of equal weight and therefore exert the same force on the surface (each would register the same on a bathroom scale), but

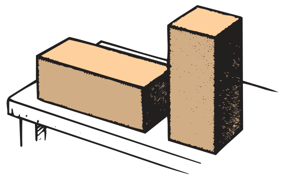

FIGURE 13.1
Although the weight of both blocks is the same, the upright block exerts greater pressure against the table.

[1]Pressure may be measured in any unit of force divided by any unit of area. The standard international (SI) unit of pressure, the newton per square meter, is called the pascal (Pa). A pressure of 1 Pa is very small and approximately equals the pressure exerted by a dollar bill resting flat on a table. Science types more often use kilopascals (1 kPa = 1000 Pa).

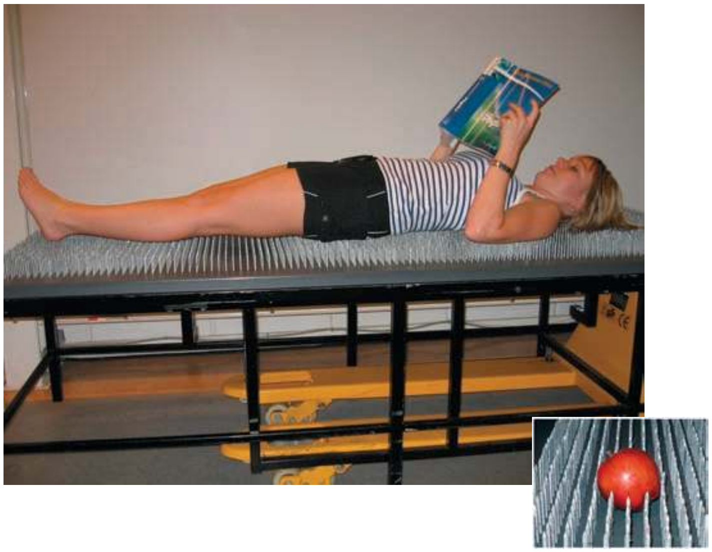

FIGURE 13.2
Physicist Sara Blomberg lies without harm on the bed of nails because her weight is distributed over hundreds of nails, which makes the pressure at the point of each nail safely small. The inset photo of the dropped apple attests to the sharpness of the nails.

the upright block exerts a greater *pressure* against the surface. If the block were tipped up so that its contact with the table were on a single corner, the pressure would be greater still.

SCREENCAST: Liquid Pressure

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- Molecules that make up a liquid can flow by sliding over one another. A liquid takes the shape of its container. Its molecules are close together and greatly resist compressive forces, so liquids, like solids, are difficult to compress.

13.2 Pressure in a Liquid

When you swim under water, you can feel the water pressure acting against your eardrums. The deeper you swim, the greater the pressure. The pressure you feel is due to the weight of the water above you. As you swim deeper, there is more water above you and therefore greater pressure. The pressure a liquid exerts depends on its depth.

The pressure of a liquid also depends on the density of the liquid. If you were submerged in a liquid more dense than water, the pressure would be correspondingly greater. The pressure due to a liquid is precisely equal to the product of weight density and depth:[2]

$$\text{Liquid pressure} = \text{weight density} \times \text{depth}$$

Simply put, the pressure a liquid exerts against the sides and bottom of a container depends on the density and the depth of the liquid. If we ignore atmospheric pressure, at twice the depth, the liquid pressure against the bottom is twice as great; at three times the depth, the liquid pressure is threefold; and so on. Or, if

[2]This equation is derived from the definitions of pressure and weight density. Consider an area at the bottom of a vessel of liquid. The weight of the column of liquid directly above this area produces pressure. From the definition,

$$\text{Weight density} = \frac{\text{weight}}{\text{volume}}$$

we can express this weight of liquid as

$$\text{Weight} = \text{weight density} \times \text{volume}$$

where the volume of the column is simply the area multiplied by the depth. Then we get

$$\text{Pressure} = \frac{\text{force}}{\text{area}} = \frac{\text{weight}}{\text{area}} = \frac{\text{weight density} \times \text{volume}}{\text{area}} = \frac{\text{weight density} \times (\cancel{\text{area}} \times \text{depth})}{\cancel{\text{area}}}$$
$$= \text{weight density} \times \text{depth}$$

For total pressure, we add to this equation the pressure due to the atmosphere on the surface of the liquid.

the liquid is two or three times as dense, the liquid pressure is correspondingly two or three times as great for any given depth. Liquids are practically incompressible; that is, their volume can hardly be changed by pressure (water volume decreases by only 50 millionths of its original volume for each atmosphere increase in pressure). So, except for small changes produced by temperature, the density of a particular liquid is practically the same at all depths.[3]

If you press your hand against a surface, and somebody else presses against your hand in the same direction, then the pressure against the surface is greater than if you pressed alone. Likewise with the atmospheric pressure that presses on the surface of a liquid. The total pressure of a liquid, then, is weight density multiplied by depth *plus* the pressure of the atmosphere. When this distinction is important, we will use the term *total pressure*. Otherwise, our discussions of liquid pressure refer to pressure without regard to the normally ever-present atmospheric pressure (more about atmospheric pressure in the next chapter).

It is important to recognize that the pressure does not depend on the *amount* of liquid present. Volume is not the key—depth is. The average water pressure acting against a dam depends on the average *depth* of the water, not on the volume of water held back, as shown in Figure 13.4.

FIGURE 13.3
The dependence of liquid pressure on depth is not a problem for the giraffe because of its large heart and its intricate system of valves and elastic, absorbent blood vessels in the brain. Without these structures, the giraffe would faint when it suddenly raises its head, and it would be subject to brain hemorrhaging when it lowers its head.

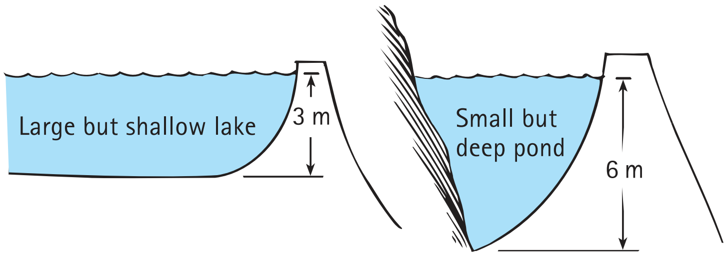

FIGURE 13.4
The large, shallow lake exerts only one-half the average pressure that the small, deep pond exerts.

VIDEO: Dam

You'll feel the same pressure whether you dunk your head a meter beneath the water surface in a small pool or to the same depth in the middle of a large lake. The same is true for a fish. Look at the connecting vases in Figure 13.5. If we hold a goldfish by its tail and dunk its head a couple of centimeters under the surface, the water pressure on the fish's head will be the same in any of the vases.

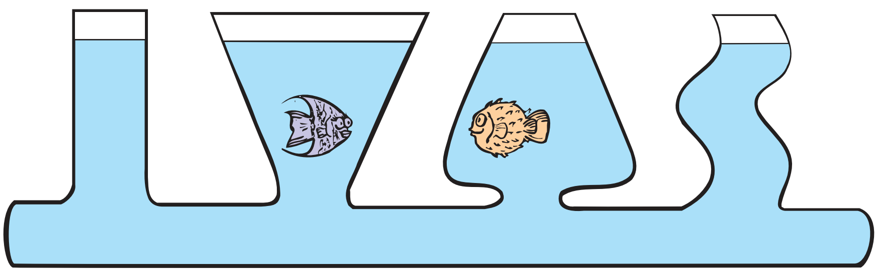

FIGURE 13.5
Liquid pressure is the same for any given depth below the surface, regardless of the shape of the containing vessel. Liquid pressure = weight density × depth (for total pressure, add the air pressure at the top).

[3]The density of fresh water is 1000 kg/m^3. Since the weight (mg) of 1000 kg is 1000 × 10 N/kg = 10,000 N, the weight density of water is 10,000 newtons per cubic meter (or, more precisely, 9800 N/kg using g = 9.8 N/kg). The water pressure beneath the surface of a lake is simply equal to this density multiplied by the depth in meters. For example, the water pressure is 10,000 N/m^2 at a depth of 1 m and 100,000 N/m^2 at a depth of 10 m. In SI units, pressure is measured in pascals, so this would be 10,000 Pa and 100,000 Pa, respectively, or, in kilopascals, 10 kPa and 100 kPa, respectively. For the *total pressure* in these cases, add the pressure of the atmosphere, 101.3 kPa.

If we release the fish and it swims a few centimeters deeper, the pressure on the fish will increase with depth and be the same no matter which vase the fish is in. If the fish swims to the bottom, the pressure will be greater, but it makes no difference what vase it swims in. All the vases are filled to equal depths, so the water pressure is the same at the bottom of each vase, regardless of its shape or volume. If water pressure at the bottom of a vase were greater than water pressure at the bottom of a neighboring narrower vase, the greater pressure would force water sideways and then up the narrower vase to a higher level until the pressures at the bottom were equalized. But this doesn't happen. Pressure is dependent on depth, not volume, so we see that there is a reason why water seeks its own level.

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- Not all Romans in ancient times believed that water couldn't flow uphill, as evidenced by some pipe systems back then that ran upward as well as downward.

The fact that water seeks its own level can be demonstrated by filling a garden hose with water and holding the two ends at the same height. The water levels will be equal. If one end is raised higher than the other, water will flow out of the lower end, even if it has to flow "uphill" part of the way. This fact was not fully understood by some of the early Romans, who built elaborate aqueducts with tall arches and roundabout routes to ensure that water would always flow slightly downward every place along its route from the reservoir to the city. If pipes were laid in the ground and followed the natural contour of the land, in some places the water would have to flow uphill, and the Romans were skeptical of this. Careful experimentation was not yet the mode, so, with plentiful slave labor, the Romans built unnecessarily elaborate aqueducts.

FIGURE 13.6
Roman aqueducts assured that water flowed slightly downhill from reservoir to city.

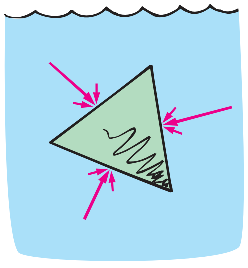

FIGURE 13.7
The forces of a liquid pressing against a surface add up to a net force that is perpendicular to the surface.

An experimentally determined fact about liquid pressure is that it is exerted equally in all directions. For example, if we are submerged in water, no matter which way we tilt our heads we feel the same amount of water pressure on our ears. Because a liquid can flow, the pressure isn't only downward. We know pressure acts sideways when we see water spurting sideways from a leak in the side of an upright can. We know pressure also acts upward when we try to push a beach ball beneath the surface of the water. The bottom of a boat is certainly pushed upward by water pressure.

When liquid presses against a surface, there is a net *force* that is *perpendicular* to the surface. Although pressure doesn't have a specific direction, force does. Consider the triangular block in Figure 13.7. Focus your attention on only the three points midway along each surface. Water is forced against each point from many directions, only a few of which are indicated. Components of the forces that are not perpendicular to the surface cancel each other out, leaving only a net perpendicular force at each point.

That's why water spurting from a hole in a bucket initially exits the bucket in a direction at right angles to the surface of the bucket in which the hole is located. Then it curves downward due to gravity. The force exerted by a fluid on a smooth surface is always at right angles to the surface.[4]

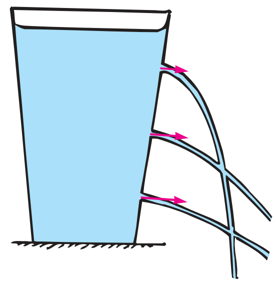

FIGURE 13.8
The force vectors act perpendicularly to the inner container surface and increase with increasing depth.

CHECK POINT

Suppose that you raise one foot when you are standing on a bathroom scale. Does the pressure you exert on the scale change? Is there a difference in the scale reading?

CHECK YOUR ANSWERS

When you shift your weight by standing on one foot, the pressure on the scale's surface doubles. But the scale doesn't measure pressure—it measures weight. Except for some jiggling as you shift your weight, the scale reading stays the same.

VIDEO: Buoyancy

13.3 Buoyancy

Anyone who has ever lifted a heavy submerged object out of water is familiar with *buoyancy*, the apparent loss of weight experienced by objects submerged in a liquid. For example, lifting a large boulder off the bottom of a riverbed is a relatively easy task as long as the boulder is below the surface. When the boulder is lifted above the surface, however, the force required to lift it is increased considerably. This is because, when the boulder is submerged, the water exerts an upward force on it that is exactly opposite to the direction of gravity's pull. This upward force is called the **buoyant force**, and it is a consequence of pressure increasing with depth. Figure 13.9 shows why the buoyant force acts upward. Forces due to water pressure are exerted everywhere against the boulder in a direction perpendicular to its surface, as shown by the vectors. Force vectors against the sides at equal depths cancel one another, so there is no horizontal buoyant force. Force vectors in the vertical direction, however, don't cancel. Pressure is greater against the bottom of the boulder because the bottom is deeper. So upward forces against the bottom are greater than downward forces against the top, producing a net force upward—the buoyant force.

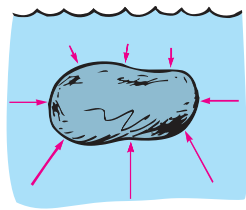

FIGURE 13.9
INTERACTIVE FIGURE MP®
The greater pressure against the bottom of a submerged object produces an upward buoyant force.

Understanding buoyancy requires understanding the expression "volume of water displaced." If a stone is placed in a container that is brimful of water, some water will overflow (Figure 13.10). Water is *displaced* by the stone. A little thought will tell us that the *volume of the stone*—that is, the amount of space it takes up—is equal to the *volume of the water displaced*. If you place any object in a container partly filled with water, the level of the surface rises (Figure 13.11). By how much? By exactly the same amount as if a volume of water were poured in that equals the volume of the submerged object. This is a good method for determining the volume of irregularly shaped objects: *A completely submerged object always displaces a volume of liquid equal to its own volume.*

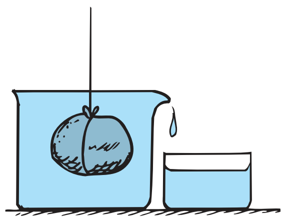

FIGURE 13.10
When a stone is submerged, it displaces water that has a volume equal to the volume of the stone.

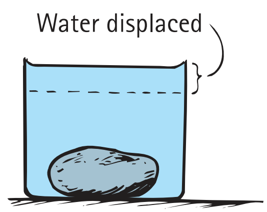

FIGURE 13.11
The increase in the water level is the same as if you poured in a volume of water equal to the stone's volume.

[4]The speed of liquid out of the hole is $\sqrt{2gh}$, where h is the depth below the free surface. Interestingly, this is the same speed the water (or anything else) would acquire if freely falling the same vertical distance h.

SCREENCAST: Buoyancy

CHECK POINT

A recipe calls for a specific amount of butter. How does the displacement method relate to the use of a kitchen measuring cup?

CHECK YOUR ANSWER

Put some water in the cup before you add the butter. Note the water-level reading on the side of the cup. Then add the butter and you'll note the water level rise. Because butter floats, poke it beneath the surface. When you subtract the lower-level reading from the higher-level reading, you know not only the volume of water displaced but also the volume of the butter.

13.4 Archimedes' Principle

The relationship between buoyancy and displaced liquid was first discovered in the 3rd century BC by the Greek scientist Archimedes. It is stated as follows:

> **An immersed object is buoyed up by a force equal to the weight of the fluid it displaces.**

This relationship is called **Archimedes' principle**. It applies to liquids and gases, both of which are fluids. If an immersed object displaces 1 kg of fluid, the buoyant force acting on it is equal to the weight of 1 kg.[5] By *immersed*, we mean either *completely* or *partially submerged*. If we immerse a sealed 1-L container halfway into the water, it will displace a half-liter of water and be buoyed up by a force equal to the weight of a half-liter of water—no matter what is in the container. If we immerse it completely (submerge it), it will be buoyed up by a force equal to the weight of a full liter of water (1 kg of mass). If the container is fully submerged and doesn't compress, the buoyant force will equal the weight of 1 kg of water at *any* depth. This is because, at any depth, the container can displace no greater volume of water than its own volume. And the weight of this displaced water (not the weight of the submerged object!) is equal to the buoyant force.

If a 30-kg object displaces 20 kg of fluid upon immersion, its apparent weight will be equal to the weight of 10 kg (100 N). Note that, in Figure 13.13, the 3-kg block has an apparent weight equal to the weight of a 1-kg block when submerged. The apparent weight of a submerged object is its usual weight in air minus the buoyant force.

If you stick your foot in water, it's immersed. If you jump into the water and sink beneath the surface, immersion is total and you're submerged.

FIGURE 13.12
A liter of water occupies a volume of 1000 cm^3, has a mass of 1 kg, and weighs 10 N (or, more precisely, 9.8 N). Its density may therefore be expressed as 1 kg/L and its weight density as 10 N/L. (Seawater is slightly denser.)

VIDEO: Archimedes Principle

SCREENCAST: Archimedes

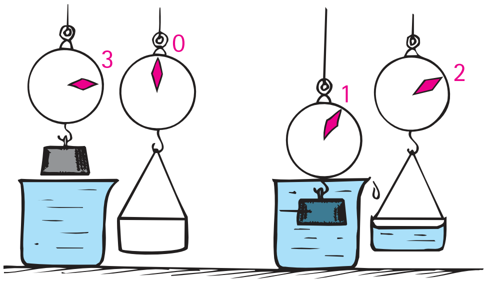

FIGURE 13.13
Objects weigh more in air than in water. When a 3-kg block is submerged, the scale reading reduces to 1 kg. The "missing" weight is equal to the weight of the 2 kg of water displaced, which equals the buoyant force.

[5]In lab, you may find it convenient to express the buoyant force in kilograms, even though a kilogram is a unit of mass and not a unit of force. So, strictly speaking, the buoyant force is the *weight* of 1 kg, which is 10 N (or, precisely, 9.8 N). Or we could as well say that the buoyant force is 1 *kilogram weight*, not simply 1 kg.

Perhaps your instructor will summarize Archimedes' principle by way of a numerical example to show that the difference between the upward-acting and the downward-acting forces due to the similar pressure differences on a submerged cube is numerically identical to the weight of fluid displaced. If the density is nearly constant, as it is for most liquids, it makes no difference how deep the cube is placed. Although the pressures are greater with increasing depths, the *difference* between the pressure up against the bottom of the cube and the pressure down against the top of the cube is the same at any depth (Figure 13.14). Whatever the shape of the submerged body, the buoyant force is equal to the weight of fluid displaced.

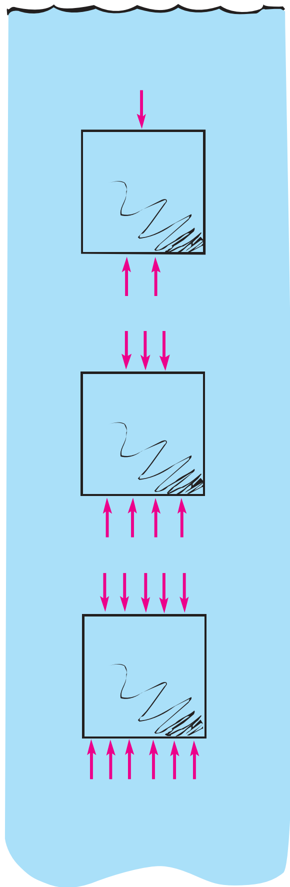

FIGURE 13.14
INTERACTIVE FIGURE

The difference between the upward and downward forces acting on the submerged block is the same at any depth.

CHECK POINT

1. **True or false? Archimedes' principle tells us that any object that displaces 10 N of liquid will be buoyed up with 10 N.**
2. **A 1-L container completely filled with lead has a mass of 11.3 kg and is submerged in water. What is the buoyant force acting on it?**
3. **As a boulder thrown into a deep lake sinks deeper and deeper into the water, does the buoyant force on it increase or decrease?**

CHECK YOUR ANSWERS

1. True. It's only the weight of the displaced liquid that counts. (Also look at it in a Newton's third law way: If the immersed object pushes 10 N of fluid aside, the displaced fluid reacts by pushing back on the immersed object with 10 N.)
2. The buoyant force equals the weight of the liter of water displaced—not the weight of the lead! One L of water has a mass of 1 kg and weighs 10 N. So the buoyant force on it is 10 N.
3. The buoyant force remains unchanged as the boulder sinks because the boulder displaces the same volume and the same weight of water at any depth.

13.5 What Makes an Object Sink or Float?

It's important to remember that the buoyant force acting on a submerged object depends on the *volume* of the object. Small objects displace small amounts of water and are acted on by small buoyant forces. Large objects displace large amounts of water and are acted on by larger buoyant forces. It is the *volume* of the submerged object—not its *weight*—that determines the buoyant force. The buoyant force is equal to the weight of the *volume of fluid* displaced. (Misunderstanding this idea is the root of much confusion that people have about buoyancy.)

The weight of an object does play a role, however, in floating. Whether an object will sink or float in a liquid depends on how the buoyant force *compares with the object's weight*. This, in turn, depends on the object's density. Consider these three simple rules:

1. **An object more dense than the fluid in which it is immersed will sink.**
2. **An object less dense than the fluid in which it is immersed will float.**
3. **An object that has a density equal to the density of the fluid in which it is immersed will neither sink nor float.**

SCREENCAST: Buoyancy on a Submarine

SCREENCAST: More on Buoyancy

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- People who can't float are, 9 times out of 10, men. Most men are more muscular and slightly denser than women. Also, cans of diet soda float, whereas cans of regular soda sink in water. What does this tell you about their relative densities?

Rule 1 seems reasonable enough because objects denser than water sink to the bottom, regardless of the water's depth. Scuba divers near the bottoms of deep bodies of water may sometimes encounter a waterlogged piece of wood hovering above the ocean floor (with a density equal to that of water at that depth), but never do they encounter hovering rocks!

From Rules 1 and 2, what can you say about people who, try as they may, cannot float? They're simply too dense! To float more easily, you must reduce your density. The formula *weight density* = *weight/volume* says you must either reduce your weight or increase your volume. Wearing a life jacket increases volume while correspondingly adding very little to your weight. It reduces your overall density.

Rule 3 applies to fish, which neither sink nor float. A fish normally has the same density as water. A fish can regulate its density by expanding and contracting an air sac in its body that changes its volume. The fish can move upward by increasing its volume (which decreases its density) and downward by contracting its volume (which increases its density).

For a submarine, weight, not volume, is varied to achieve the desired density. Water is taken into or blown out of its ballast tanks. Similarly, the overall density of a crocodile increases when it swallows stones. From 4 kg to 5 kg of stones have been found in the stomachs of large crocodiles. Because of this increased density, the crocodile swims lower in the water, thus exposing itself less to its prey (Figure 13.15).

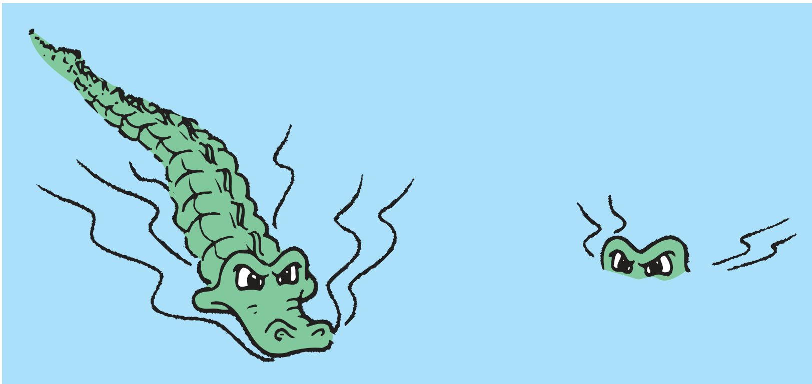


FIGURE 13.15
(Left) A crocodile coming toward you in the water. (Right) A stoned crocodile coming toward you in the water.

CHECK POINT

1. **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?**
2. **If a fish makes itself denser, it will sink; if it makes itself less dense, it will rise. In terms of the buoyant force, why is this so?**

CHECK YOUR ANSWERS

1. The buoyant force is the same on both blocks because they displace the same volume of water. For submerged objects, the buoyant force is determined by only the volume of water displaced, not the object's weight.
2. When the fish makes itself more dense by decreasing its volume, it displaces less water, so the buoyant force decreases. When the fish makes itself less dense by expanding its volume, more water is displaced and the buoyant force increases.

13.6 Flotation

Primitive peoples made their boats of wood. Could they have conceived of an iron ship? We don't know. The idea of floating iron might have seemed strange. Today it is easy for us to understand how a ship made of iron can float.

Consider a 1-ton block of solid iron. Because iron is nearly 8 times denser than water, the block displaces only 1/8 ton of water when submerged, which is not enough to keep it afloat. Suppose we reshape the same iron block into a bowl (Figure 13.16). It still weighs 1 ton. But when we put it in water, it displaces a greater volume of water than when it was a block. The deeper the iron bowl is immersed, the more water it displaces and the greater the buoyant force acting on it. When the buoyant force equals 1 ton, the bowl will sink no farther.

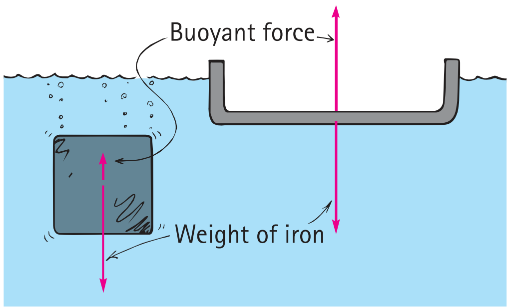


FIGURE 13.16
An iron block sinks, while the same quantity of iron shaped like a bowl floats.

When any boat displaces a weight of water equal to its own weight, it floats. This is called the **principle of flotation**:

A floating object displaces a weight of fluid equal to its own weight.

Every ship, every submarine, and every blimp must be designed to displace a weight of fluid equal to its own weight. Thus, a 10,000-ton ship must be built wide enough to displace 10,000 tons of water before it sinks too deep in the water. The same holds true for vessels in air. A blimp that weighs 100 tons displaces at least 100 tons of air. If it displaces more, it rises; if it displaces less, it falls. If it displaces exactly its weight, it hovers at constant altitude.

VIDEO: Flotation

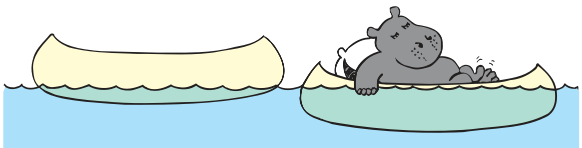


FIGURE 13.17
The weight of a floating object equals the weight of the water displaced by the submerged part.

For a given volume of displaced fluid, a denser fluid exerts a greater buoyant force than a less dense fluid. A ship, therefore, floats higher in saltwater than in fresh water because saltwater is slightly denser. Similarly, a solid chunk of iron floats in mercury, even though it sinks in water.

The physics of Figure 13.18 is nicely employed by the Falkirk Wheel, a unique rotating boat lift that replaced a series of 11 locks in Scotland. Connected to its 35-m-tall wheel are two gondolas brimful of water. When one or more boats enter a gondola, the water overflow weighs exactly as much as the boat(s). So the water-filled gondolas always weigh the same whether or not they carry boats, and the wheel always remains balanced. Therefore, in spite of its enormous mass, the wheel rotates each half revolution with very little power input.

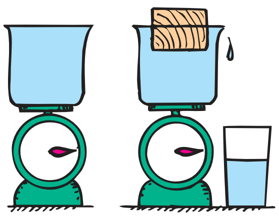


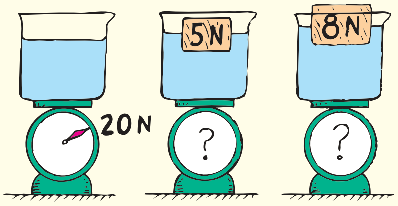
FIGURE 13.18
A floating object displaces a weight of fluid equal to its own weight.

FIGURE 13.19
The Falkirk Wheel has two balanced water-filled gondolas, one going up and one going down. The gondolas rotate as the wheel turns, so the water and boats don't tip out.

SCREENCAST: Buoyancy Problems

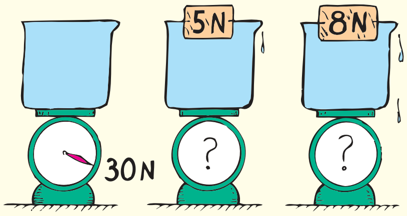
CHECK POINT

1. **A beaker more than half full of water weighs 20 N. What will be the scale reading when**



   (a) a 5-N block of wood floats in it?
   (b) an 8-N block of wood floats in it?

2. **The same beaker when brimful of water weighs 30 N. What will be the scale reading, after overflow, when**



   (a) a 5-N block of wood floats in it?
   (b) an 8-N block of wood floats in it?

CHECK YOUR ANSWERS

1. The scale readings will increase as weight is added: (a) 20 N + 5 N = 25 N, (b) 20 N + 8 N = 28 N.
2. For the brimful beaker, the displacement of water by the floating blocks causes water to overflow. (a) The 5-N block causes an overflow of 5 N of water, and (b) the 8-N block spills 8 N of water. So the scale reading doesn't change; it remains 30 N.

Only in the special case of floating does the buoyant force acting on an object equal the object's weight.

FLOATING MOUNTAINS

The tip of a floating iceberg above the ocean's surface is approximately 10% of the whole iceberg. That's because ice is 0.9 times the density of water, so 90% of it submerges in water. Similarly, a mountain floats on the Earth's semiliquid mantle with only its tip showing. That's because Earth's continental crust is about 0.85 times the density of the mantle it floats upon; thus, about 85% of a mountain extends beneath the Earth's surface. So, like floating icebergs, mountains are appreciably deeper than they are high.

There is an interesting gravitational sidelight to this: Recall, from Chapter 9, that the gravitational field at Earth's surface varies slightly with varying densities of underlying rock (which is valuable information to geologists and oil prospectors), and gravitation is less at the top of a mountain because of the greater distance to Earth's center. Combining these ideas, we see that because the bottom of a mountain extends deep into Earth's mantle, there is increased distance between a mountaintop and the denser mantle. This increased "gap" further reduces gravitation at the top of a mountain.

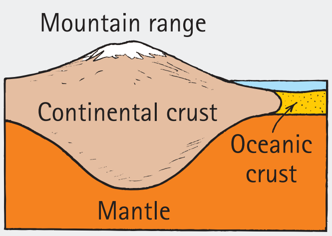


FIGURE 13.20 The continental crust is deeper beneath mountains.

Another interesting fact about mountains: If you could shave off the top of an iceberg, the iceberg would be lighter and would be buoyed up to nearly its original height before being shaved. Similarly, when mountains erode, they are lighter and they are pushed up from below to float to nearly their original heights. So, when a kilometer of mountain erodes away, some 85% of a kilometer of mountain thrusts up from below. That's why it takes so long for mountains to weather away.

CHECK POINT

A river barge loaded with gravel approaches a low bridge that it cannot quite pass under. Should gravel be removed *from* or added *to* the barge?

CHECK YOUR ANSWER

Ho, ho, ho! Do you think ol' Hewitt is going to give *all* the answers to Check Point questions? Good teaching is asking good questions, not providing all the answers. You're on your own with this one!

13.7 Pascal's Principle

One of the most important facts about fluid pressure is that a change in pressure at one part of the fluid will be transmitted undiminished to all other parts of the fluid. For example, if the pressure of city water is increased at the pumping station by 10 units of pressure, then the pressure everywhere in the pipes of the connected system will be increased by 10 units of pressure (provided that the water is at rest). This rule, discovered in the 17th century by Blaise Pascal, is called **Pascal's principle**:

> **A change in pressure at any point in an enclosed fluid at rest is transmitted undiminished to all points in the fluid.**

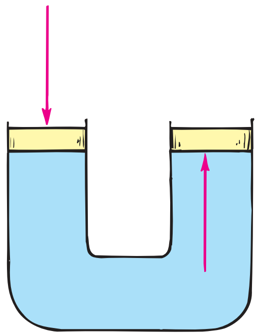


FIGURE 13.21
The force exerted on the left piston increases the pressure in the liquid and is transmitted to the right piston.

Fill a U-tube with water and place pistons at each end, as shown in Figure 13.21. Pressure exerted against the left piston will be transmitted throughout the liquid and against the bottom of the right piston. (The pistons are simply "plugs" that can slide freely but snugly inside the tube.) The pressure that the left piston exerts against the water will be exactly equal to the pressure the water exerts against the right piston. This is nothing to write home about. But suppose you make the tube on the right side wider and use a piston of larger area: Then the result will be impressive. In Figure 13.22 the piston on the right has 50 times the area of the piston on the left (let's say that the left piston has a cross-sectional area of 100 square centimeters and the right piston has a cross-sectional area of 5000 square centimeters). Suppose a 10-kg load is placed on the left piston. Then an additional pressure (nearly 1 N/cm^2) due to the weight of the load is transmitted throughout the liquid and up against the larger piston. Here is where the difference between force and pressure is evident. The additional pressure is exerted against every square centimeter of the larger piston. Since there is 50 times the area, 50 times as much force is exerted on the larger piston. Thus, the larger piston will support a 500-kg load—50 times the load on the smaller piston!

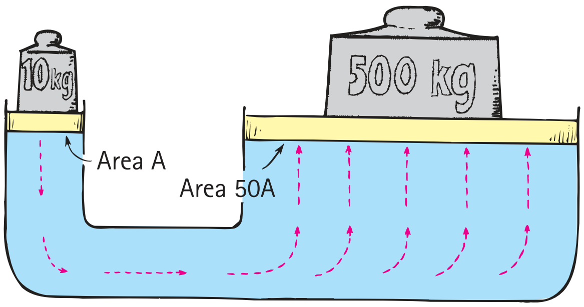


FIGURE 13.22
A 10-kg load on the left piston will support 500 kg on the right piston.

SCREENCAST: Pascal's Principle

This *is* something to write home about because we can multiply forces using such a device. One newton of input produces 50 newtons of output. By further increasing the area of the larger piston (or reducing the area of the smaller piston), we can multiply the force, in principle, by any amount. Pascal's principle underlies the operation of the hydraulic press.

The hydraulic press does not violate energy conservation because a decrease in distance moved compensates for the increase in force. When the small piston in Figure 13.22 is moved downward 10 centimeters, the large piston will be raised only 1/50 of this, or 0.2 centimeter. The input force multiplied by the distance moved by the smaller piston is equal to the output force multiplied by the distance moved by the larger piston; this is one more example of a simple machine operating on the same principle as a mechanical lever.

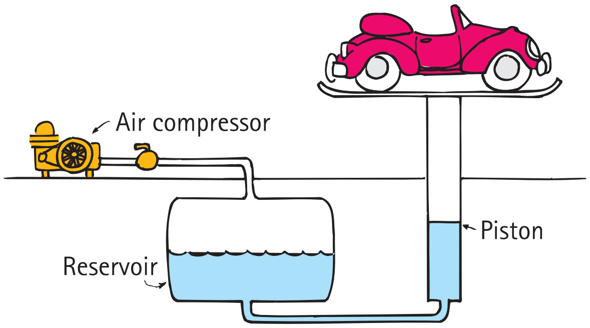


FIGURE 13.23
Pascal's principle in a service station.

Pascal's principle applies to all fluids, whether gases or liquids. A typical application of Pascal's principle for gases and liquids is the automobile lift seen in many service stations (Figure 13.23). Increased air pressure produced by an air compressor is transmitted through the air to the surface of oil in an underground reservoir. The oil, in turn, transmits the pressure to a piston, which lifts the automobile. The relatively low pressure that exerts the lifting force against the piston is about the same as the air pressure in automobile tires.

Hydraulics is employed by modern devices ranging from very small to enormous. Note the hydraulic pistons in almost all construction machines where heavy loads are involved. The many applications of Pascal's principle have truly changed the landscape of our world.

FIGURE 13.24
Pascal's principle is at work in the hydraulic devices on these incredible machines. We can only wonder whether Pascal envisioned the extent to which his principle would lead to the lifting of huge loads so easily.

CHECK POINT

1. **As the automobile in Figure 13.23 is being lifted, how does the oil-level change in the reservoir compare with the distance the automobile moves?**
2. **If a friend commented that a hydraulic device is a common way of multiplying energy, what would you say?**

CHECK YOUR ANSWERS

1. The car moves up a greater distance than the oil level drops, since the area of the piston is smaller than the surface area of the oil in the reservoir.
2. No, no, no! Although a hydraulic device, like a mechanical lever, can multiply *force*, it always does so at the expense of distance. Energy is the product of force and distance. If you increase one, you decrease the other. No device has ever been found that can multiply energy!

13.8 Surface Tension

Suppose you suspend a bent piece of clean wire from a sensitive spiral spring (Figure 13.25), lower the wire into water, and then raise it. As you attempt to free the wire from the water surface, you see from the stretched spring that the water surface exerts an appreciable force on the wire. The water surface resists being stretched because it has a tendency to contract. This is evident when a fine-haired paintbrush is wet. When the brush is under water, the hairs are fluffed pretty much as they are when the brush is dry, but when the brush is lifted out of the water, the surface film of water contracts and pulls the hairs together (Figure 13.26). This contractive tendency of the surface of liquids is called **surface tension**.

Surface tension accounts for the spherical shape of liquid drops. Raindrops, oil drops, and falling drops of molten metal are all spherical because their surfaces tend to contract and force each drop into the shape that has the smallest surface area. This is a sphere, the geometrical figure that has the smallest surface area for a given volume. For this reason, the mist and dewdrops on spider webs or on the downy leaves of plants are nearly spherical blobs. (The larger they are, the more gravity will flatten them.)

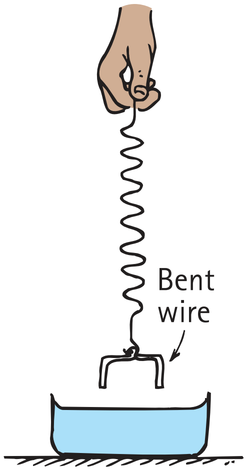


FIGURE 13.25
When the bent wire is lowered into the water and then raised, the spring will stretch because of surface tension.

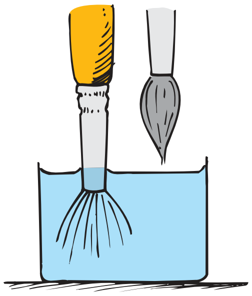


FIGURE 13.26
When the brush is taken out of the water, the hairs are held together by surface tension.

FIGURE 13.27
Small blobs of water are drawn by surface tension into spherical shapes.

Surface tension is caused by molecular attractions. Beneath the surface, each molecule is attracted in every direction by neighboring molecules, resulting in no tendency to be pulled in any specific direction. A molecule on the surface of a liquid, however, is pulled only by neighboring molecules on each side and downward from below; there is no pull upward (Figure 13.28). These molecular attractions thus tend to pull the molecule from the surface into the liquid, and this tendency minimizes the surface area. The surface behaves as if it were tightened into an elastic film. This is evident when a dry steel needle or paper clip seems to float on still water. Figure 13.29 shows a paper clip not floating *in* the water, but resting

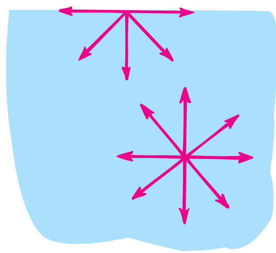


FIGURE 13.28
A molecule at the surface is pulled only sideways and downward by neighboring molecules. A molecule beneath the surface is pulled equally in all directions.

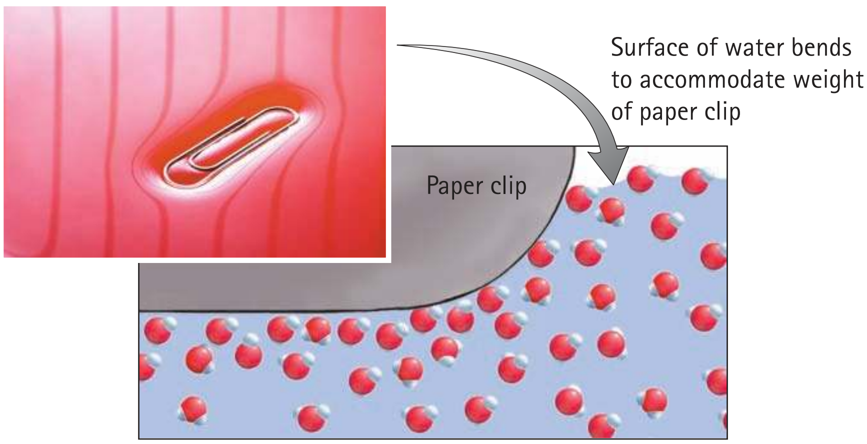


FIGURE 13.29
A paper clip rests on water, pushing the surface down slightly without sinking.

FIGURE 13.30
Bubble Master Tom Noddy blows bubbles within bubbles. The large bubble is elongated due to blowing, but it will quickly settle to a spherical shape due to surface tension.

on the water. The slight depression in the water surface is caused by the weight of the clip, which pushes down on the water. The elastic tendency found at the surface is surface tension, enough to support the weight of the clip. Surface tension allows certain insects, such as water striders, to run across the surface of a pond.

The surface tension of water is greater than that of other common liquids, and pure water has a stronger surface tension than soapy water. We can see this when a little soap film on the surface of water is effectively pulled out over the entire surface. This minimizes the surface area of the water. The same thing happens for oil or grease floating on water. Oil has less surface tension than cold water, and it is drawn out into a film covering the whole surface. This spreading is apparent in oil spills. Hot water, however, has less surface tension than cold water because the faster-moving molecules are not bonded as tightly. This allows the grease or oil in hot soups to float in little bubbles on the surface of the soup. When the soup cools and the surface tension of the water increases, the grease or oil is dragged out over the surface of the soup. The soup becomes "greasy." Hot soup tastes different from cold soup primarily because the surface tension of water in the soup changes with temperature.

13.9 Capillarity

When the end of a thoroughly clean glass tube with a small inside diameter is dipped into water, the water wets the inside of the tube and rises in it. In a tube with a bore of about ½ millimeter in diameter, for example, the water rises slightly higher than 5 centimeters. With a still smaller bore, the water rises much higher (Figure 13.31). This rise of a liquid in a fine hollow tube or in a narrow space is called **capillarity**.

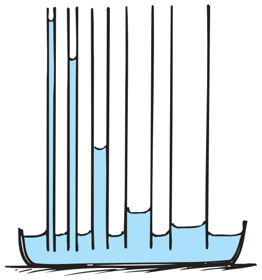


FIGURE 13.31
Capillary tubes.

When you think of capillarity, think of molecules as sticky balls. Water molecules stick to glass more than to each other. The attraction between unlike substances such as water and glass is called *adhesion*. The attraction between like substances, molecular stickiness, is called *cohesion*. When a glass tube is dipped into water, the adhesion between the glass and the water causes a thin film of water to be drawn up over the inner and outer surfaces of the tube (Figure 13.32a). Surface tension causes this film to contract (Figure 13.32b). The film on the outer surface contracts enough to make a rounded edge. The film on the inner surface contracts more and raises water with it until the adhesive force is balanced by the weight of the water lifted (Figure 13.32c). In a narrower tube, the weight of the water in the tube is small and the water is lifted higher than it would be if the tube were wider.

If a paintbrush is dipped partway into water, the water will rise up into the narrow spaces between the bristles by capillary action. If your hair is long, let it hang into the sink or bathtub, and water will seep up to your scalp in the same way. This is how oil soaks upward in a lamp wick and water soaks into a bath towel when one end hangs in water. Dip one end of a lump of sugar in coffee, and the entire lump is quickly wet. Capillary action is essential for plant growth. In trees it brings water to the high branches and leaves from the plant's roots and transports sap and nourishment from the leaves to the roots. Just about everywhere we look, we can see capillary action at work. That's nice.

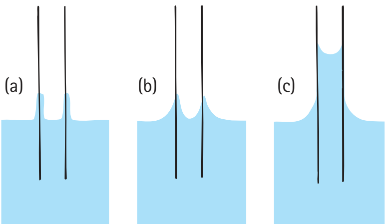


FIGURE 13.32
Hypothetical stages of capillary action, as seen in a cross-sectional view of a capillary tube.

But, from the point of view of an insect, capillarity is not so nice. Recall from Chapter 12 that, because of an insect's relatively large surface area, it falls slowly in air. Gravity poses almost no risk at all—but not so with capillarity. Being in the grip of water may be fatal to an insect—unless it is equipped for water like a water strider.

For instructor-assigned homework, go to www.masteringphysics.com MP

SUMMARY OF TERMS (KNOWLEDGE)

Pressure The ratio of force to the area over which that force is distributed:

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

$$\text{Liquid pressure} = \text{weight density} \times \text{depth}$$

Buoyant force The net upward force that a fluid exerts on an immersed object.

Archimedes' principle An immersed body is buoyed up by a force equal to the weight of the fluid it displaces.

Principle of flotation A floating object displaces a weight of fluid equal to its own weight.

Pascal's principle The pressure applied to a motionless fluid confined in a container is transmitted undiminished throughout the fluid.

Surface tension The tendency of the surface of a liquid to contract in area and thus to behave like a stretched elastic membrane.

Capillarity The rise of a liquid in a fine, hollow tube or in a narrow space.

READING CHECK QUESTIONS (COMPREHENSION)

13.1 Pressure

1. How is pressure related to area?

13.2 Pressure in a Liquid

2. How does pressure at the bottom of a body of water relate to the weight of water above each square meter of the bottom surface?
3. What is meant by weight density? How does the pressure exerted by a column of water depend upon weight density?
4. Why does the density of a liquid not undergo much of a change as we go to lower depths?
5. How does the water pressure 1 m below the surface of a small pond compare with the water pressure 1 m below the surface of a huge lake?
6. When a hole is punched in a container filled with water, why does the emerging water curve downward and not fall vertically upon exiting?

13.3 Buoyancy

7. Why is it easier to lift an object submerged in liquid?
8. What is the basic cause of the buoyancy experienced by submerged objects?
9. How does the volume of a completely submerged object compare with the volume of water displaced?

13.4 Archimedes' Principle

10. What is the maximum volume of water that can be displaced by an object immersed in water?
11. Does Archimedes' principle apply only to liquids?
12. What is the mass of 1 L of water? Its weight in newtons?
13. If a 1-L container is immersed halfway into water, what is the volume of the water displaced? What is the buoyant force on the container?

13.5 What Makes an Object Sink or Float?

14. Is the buoyant force on a submerged object equal to the weight of the object itself or equal to the weight of the fluid displaced by the object?
15. What happens when an object is immersed in a fluid that has a higher density than the object?
16. Does the buoyant force on a submerged object depend on the volume of the object or on the weight of the object?
17. Fill in the blanks: An object denser than water will ______ in water. An object less dense than water will ______ in water. An object that has the same density as water will ______ in water.
18. How is a crocodile able to swim lower in water? How do fish regulate their density?

13.6 Flotation

19. It was emphasized earlier that the buoyant force does not equal an object's weight but does equal the weight of the displaced water. Now we say that the buoyant force equals the object's weight. Isn't this a grand contradiction? Explain.
20. State the principle of flotation. Why does an iron bowl experience higher buoyant force than a block of iron of the same weight?

13.7 Pascal's Principle

21. How is the law of conservation of energy not violated during the operation of the hydraulic press?
22. If the pressure in a hydraulic press is increased by an additional 10 N/cm^2, how much extra load will the output piston support if its cross-sectional area is 50 cm^2?

13.8 Surface Tension

23. Why are raindrops and oil drops generally spherical in shape?
24. Is the surface tension of oil greater than that of water?

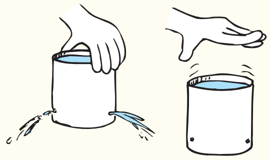
13.9 Capillarity

25. Distinguish between *adhesive* and *cohesive* forces.
26. How does the height to which water is lifted in a capillary tube relate to adhesion and the weight of the water lifted?

THINK AND DO (HANDS-ON APPLICATION)

27. Place an egg in a pan of tap water. Then dissolve salt in the water until the egg floats. How does the density of an egg compare with that of tap water? With that of saltwater?

28. If you punch a couple of holes in the bottom of a water-filled container, water will spurt out because of water pressure. Now drop the container, and, as it freely falls, note that the water no longer spurts out! If your friends don't understand this, could you figure it out and explain it to them?



29. Float a water-soaked Ping-Pong ball in a can of water held more than a meter above a rigid floor. Then drop the can. Careful inspection will show that the ball was pulled beneath the surface as both the ball and the can drop. (What does this say about surface tension?) More dramatically, when the can makes impact with the floor, what happens to the ball, and why? Try it and you'll be astonished! (*Caution*: Unless you're wearing safety goggles, keep your head away from above the can when it makes impact.)

30. Soap greatly weakens the cohesive forces between water molecules. You can see this by adding some oil to a bottle of water and shaking it so that the oil and water mix. Notice that the oil and water quickly separate as soon as you stop shaking the bottle. Now add some liquid soap to the mixture. Shake the bottle again and you will see that the soap makes a fine film around each little oil bead and that a longer time is required for the oil to coalesce after you stop shaking the bottle. This is how soap works in cleaning. It breaks the surface tension around each particle of dirt so that the water can reach the particles and surround them. The dirt is carried away in rinsing. Soap is a good cleaner only in the presence of water.

31. Sprinkle some black pepper on the surface of some pure water in a saucer. The pepper floats. Add a drop of liquid dish soap to the surface, and the pepper grains repel from the soap droplet. Stir gently once or twice and watch the pepper sink.

PLUG AND CHUG (EQUATION FAMILIARIZATION)

$$\textbf{Pressure} = \frac{\textbf{force}}{\textbf{area}}$$

32. Calculate the pressure a 2-N book exerts on the table it rests on if its area of contact is 50 cm^2.

$$\textbf{Pressure} = \textbf{weight density} \times \textbf{depth}$$

(Use 10,000 N/m³ for the weight density of water, and ignore the pressure due to the atmosphere in the calculations below.)

33. Calculate, in kPa, the pressure exerted by a column of water that is 10-m tall. Assume the weight density of water to be 10,000 N/m^3, and ignore the pressure due to the atmosphere.

34. Show that the water pressure at the bottom of the 50-m-high water tower in the chapter-opening photo is 500,000 N/m^2, which is approximately 500 kPa.

35. The depth of water behind the Hoover Dam is 220 m. Show that the water pressure at the base of this dam is 2200 kPa.

36. The top floor of a building is 20 m above the basement. Show that the water pressure in the basement is nearly 200 kPa greater than the water pressure on the top floor.

THINK AND SOLVE (MATHEMATICAL APPLICATION)

37. Calculate the average force per nail when Sara, who weighs 120 pounds, lies on a bed of nails and is supported by 600 nails (see Figure 13.2).

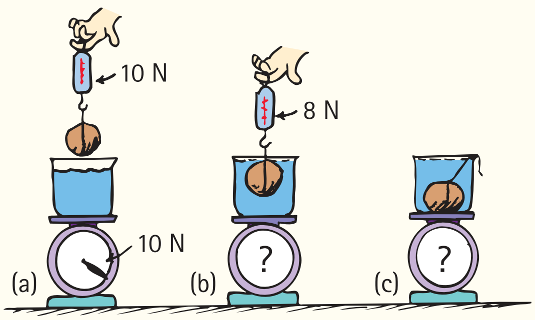
38. Suppose that you balance a 5-kg ball on the tip of your finger, which has an area of 1 cm^2. Show that the pressure on your finger is 50 N/cm^2, which is 500 kPa.

39. A 12-kg piece of metal displaces 2 L of water when submerged. Show that its density is 6000 kg/m^3. How does this compare with the density of water?

40. A 1-m-tall barrel is closed on top except for a thin pipe extending 5 m up from the top. When the barrel is filled with water up to the base of the pipe (1 meter deep), the water pressure on the bottom of the barrel is 10 kPa. What is the pressure on the bottom when water is added to fill the pipe to its top?

41. A dike in Holland springs a leak through a hole of area 1 cm^2 at a depth of 2 m below the water surface. How much force must a boy apply to the hole with his thumb to stop the leak? Could he do it?

42. In lab you find that a 1-kg rock suspended above water weighs 10 N. When the rock is suspended beneath the surface of the water, the scale reads 8 N.



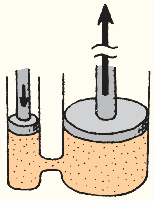
a. What is the buoyant force on the rock?

b. If the container of water weighs 10 N on the weighing scale, what is the scale reading when the rock is suspended beneath the surface of the water?

c. What is the scale reading when the rock is released and rests at the bottom of the container?

43. A merchant in Katmandu sells you a solid gold 1-kg statue for a very reasonable price. When you get home, you wonder whether or not you got a bargain, so you lower the statue into a container of water and measure the volume of displaced water. Show that, for pure gold, the volume of water displaced will be 51.8 cm^3.

44. In the hydraulic pistons shown in the sketch, the small piston has a diameter of 2 cm. The large piston has a diameter of 6 cm. How much more force can the larger piston exert compared with the force applied to the smaller piston?



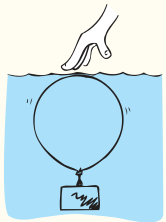
45. Your friend of mass 100 kg can just barely float in fresh water. Calculate her approximate volume.

THINK AND RANK (ANALYSIS)

46. Rank the pressures from greatest to least for the following:
    a. Bottom of a 20-cm-tall container of saltwater
    b. Bottom of a 20-cm-tall container of fresh water
    c. Bottom of a 5-cm-tall container of mercury

47. Rank the following from greatest to least for the percentage of its volume above the water line:
    a. Basketball floating in fresh water
    b. Basketball floating in saltwater
    c. Basketball floating in mercury

48. Think about what happens to the volume of an air-filled balloon on top of water and beneath the water. Then rank the buoyant forces on a weighted balloon in water, from greatest to least, when it is
    a. barely floating with its top at the surface.
    b. pushed 1 m beneath the surface.
    c. pushed 2 m beneath the surface.



THINK AND EXPLAIN (SYNTHESIS)

49. What common liquid covers more than two-thirds of our planet, makes up 60% of our bodies, and sustains our lives and lifestyles in countless ways?

50. You know that a sharp knife cuts better than a dull knife. Do you know why this is so? Defend your answer.

51. Which is more likely to hurt: being stepped on by a 200-lb man wearing loafers or being stepped on by a 100-lb woman wearing high heels?

52. Which do you suppose exerts more pressure on the ground: a 5000-kg elephant or a 50-kg lady standing on spike heels? (Which will be more likely to make dents in a linoleum floor?) Approximate a rough calculation for each.

53. Why are persons who are confined to bed less likely to develop bedsores on their bodies if they rest on a waterbed rather than on an ordinary mattress?

54. Why is blood pressure measured in the upper arm, at the elevation of your heart?

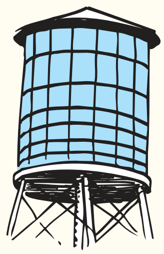
55. Why does your body get more rest when you're lying down than when you're sitting? Is blood pressure in your legs greater?

56. When you are standing, blood pressure in your legs is greater than in your upper body. Would this be true for an astronaut in orbit? Defend your answer.

57. If water faucets upstairs and downstairs are turned fully on, will more water per second flow out of the upstairs faucets or the downstairs faucets?

58. How does water pressure 1 m beneath the surface of a lake compare with water pressure 1 m beneath the surface of a swimming pool?

59. The sketch shows a wooden reservoir reinforced with metal hoops that supplies water to a farm. (a) Why is it elevated? (b) Why are the hoops closer together near the bottom part of the tank?



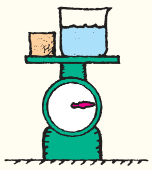
60. A block of aluminum with a volume of 10 cm^3 is placed in a beaker of water filled to the brim. Water overflows. The same is done in another beaker with a 10-cm^3 block of lead. Does the lead displace more, less, or the same amount of water?

61. A block of aluminum with a mass of 1 kg is placed in a beaker of water filled to the brim. Water overflows. The same is done in another beaker with a 1-kg block of lead. Does the lead displace more, less, or the same amount of water?

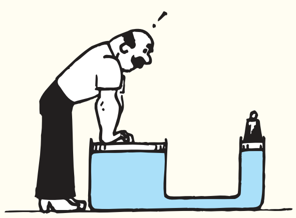
62. A block of aluminum with a weight of 10 N is placed in a beaker of water filled to the brim. Water overflows. The same is done in another beaker with a 10-N block of lead. Does the lead displace more, less, or the same amount of water? (Why do your answers differ from answers to the preceding two questions?)

63. In 1960, the U.S. Navy's bathyscaphe *Trieste* (a submersible) descended to a depth of nearly 11 km in the Marianas Trench near the Philippines in the Pacific Ocean. Instead of a large viewing window, it had a small circular window 15 cm in diameter. What is your explanation for so small a window?

64. If you've wondered about the flushing of toilets on the upper floors of city skyscrapers, how do you suppose the plumbing is designed so that there is not an enormous impact of sewage arriving at the basement level? (Check your speculations with someone who is knowledgeable about architecture.)
65. Does volume decide the pressure exerted by a liquid?
66. When you are bathing at a stony beach, why do the stones at the bottom hurt your feet less when you're standing in deep water?
67. If liquid pressure were the same at all depths, would there be a buoyant force on an object submerged in the liquid? Explain.
68. Why is it easier to float in saltwater than in fresh water?
69. In answering the question of why bodies float higher in saltwater than in fresh water, your friend replies that the reason is that saltwater is denser than fresh water. (Does your friend often recite only factual statements that relate to the answers and not provide any concrete reasons?) How would you answer the same question?
70. A can of diet soda floats in water, whereas a can of regular soda sinks. Explain this phenomenon first in terms of density and then in terms of weight versus buoyant force.
71. Why will a block of iron float in mercury but sink in water?
72. The mountains of the Himalayas are slightly less dense than the mantle material upon which they "float." Do you suppose that, like floating icebergs, they are deeper than they are high?
73. Why is a high mountain composed mostly of lead an impossibility on Earth?
74. How much force is needed to hold a nearly weightless but rigid 1-L carton beneath the surface of water?
75. Why will a volleyball held beneath the surface of water have more buoyant force than if it is floating?
76. Why does an inflated beach ball pushed beneath the surface of water swiftly shoot above the water surface when it is released?
77. Why is it inaccurate to say that heavy objects sink and light objects float? Give exaggerated examples to support your answer.
78. Why is the buoyant force on a submerged submarine appreciably greater than the buoyant force on it while it is floating?
79. Will a rock gain or lose buoyant force as it sinks deeper in water? Or will the buoyant force remain the same at greater depths? Defend your answer.
80. Will a swimmer gain or lose buoyant force as she swims deeper in the water? Or will her buoyant force remain the same at greater depths? Defend your answer, and contrast it with your answer to the preceding question.
81. The density of a rock doesn't change when it is submerged in water, but your density changes when you are submerged. Explain.
82. The weight of the human brain is about 15 N. The buoyant force supplied by fluid around the brain is about 14.5 N. Does this mean that the weight of fluid surrounding the brain is at least 14.5 N? Defend your answer.
83. A ship sailing from the ocean into a freshwater harbor sinks slightly deeper into the water. Does the buoyant force on the ship change? If so, does it increase or decrease?
84. The relative densities of water, ice, and alcohol are 1.0, 0.9, and 0.8, respectively. Do ice cubes float higher or lower in a mixed alcoholic drink? Comment on ice cubes submerged at the bottom of a cocktail.
85. When an ice cube in a glass of water melts, does the water level in the glass rise, fall, or remain unchanged? Does your answer change if the ice cube has many air bubbles in it? How about if the ice cube contains many grains of heavy sand?
86. When the wooden block is placed in the beaker, what happens to the scale reading? Answer the same question for an iron block.



87. One gondola in the Falkirk Wheel carries a 50-ton boat, while the other carries a 100-ton boat. Why do the gondolas nevertheless weigh the same?
88. Consider both a 50-ton boat and a 100-ton boat floating side by side in the gondola of the Falkirk Wheel, while the opposite gondola carries no boats at all. Why do the gondolas nevertheless weigh the same?
89. A small aquarium half-filled with water is on a spring scale. Will the reading of the scale increase or remain the same if a fish is placed in the aquarium? (Will your answer be different if the aquarium is initially filled to the brim?)
90. What would you experience when swimming in water in an orbiting space habitat where the simulated gravity is g? Would you float in the water as you do on Earth?
91. We say that the shape of a liquid is the same as the shape of its container. But, with no container and no gravity, what is the natural shape of a blob of water? Why?
92. If you release a Ping-Pong ball beneath the surface of water, it will rise to the surface. Would it do the same if it were inside a big blob of water floating weightless in an orbiting spacecraft?
93. So you're having a run of bad luck, and you slip quietly into a small, calm pool as hungry crocodiles lurking at the bottom are relying on Pascal's principle to help them to detect a tender morsel. What does Pascal's principle have to do with their delight at your arrival?
94. In the hydraulic arrangement shown, the larger piston has an area that is 50 times that of the smaller piston. The strong man hopes to exert enough force on the large piston to raise the 10 kg that rest on the small piston. Do you think he will be successful? Defend your answer.



95. In the hydraulic arrangement shown in Figure 13.22, the multiplication of force is equal to the ratio of the areas of the large and small pistons. Some people are surprised to learn that the area of the liquid surface in the reservoir of the arrangement shown in Figure 13.23 is immaterial. What is your explanation to resolve this confusion?

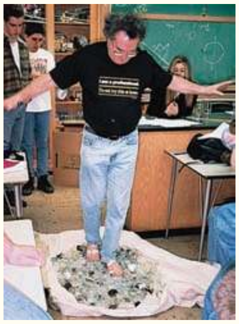
96. Why will hot water flow more readily than cold water through small leaks in a car radiator?

97. A small, dry paper clip can rest on the surface of still water. Why can't a heavier paper clip do the same without sinking?

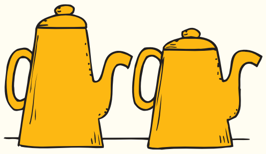
98. A chunk of steel will sink in water. But a steel razor blade, carefully placed on the surface of water, will not sink. What is your explanation?

THINK AND DISCUSS (EVALUATION)

99. The photo shows physics instructor Marshall Ellenstein walking barefoot on broken glass bottles in his class. Discuss the physics concept that Marshall is demonstrating. Why is he careful to be sure that the broken pieces are small and numerous? (The Band-Aids on his feet are for humor!)



100. Discuss which teapot holds more liquid, and why.



101. There is a legend of a Dutch boy who bravely held back the whole North Sea by plugging a hole in a dike with his finger. Discuss whether or not this is possible and reasonable. (See also Think and Solve 41.)

102. There is a story about Pascal's assistant climbing a ladder and pouring a small container of water into a tall, thin, vertical pipe inserted into a wooden barrel full of water below. The barrel burst when the water in the pipe reached about 12 m. This was all the more intriguing because the weight of added water in the tube was very small. Discuss and explain.

103. Suppose you wish to lay a level foundation for a house on hilly, bushy terrain. Discuss how you could use a garden hose filled with water to determine equal elevations at distant points.

104. A piece of iron placed on a block of wood makes the block float lower in the water. If the iron were instead suspended beneath the wood, would the wood float as low, lower, or higher? Discuss.

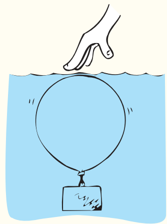
105. Compared with an empty ship, would a ship loaded with a cargo of Styrofoam sink deeper into the water or rise in the water? Discuss.

106. If a submarine starts to sink, will it continue to sink to the bottom if no changes are made? Discuss.

107. A barge filled with scrap iron is in a canal lock. If the iron is thrown overboard, does the water level at the side of the lock rise, fall, or remain unchanged? This makes for a good discussion!

108. Would the water level in a canal lock go up or down if a battleship in the lock sank? Another good discussion.

109. A balloon is weighted so that it is barely able to float in water. If it is pushed beneath the surface, will it return to the surface, stay at the depth to which it is pushed, or sink? In your discussion, consider any change in the balloon's density change.



110. Suppose that you are given the choice between two life preservers that are identical in size, the first a light one filled with Styrofoam and the second, a very heavy one, filled with gravel. If you submerge these life preservers in the water, upon which will the buoyant force be greater? Upon which will the buoyant force be ineffective? Discuss why your answers differ.

111. On a boat ride, the skipper gives you an extra-large life preserver filled with lead pellets. When he sees the skeptical look on your face, he says that you'll experience a greater buoyant force if you fall overboard than your friends who wear regular-sized Styrofoam-filled life preservers. Is he being truthful?

112. Greta Novak is treated to remarkable flotation in the very-salty Dead Sea. How does the buoyant force on her compare when she is floating in fresh water? In answering this question, discuss differences in the volume of water displaced in the two cases.

113. Would buoyancy occur in the absence of weight? Discuss the buoyancy that would or wouldn't occur in the International Space Station.

114. If the gravitational field of Earth were to increase, would a fish float to the surface, sink, or stay at the same depth?