19 LIQUIDS

THE BIG IDEA In the liquid phase, molecules can flow freely from position to position by sliding over one another. A liquid takes the shape of its container.

We live on the only planet in the solar system covered mostly by a liquid. Earth's oceans are made of H_2O in the liquid phase. If Earth were a little closer to the sun, the oceans would turn to vapor. If Earth were a little farther away, most of its surface, not just its polar regions, would be solid ice. It's nice that Earth is where it is.

In the liquid phase, molecules can flow freely from position to position by sliding over one another. A liquid takes the shape of its container.

discover!

When Does a Liquid Behave Like a Solid?

1. Put one cup of cornstarch in bowl.
2. While stirring, add ½ cup of water.
3. Try pushing on the mixture hard, then softly then stir the mixture quickly, then very slowly.
4. After pouring some of the mixture on the table, push on the puddle with the side of your hand.
5. Try to pick up mixture. Once you have it in your hands, try to keep it in solid form by continually kneading it.

Analyze and Conclude

1. **Observing** What is unusual about the mixture of cornstarch and water?
2. **Predicting** What do you suppose would happen if you were to try to play catch with the mixture?
3. **Making Generalizations** Can you think of other substances that change from a liquid to a solid state, or vice versa, when stressed?

19.1 Liquid Pressure

A liquid in a container exerts forces on the walls and bottom of the container. To investigate the interaction between the liquid and a surface, it is useful to discuss the concept of *pressure.* Recall from Chapter 6 that pressure is defined as the force per unit area on which the force acts.[19.1.1]

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

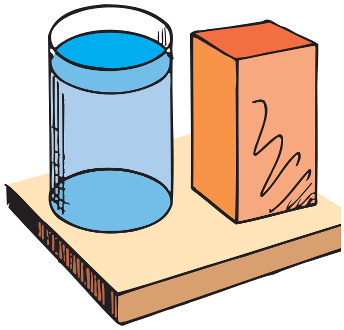
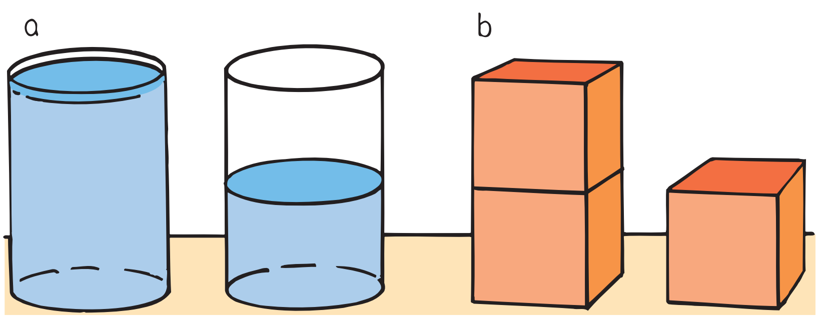


FIGURE 19.1 ▲
The liquid exerts a pressure against the bottom of its container, just as the block exerts a pressure against the table.

The pressure that a block exerts on a table is simply the weight of the block divided by its area of contact. Similarly, for a liquid in a cylindrical container like the one shown in Figure 19.1, the pressure the liquid exerts against the bottom of the container is the weight of the liquid divided by the area of the container bottom. (We'll ignore for now the additional atmospheric pressure.) **The pressure of a liquid at rest depends only on gravity and the density and depth of the liquid.**

Density How much a liquid weighs, and thus how much pressure it exerts, depends on its density. Consider two identical containers, one filled with mercury and the other filled to the same depth with water. For the same depth, the denser liquid exerts more pressure. Mercury is 13.6 times as dense as water. So for the same volume of liquid, the weight of mercury is 13.6 times the weight of water. Thus, the pressure of mercury on the bottom is 13.6 times the pressure of water.

Depth For any given liquid, the pressure on the bottom of the container will be greater if the liquid is deeper. Consider the two containers in Figure 19.2a. The liquid in the first container is twice as deep as the liquid in the second container. As with the two blocks on top of each other in Figure 19.2b, liquid pressure at the bottom of the first container will be twice that of the second container.

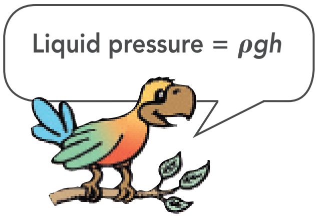


◀ **FIGURE 19.2**
Liquid pressure depends on depth. **a.** The liquid in the first container is twice as deep, so the pressure on the bottom is twice that exerted by the liquid in the second container. **b.** Similarly, the two blocks exert twice as much pressure on the table as one block.

discover!

How does depth affect blood pressure?

1. Note how the veins on the back of your hands stand out when you bend over so your hands are the lowest part of your body.
2. Note the difference when you hold your hands above your head.
3. **Think** Why is your blood pressure measured in your upper arm, level with your heart?



The pressure of a liquid at rest does not depend on the shape of the container or the size of its bottom surface. Liquids are practically incompressible, so except for changes in temperature, the density of a liquid is normally the same at all depths. The pressure created by a liquid[19.1.2] is

$$\text{pressure due to liquid} = \text{density} \times g \times \text{depth}$$

At a given depth, a given liquid exerts the same pressure against *any* surface—the bottom or sides of its container, or even the surface of an object submerged in the liquid to that depth. The pressure a liquid exerts depends on its density and depth.

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 density $\times$ g $\times$ 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 in addition to the normally ever-present atmospheric pressure. (You'll learn more about atmospheric pressure in the next chapter.)

Volume It may surprise you that the pressure of a liquid does not depend on the amount of liquid. Neither the volume nor even the total weight of liquid matters. For example, if you sampled water pressure at 1 meter beneath the surface of a large lake and 1 meter beneath the surface of a small pool, the pressures would be the same.[19.1.3] The dam that must withstand the greater pressure is the dam with the deepest water behind it, not the most water as shown in Figure 19.3.

think!

A brick mason wishes to mark the back of a building at the exact height of bricks already laid at the front of the building. How can he measure the same height using only a garden hose and water?
Answer: 19.1

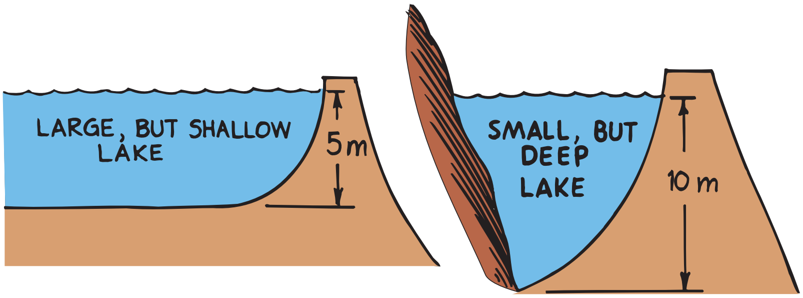
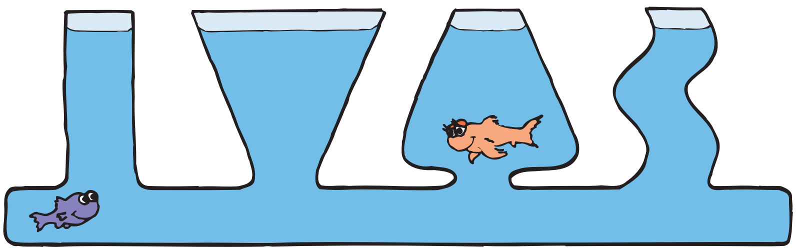


FIGURE 19.3
The water pressure is greater at the bottom of the deeper lake, not the lake with more water. The dam holding back water twice as deep must withstand greater average water pressure, regardless of the total volume of water.

The fact that water pressure depends on depth and not on volume is nicely illustrated with the "Pascal's vases" shown in Figure 19.4. Note that the water's surface in each of the connected vases is at the same level. This occurs because the pressures at equal depths beneath the surfaces are the same. At the bottom of all four vases, for example, the presures are equal. If they were not, liquid would flow until the pressures were equalized. This is why we say "water seeks its own level."

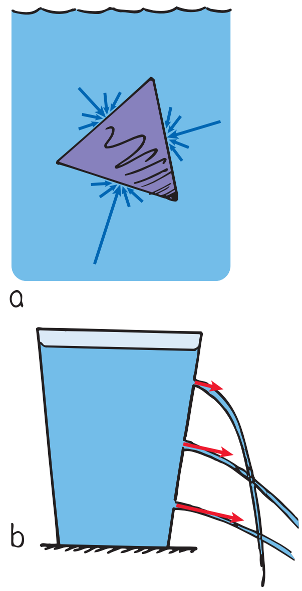
FIGURE 19.4
The pressure of the liquid is the same at any given depth below the surface, regardless of the shape of the container.



At any point within a liquid, the forces that produce pressure are exerted equally in all directions. For example, when you are swimming under water, no matter which way you tilt your head, you feel the same amount of water pressure on your ears.

When the liquid is pressing against a surface, there is a force from the liquid directed perpendicular to the surface as shown in Figure 19.5a. If there is a hole in the surface, the liquid initially will move perpendicular to the surface. Gravity, of course, causes the path of the liquid to curve downward as shown in Figure 19.5b. At greater depths, the net force is greater, and the velocity of the escaping liquid is greater.

FIGURE 19.5
The forces in a liquid produce pressure. **a.** The forces against a surface add up to a net force that is perpendicular to the surface. **b.** Liquid escaping through a hole initially moves perpendicular to the surface.



CONCEPT CHECK What determines the pressure of a liquid?

19.2 Buoyancy

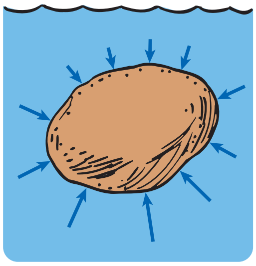


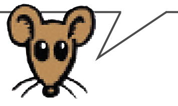
FIGURE 19.6 ▲
The upward forces against the bottom of a submerged object are greater than the downward forces against the top. There is a net upward force, the buoyant force.

If you have ever lifted a submerged object out of water, you are familiar with buoyancy. **Buoyancy** is the apparent loss of weight of objects when submerged in a liquid. It is a lot easier to lift a boulder submerged on the bottom of a riverbed than to lift it above the water's surface. The reason is that when the boulder is submerged, the water exerts an upward force that is opposite in direction to gravity. This upward force is called the buoyant force. The **buoyant force** is the net upward force exerted by a fluid on a submerged or immersed object.

To understand where the buoyant force comes from, look at Figure 19.6. The arrows represent the forces within the liquid that produce pressure against the submerged boulder. The forces are greater at greater depth. The forces acting horizontally against the sides cancel each other, so the boulder is not pushed sideways. But the forces acting upward against the bottom are greater than those acting downward against the top because the bottom of the boulder is deeper. The difference in upward and downward forces is the buoyant force.

✓ **When the weight of a submerged object is greater than the buoyant force, the object will sink. When the weight is less than the buoyant force, the object will rise to the surface and float.** When the weight is equal to the buoyant force, the submerged object will remain at any level, like a fish.

Stick your foot in a swimming pool and your foot is immersed. Jump in and sink below the surface and immersion is total—you're submerged.



To further understand buoyancy, it helps to think more about what happens when an object is placed in water. If a stone is placed in a container of water, the water level will rise as shown in Figure 19.7. Water is said to be displaced, or pushed aside, by the stone. A little thought will tell us that the volume—that is, the amount of space taken up, or the number of cubic centimeters—of water displaced is equal to the volume of the stone. *A completely submerged object always displaces a volume of liquid equal to its own volume.*

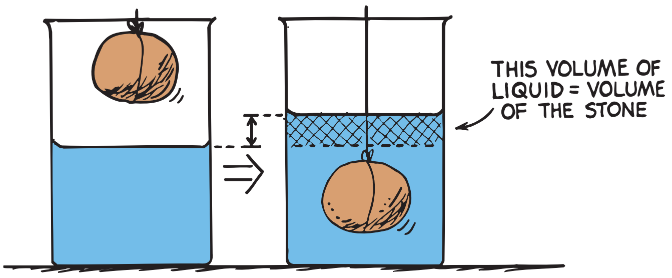


FIGURE 19.7 ▲
When an object is submerged, it displaces a volume of water equal to the volume of the object itself.

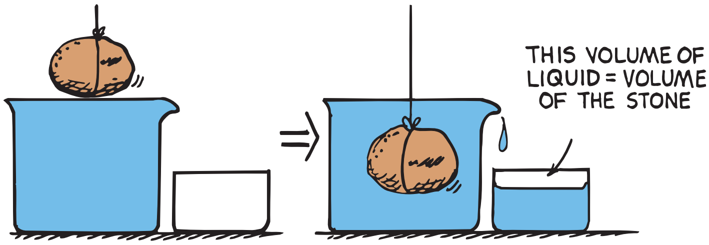


FIGURE 19.8
When an object is submerged in a container that is initially brim full, the volume of water that overflows is equal to the volume of the object itself.

As Figure 19.8 shows, this gives us a good way to determine the volume of an irregularly shaped object. Simply submerge it in water in a measuring cup and note the apparent increase in volume of the water. That increase is equal to the volume of the submerged object. You'll find this technique handy whenever you want to determine the density of things like rocks that have irregular shapes.

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CONCEPT CHECK What determines if an object will sink or float?

19.3 Archimedes' Principle

Archimedes' principle describes the relationship between buoyancy and displaced liquid. It was discovered in ancient times by the Greek philosopher Archimedes (third century B.C.). **Archimedes' principle states that the buoyant force on an immersed object is equal to the weight of the fluid it displaces.** Archimedes' principle is true for liquids and gases, which are both fluids.

Immersed means "either completely or partially submerged." For example, if we immerse a sealed 1-liter container like the one shown in Figure 19.9 halfway into water, it will displace half a liter of water and be buoyed up by the weight of half a liter of water. If we immerse it all the way (submerge it), it will be buoyed up by the weight of a full liter of water (10 newtons). Unless the completely submerged container becomes compressed, the buoyant force will equal the weight of 1 liter of water at *any* depth.[19.3] Why? Because the container will displace the same volume of water, and hence the same weight of water, at any depth. The weight of this displaced water (not the weight of the submerged object!) is the buoyant force.

think!
A 1-liter (L) container filled with mercury has a mass of 13.6 kg and weighs 136 N. When it is submerged in water, what is the buoyant force on it?
Answer: 19.3.1

FIGURE 19.9
A liter of water occupies 1000 cubic centimeters, has a mass of 1 kilogram, and weighs 10 N. Any object with a volume of 1 liter will experience a buoyant force of 10 N when fully submerged in water.

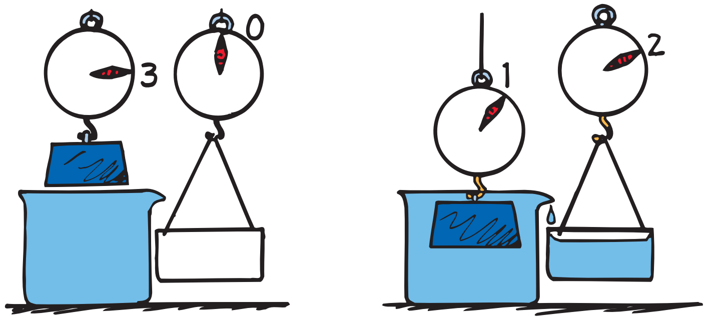


FIGURE 19.10 ▶
A brick weighs less in water than in air. The buoyant force on the submerged brick is equal to the weight of the water displaced.

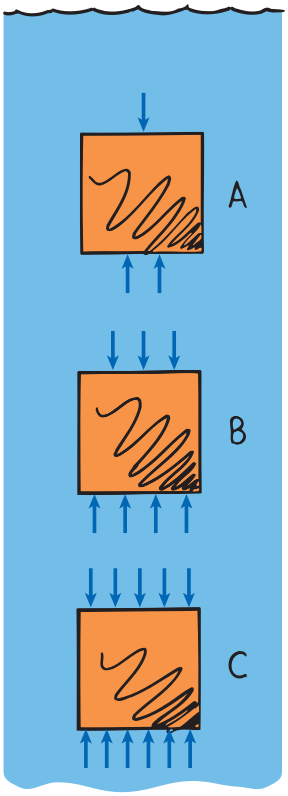


FIGURE 19.11 ▲
The difference in the upward force and the downward force acting on the submerged block is the same at any depth.

A 300-gram brick weighs about 3 N in air. Suppose as shown in Figure 19.10, the brick displaces 2 N of water when it is submerged. The buoyant force on the submerged brick will also equal 2 N. The brick will seem to weigh less under water than above water. The apparent weight of a submerged object is its weight in air minus the buoyant force. In the water, the block's apparent weight will be 3 N minus the 2-N buoyant force, or 1 N. So the block's appears lighter under water by an amount equal to the weight of water (2 N) that has spilled into the smaller container.

For any submerged block, the upward force due to water pressure on the bottom of the block, minus the downward force due to water pressure on the top, equals the weight of liquid displaced. As long as the block is submerged, depth makes no difference. Why? Because although there is more pressure at greater depths, the *difference* in pressures on the bottom and top of the block is the same at any depth as shown in Figure 19.11. Whatever the shape of a submerged object, the buoyant force equals the weight of liquid displaced.

CONCEPT CHECK **What does Archimedes' principle state?**

think!

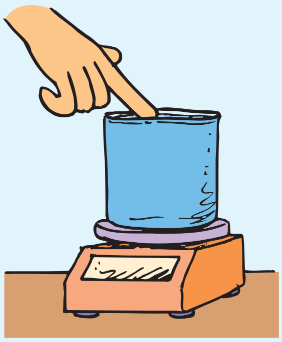
A solid block is held suspended beneath the water in the three positions, A, B, and C, shown in Figure 19.11. In which position is the buoyant force on it greatest?
Answer: 19.3.2

A stone is thrown into a deep lake. As it sinks deeper and deeper into the water, does the buoyant force on it increase, decrease, or remain unchanged?
Answer: 19.3.3

discover!

How Does Displacing Water Affect the Reading on a Scale?

1. Place a beaker of water on a scale and note the reading.
2. What do you think will happen to the reading if you lightly touch the surface of the water with your finger?
3. What do you think will happen to the reading if you push the water downward?
4. **Think** How does displacing some water affect the depth of the water? How does the depth of the water affect the pressure on the bottom of the beaker? How does the pressure affect the reading on the scale?



19.4 Does It Sink, or Does It Float?

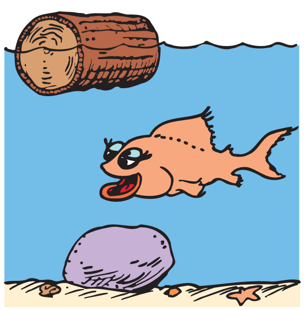
We have learned that the buoyant force on a submerged object depends on the object's volume. A smaller object displaces less water, so a smaller buoyant force acts on it. A larger object displaces more water, so a larger buoyant force acts on it. The submerged object's *volume*—not its *weight*—determines buoyant force. (A misunderstanding of this idea is at the root of a lot of confusion that you or your friends may have about buoyancy!)

So far we've focused on the weight of displaced fluid, not the weight of the submerged object. Now we consider its role.

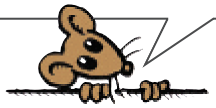
Whether an object sinks or floats (or does neither) depends on both its buoyant force (up) and its weight (down)—how great the buoyant force is compared *with the object's weight.* Careful thought will show that when the buoyant force exactly equals the weight of a completely submerged object, then the object's weight must equal the weight of displaced water. Since the volumes of the object and of the displaced water are the same, the density of the object must equal the density of water.

Look at Figure 19.12. The fish is "at one" with the water—it doesn't sink or float. The density of the fish equals the density of water. If the fish were somehow bloated up, it would be less dense than water, and would float to the top. If the fish swallowed a stone and became more dense than water, it would sink to the bottom.

FIGURE 19.12 ▼
The wood floats because it is less dense than water. The rock sinks because it is more dense than water. The fish neither rises nor sinks because it has the same density as water.



Cans of diet drinks float in water, while sugared drinks sink! Diet drinks are less dense than water. Sugared drinks are denser than water.



Sinking and floating can be summed up in three simple rules.

1. **An object more dense than the fluid in which it is immersed sinks.**
2. **An object less dense than the fluid in which it is immersed floats.**
3. **An object with density equal to the density of the fluid in which it is immersed neither sinks nor floats.**

From these rules, what do we say about people who, try as they may, cannot float?[19.4] They're simply too dense! To float more easily, you must reduce your density. Since density is mass divided by volume, you must either reduce your mass or increase your volume. Taking in a lung full of air can increase your volume (temporarily!). A life jacket does the job better. It increases volume while adding little to your mass.

The density of a submarine is controlled by the flow of water into and out of its ballast tanks. In this way the weight of the submarine can be varied to achieve the desired average density. A fish regulates its density by expanding or contracting an air sac that changes its volume. The fish can move upward by increasing its volume (which decreases density) and downward by contracting its volume (which increases density). A crocodile increases its density when it swallows stones. From 4 to 5 kg of stones have been found lodged in the front part of the stomach in large crocodiles. With its increased density, a crocodile like the one in Figure 19.13, swims lower in the water and exposes less of itself to its prey.

think!

We know that if a fish makes itself more dense, it will sink; if it makes itself less dense, it will rise. In terms of buoyant force, why is this so?
Answer: 19.4

CONCEPT CHECK What are the three rules of sinking and floating?

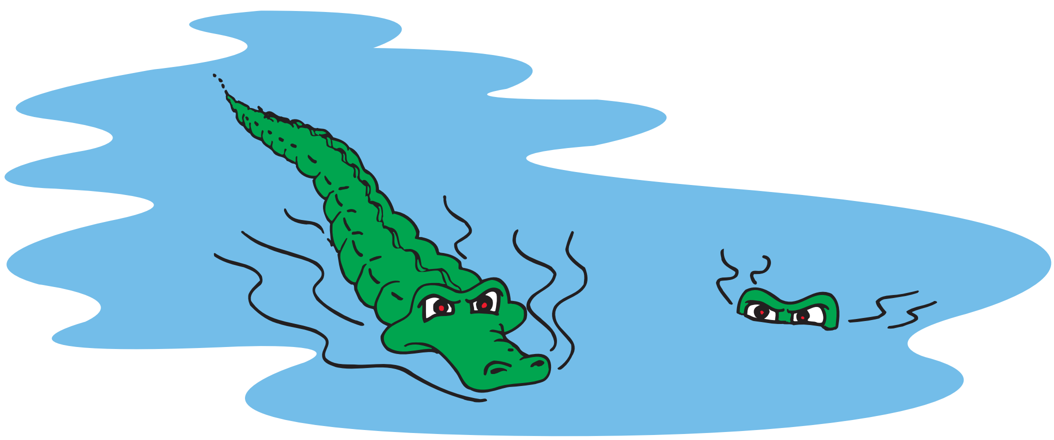


FIGURE 19.13 ▲
The crocodile on the left is less dense than the crocodile on the right because its belly is not full of stones.

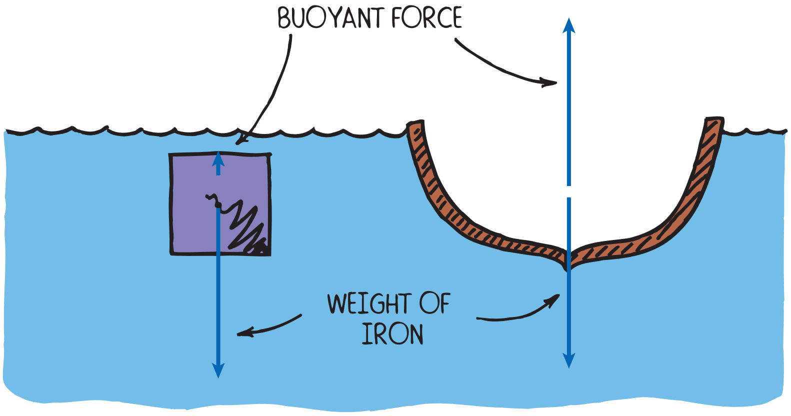


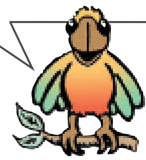
FIGURE 19.14
A solid iron block sinks, while the same block shaped to occupy at least eight times as much volume floats.

19.5 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 solid 1-ton block of iron. Iron is nearly eight times as dense as water, so when it is submerged, it will displace only 1/8 ton of water. The buoyant force will be far from enough to keep it from sinking. Suppose we reshape the same iron block into a bowl shape, as shown in Figure 19.14. The iron bowl still weighs 1 ton. If you lower the bowl into a body of water, it displaces a greater volume of water than before. The deeper the bowl is immersed, the more water is displaced and the greater is the buoyant force exerted on the bowl. When the weight of the displaced water equals the weight of the bowl, it will sink no farther. It will float because the buoyant force now equals the weight of the bowl. This is an example of the principle of flotation.

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



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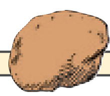


Floating Mountains Just as most of a floating iceberg is below the water's surface, most of a mountain is below ground level. Mountains "float" too! About 15% of a mountain is above the surrounding ground level. The rest extends deep into Earth, resting on the dense semiliquid mantle. If we could shave off the top of an iceberg, the iceberg would be lighter and float higher. Similarly, when mountains erode they float higher. That's why it takes so long for mountains to weather away. As the mountain wears away, it floats higher, pushed up from below. When a mile of mountain erodes away, 85% of it comes back.

FIGURE 19.15 ▼
The weight of the floating canoe equals the weight of the water displaced by the submerged part of the canoe.

✓ **The principle of flotation states that a floating object displaces a weight of fluid equal to its own weight.**[19.5] Figure 19.16 demonstrates a simple experiment you can do to test the principle of flotation.

Every ship must be designed to displace a weight of water 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 below the surface. The canoe in Figure 19.15 and the ship in Figure 19.17 float lower in the water when they are loaded. The weight of the load equals the weight of the extra water displaced.

Think about a submarine beneath the surface. If it displaces a weight of water greater than its own weight, it will rise. If it displaces less, it will go down. If it displaces exactly its weight, it will remain at constant depth. Water has slightly different densities at different temperatures, so a submarine must make periodic adjustments as it moves through the ocean. As the next chapter shows, a hot-air balloon obeys the same rules.

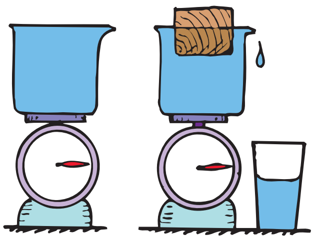


FIGURE 19.16 ▲
A floating object displaces a weight of liquid equal to its own weight.

CONCEPT CHECK What does the principle of flotation state?

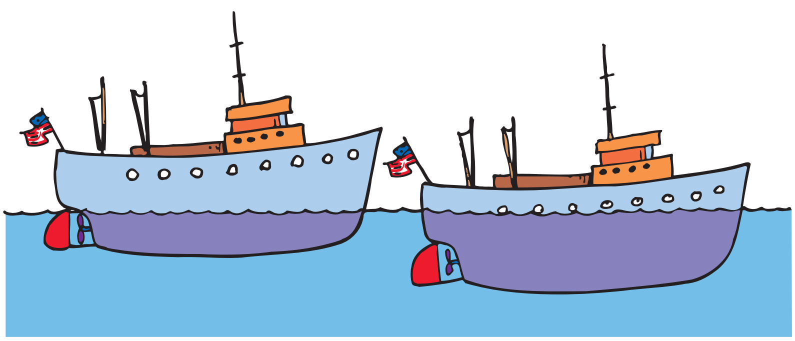
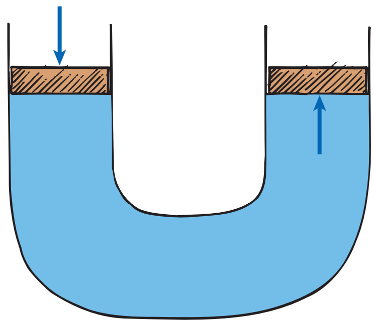


FIGURE 19.17 ▲
The same ship is shown empty and loaded. The weight of the ship's load equals the weight of extra water displaced.



◀ **FIGURE 19.18**
The force exerted on the left piston increases the pressure in the liquid and is transmitted to the right piston.

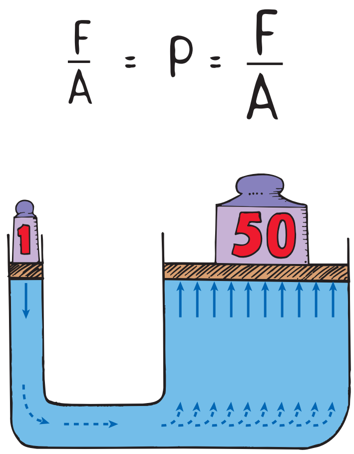
19.6 Pascal's Principle

Push a stick against a wall and you can exert pressure at a distance. Interestingly enough, we can do the same with a fluid. Whenever we change the pressure in one part of a fluid, this change is transmitted to other parts. For example, if the pressure of city water is increased at the pumping station by 10 units of pressure, the pressure everywhere in the pipes of the connected system will be increased by 10 units of pressure (when water is not moving). **Pascal's principle** describes how changes in a pressure are transmitted in a fluid. **Pascal's principle states that changes in pressure at any point in an enclosed fluid at rest are transmitted undiminished to all points in the fluid and act in all directions.**

Pascal's principle was discovered in the seventeenth century by Blaise Pascal, for whom the SI unit of pressure is named. Pascal's principle is employed in a hydraulic press. If you fill a U-shaped tube with water and place pistons at each end, as shown in Figure 19.18, 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 fit snugly but can freely slide inside the tube.) The pressure the left piston exerts against the water will be exactly equal to the pressure the water exerts against the right piston if the levels are the same.

This is nothing to get excited about. But suppose you make the tube on the right side wider and use a piston of larger area; then the result is impressive. In Figure 19.19 the piston on the left has an area of 1 square centimeter, and the piston on the right has an area fifty times as great, 50 square centimeters. Suppose there is a 1-newton load on the left piston. Then an additional pressure of 1 newton per square centimeter (1 N/cm^2) is transmitted throughout the liquid and up against the larger piston. Here is where the difference between force and pressure comes in. The additional pressure of 1 N/cm^2 is exerted against *every* square centimeter of the larger piston. Since there are 50 square centimeters, the total extra force exerted on the larger piston is 50 newtons. Thus, the larger piston will support a 50-newton load. This is 50 times the load on the smaller piston!

FIGURE 19.19 ▼
A 1-N load on the left piston will support 50 N on the right piston.



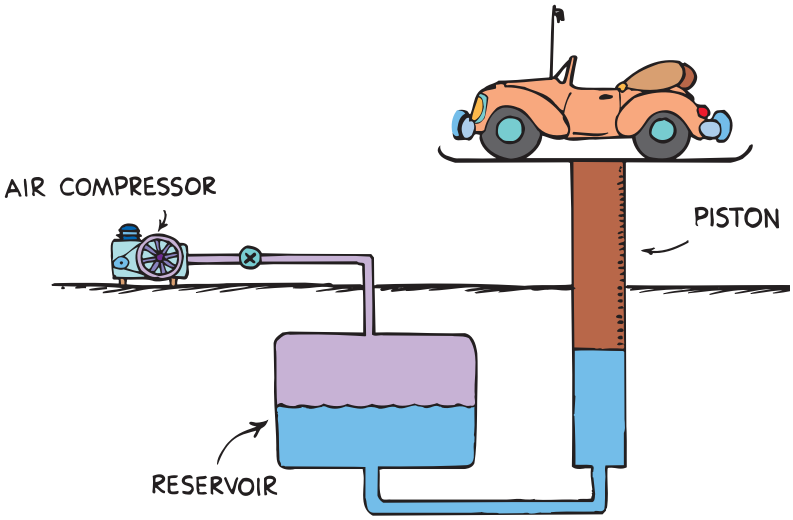


FIGURE 19.20 ▶ The automobile lift in a service station is an application of Pascal's Principle. A low-pressure exerted over a relatively large area produces a large force.

think!

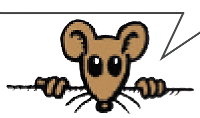
As the automobile in Figure 19.20 is being lifted, how does the change in oil level in the reservoir compare with the distance the automobile moves?
Answer: 19.6

This is quite remarkable, for we can multiply forces with such a device—1 newton input, 50 newtons output. By further increasing the area of the larger piston (or reducing the area of the smaller piston), we can multiply forces to any amount. Pascal's principle underlies the operation of the hydraulic press.

The hydraulic press does not violate energy conservation, for the increase in force is compensated for by a decrease in distance moved. When the small piston in the last example is moved downward 10 cm, the large piston will be raised only one-fiftieth of this, or 0.2 cm. Very much like a mechanical lever, the input force multiplied by the distance it moves is equal to the output force multiplied by the distance it moves. The hydraulic press is a "machine," much like those discussed in Section 9.8.

Pascal's principle applies to all fluids (gases and liquids). A typical application of Pascal's principle for gases and liquids is the automobile lift shown in Figure 19.20. The automobile lift is in many service stations. Compressed air exerts pressure on the oil in an underground reservoir. The oil in turn transmits the pressure to a cylinder, 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 the tires of the automobile, because a low pressure exerted over a relatively large area produces a considerable force. It's important to note that the oil surface doesn't act like the input pistons of Figures 19.18 and 19.19. Whatever air pressure the compressor supplies to the reservoir, regardless of the oil's surface area, is transmitted through the oil to the piston that raises the car.

Although water covers two-thirds of the planet, oceans are the least understood ecosystems and likely the most at risk.



CONCEPT CHECK What does Pascal's principle state?

19 REVIEW

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Concept Summary

- The pressure of a liquid at rest depends only on gravity and the density and depth of the liquid.
- When the weight of a submerged object is greater than the buoyant force, the object will sink. When the weight is less than the buoyant force, the object will rise to the surface and float.
- Archimedes's principle states that the buoyant force on an immersed object is equal to the weight of the fluid it displaces.
- Sinking and floating can be summed up in three simple rules:
  1. An object more dense than the fluid in which it is immersed sinks.
  2. An object less dense than the fluid in which it is immersed floats.
  3. An object with density equal to the density of the fluid in which it is immersed neither sinks nor floats.
- The principle of flotation states that a floating object displaces a weight of fluid equal to its own weight.
- Pascal's principle states that changes in pressure at any point in an enclosed fluid at rest are transmitted undiminished to all points in the fluid and act in all directions.

Key Terms

buoyancy *(p. 366)*

buoyant force *(p. 366)*

Archimedes' principle *(p. 367)*

Pascal's principle *(p. 373)*

think! Answers

19.1 To measure the same height, the brick mason can extend a garden hose that is open at both ends from the front to the back of the house, and fill it with water until the water level reaches the height of bricks in the front. Since water seeks its own level, the level of water in the other end of the hose will be the same!

19.3.1 The buoyant force equals the weight of 1 L of water (about 10 N) because the *volume* of displaced water is 1 L.

19.3.2 The buoyant force is the same at all three positions, because the amount of water displaced is the same in A, B, and C.

19.3.3 The volume of displaced water is the same at any depth. Water is practically incompressible, so its density is the same at any depth, and equal volumes of water weigh the same. The buoyant force on the stone remains unchanged as it sinks deeper and deeper.

19.4 When the fish increases its density by decreasing its volume, it displaces less water, so the buoyant force decreases. When the fish decreases its density by expanding, it displaces more water, and the buoyant force increases.

19.6 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.

19 ASSESS

Check Concepts

Section 19.1

1. Distinguish between *pressure* and *force*.

2. What is the relationship between liquid pressure and depth of a liquid? Between liquid pressure and density?

3. **a.** By how much does the water pressure on a submarine change when the submarine dives to double its previous depth (neglect the very real effect of atmospheric pressure above)?
   b. If the submarine operated in fresh water, would the pressure it feels be greater or less than at the same depth in salt water?

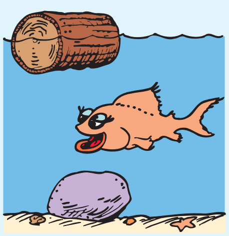
4. How does water pressure 1 meter below the surface of a small pond compare with water pressure 1 meter below the surface of a huge lake?

5. If you immerse a tin can with a small hole in it in water so that water spurts through the hole, what will be the direction of water flow where the hole is?

Section 19.2

6. Why does the buoyant force act upward for an object submerged in water?

7. How does the buoyant force that acts on a fish compare with the weight of the fish?



8. Why does the buoyant force on submerged objects not act sideways?

9. How does the volume of a completely submerged object compare with the volume of water displaced?

Section 19.3

10. When an object is said to be immersed in water, does this mean it is completely submerged? Does it mean it is partially submerged? Does the word *immersed* apply to either case?

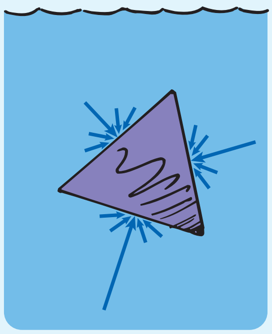
11. What is the mass of 1 liter of water in kilograms? What is its weight in newtons?

12. **a.** Does the buoyant force on a submerged object depend on the weight of the object itself or on the weight of the fluid displaced by the object?
    b. Does it depend on the weight of the object itself or on its volume? Defend your answer.

Section 19.4

13. When the buoyant force on a submerged object is equal to the weight of the object, how do the densities of the object and water compare?

14. When the buoyant force on a submerged object is more than the weight of the object, how do the densities of the object and water compare?



15. When the buoyant force on a submerged object is less than the weight of the object, how do the densities of the object and water compare?

16. a. How is the density of a submarine controlled?
    b. How is the density of a fish controlled?

Section 19.5

17. Does the buoyant force on a floating object depend on the weight of the object itself or on the weight of the fluid displaced by the object? Or are these both the same for the special case of floating?

18. What is the buoyant force that acts on a 100-ton ship? (To make things simple, give your answer in tons.)

Section 19.6

19. According to Pascal's principle, what happens to the pressure in all parts of a confined fluid when you produce an increase in pressure in one part?

20. When the pressure in a hydraulic press is increased by an additional 10 N/cm^2, how much extra load will the output piston support when its cross-sectional area is 50 square centimeters?

Plug and Chug

Use the following equations to help you answer Questions 21–25.

Density: $\rho = m/V$
Pressure: $P = F/A$
Liquid pressure: $P = \rho g h$

21. Calculate the amount of pressure you experience when you balance a 5-kg ball on the tip of your finger, say of area 1 cm^2?

22. Calculate the water pressure at the base of Hoover Dam. The depth of water behind the dam is 220 m. (Neglect the pressure due to the atmosphere.)

23. Calculate the water pressure in the pipes at the bottom of a high-rise building that is fed by a reservoir 30 m above on the roof.

24. An 8.6-kg piece of metal displaces 1 liter of water when submerged. Calculate its density.

25. A 4.7-kg piece of metal displaces 0.6 liter of water when submerged. Calculate its density.

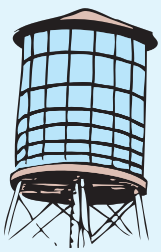
Think and Explain ......

26. Stand on a bathroom scale and read your weight. When you lift one foot up so you're standing on the other foot, does the reading change? Does a scale read force or pressure?

27. Which is more likely to hurt—being stepped on by a man wearing loafers or being stepped on by a half-as-heavy woman wearing spike heels? Defend your answer.

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

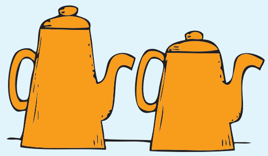
29. The sketch shows a reservoir that supplies water to a farm. It is made of wood and is reinforced with metal hoops.
  a. Why is it elevated?
  b. Why are the hoops closer together near the bottom part of the tank?



30. If water faucets upstairs and downstairs are turned fully on, will more water per second flow out the downstairs faucet? Or will the water flowing from the faucets be the same?

31. In a deep dive, a whale is appreciably compressed by the pressure of the surrounding water. What happens to the whale's density?

32. Which teapot holds more liquid?



33. What physics principle accounts for the observation that water seeks its own level?

34. When you are bathing on a stony beach, why do the stones hurt your feet less when you step in deep water?

35. If liquid pressure were the same at all depths, would there be a buoyant force on an object submerged in the liquid? Explain.

36. If a 1-L container is immersed halfway in water, what volume of water is displaced? What is the buoyant force on the container?

37. How much force is needed to push a nearly weightless but rigid 1-L carton beneath a surface of water?

38. Why will a volleyball held beneath the surface of water have more buoyant force than if it is floating?

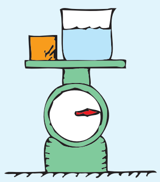
39. A barge filled with scrap iron is in a canal lock. If the iron is thrown overboard, does the water level at the side of the lock rise, fall, or remain unchanged? Explain.

40. Would the water level in a canal lock go up or down if a ship in the lock were to sink?

41. A ship sailing from the ocean into a freshwater harbor sinks slightly deeper into the water. Does the buoyant force on it change? If so, does the force increase or decrease?

42. Suppose you have two life preservers that are identical in size, the first a light one filled with foam and the second a very heavy one filled with lead pellets. If you submerge these life preservers in water, upon which will the buoyant force be greater? Upon which will the buoyant force be ineffective? Why are your answers different?

43. When the block of wood is placed in the beaker, what happens to the scale reading? Answer the same question for an iron block.



44. 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 contains many air bubbles? Does your answer change if the ice cube contains many grains of heavy sand?

45. 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 rests on the small piston. Do you think he will be successful? Explain.

46. Hydraulic devices multiply forces. Why does this not violate the law of conservation of energy?

Think and Solve

You may need the following information for some of the Think and Solve problems that follow.

The density ρ of fresh water is 1000 kg/m^3, or equivalently, 1.00 kg/liter. Weight density ρ_w is 9800 N/m^3, or equivalently, 9.80 N/liter. For sea water, these values are 1030 kg/m^3, or 1.03 kg/liter, and 10,094 N/m^3, or 10.094 N/liter.

47. Which produces more pressure on the ground, an elephant or a woman balancing on high heels? Assume an elephant weighs 500 times more than the woman, and the cross-sectional area of its feet is 10,000 times greater than that of the woman's heels.

48. A hole of area 12 cm^2 is made in the bottom of a barge 1.5 m below the freshwater surface. A board is held over the hole from inside the barge to stop water from leaking in. Show that the force necessary to hold the board in position is 18 N.

49. The water level at the top of a water tower is 50 m above ground level.
   a. Show that the gravitational potential energy (*mgh*) of each kilogram of water at the water surface in the tower is 500 J relative to ground level.
   b. Show that the water pressure at the base of the tower is 500,000 N/m^2.

19 ASSESS *(continued)*

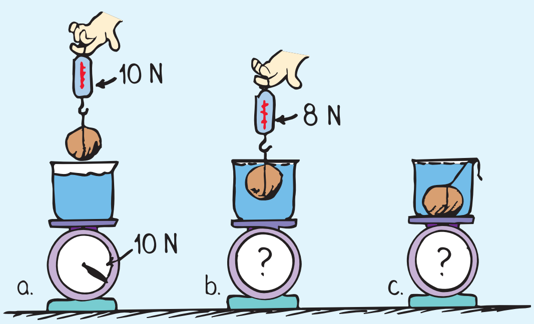
50. A dike in Holland springs a leak through a hole of area 1 cm^2 at a depth of 2 m below the water surface. With what force would a boy have to push on the hole with his thumb to stop the leak? Could he do it?

51. When a 1.8-kg wrench is suspended in water from a spring scale, the scale reading is 1.6 kg. What is the density of the wrench?

52. A 13.5-kg block of metal displaces 5 liters of water when submerged. What kind of metal is likely to compose the block?

53. Phil can support 100 N of iron (ρ = 7,800 kg/m^3) in water. How many newtons can he support in air?

54. 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.



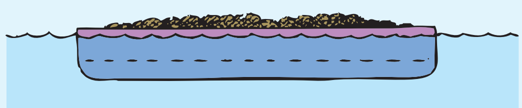
a. What is the buoyant force on the rock?
b. If a container of water on a bathroom-type scale weighs 10 N, what is the scale reading when the rock is suspended beneath the surface of the water?
c. What is the scale reading when the rock is released and rests at the bottom of the container?

55. A merchant in Katmandu sells you a solid gold 1.000-kg statue for a very reasonable price. You wonder whether or not you got a bargain, so you lower the statue into a measuring cup and measure its volume. What volume will verify that it's pure gold?

56. A prospector desires to know if a nugget is pure gold. The nugget has a mass of 380 grams on a balance. When immersed in water its mass appears as 350 grams. Is the nugget pure gold?

57. Consider a friend of mass 100 kg who can just barely float in fresh water. Show that the volume of your friend is about 0.1 m^3.

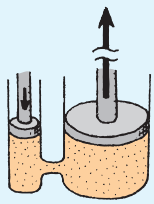
58. A gravel barge, rectangular in shape, is 4 m wide and 10 m long. When loaded, it sinks 2 m in the water. Show that the weight of gravel in the barge is 800,000 N.



59. A rectangular barge 5 m long and 2 m wide floats in fresh water.
a. Show that the barge will sink 5 cm lower when loaded with 500 kg of sand.
b. If the barge can only be pushed 10 cm deeper into the water before water overflows to sink it, how many kilograms of sand can it carry?

60. A circus elephant weighing 18,800 N is taken on board a barge of length 6.2 m and breadth 3.0 m, which floats in a river. Show that the barge sinks 10 cm when the elephant gets on board.

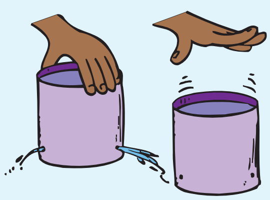
61. In the hydraulic pistons shown in the sketch, the small piston has a diameter of 2 cm and the large piston has a diameter of 6 cm. How much force can the larger piston exert compared with the force applied to the smaller piston?



Activities

62. Try to float an egg in water. Then dissolve salt in the water until the egg floats. How does the density of an egg compare with the density of tap water? Salt water? How do you know?

63. Punch a couple of holes in the bottom of a water-filled container, and water will spurt out because of water pressure (left of figure). Now drop the container and watch what happens. Explain your observations. (Hint: What happens to g, and hence weight, and hence weight density, and hence pressure in the reference frame of the falling container?)



64. Make a Cartesian diver like the one shown below. Completely fill a large, pliable plastic bottle with water. Partially fill a small pill bottle so that it just barely floats when capped, turned upside down, and placed in the large bottle. (You may have to experiment to get it just right.) Once the pill bottle is barely floating, secure the lid or cap on the large bottle so that it is airtight. When you press the sides of the large bottle, the pill bottle sinks; when you release it, the bottle returns to the top. Experiment by squeezing the bottle different ways to get different results. Explain the behavior you see.

More Problem-Solving Practice
Appendix F