WATER DOWSING

The practice of water dowsing, which goes back to ancient times in Europe and Africa, was carried across the Atlantic to America by some of the earliest settlers. Dowsing refers to the practice of using a forked stick, or a rod, or some similar device to locate underground water, minerals, or hidden treasure. In the classic method of dowsing, each hand grasps a fork, with palms upward. The pointed end of the stick points skyward at an angle of about 45°. The dowser walks back and forth over the area to be tested, and, when passing over a source of water (or whatever else is being sought), the stick is supposed to rotate downward. Some dowsers have reported an attraction so great that blisters formed on their hands. Some claim special powers that enable them to "see" through soil and rock, and some are mediums who go into trances when conditions are especially favorable. Although most dowsing is done at the actual site, some dowsers claim to be able to locate water simply by passing the stick over a map.

Since drilling a well is an expensive process, the dowser's fee is usually seen as reasonable. The practice is widespread, with thousands of dowsers active in the United States. This is because dowsing works. The dowser can hardly miss—not because of special powers, but because groundwater is within 100 meters of the surface at almost every spot on Earth.

If you drill a hole into the ground, you'll find that the wetness of the soil varies with depth. Near the surface, pores and open spaces are filled mostly with air. Deeper, the pores are saturated with water. The upper boundary of this water-saturated zone is called the *water table*. It usually rises and falls with the contour of the surface topography. Wherever you see a natural lake or pond, you're seeing a place where the water table extends above the surface of the land.

The depth, quantity, and quality of water below the water table are studied by hydrologists, who rely on a variety of technological techniques—water dowsing *not* being one of them. Findings of the U.S. Geological Survey conclude that water dowsing falls into the category of pseudoscience. As mentioned in Chapter 1, the real test of a water dowser would be finding a location in which water can't be found.

Buoyancy

THE Physics Place
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 it 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 pressures 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.

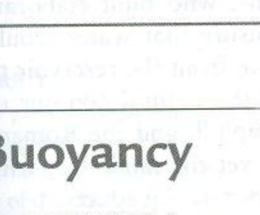

FIGURE 13.9
The greater pressure against the bottom of a submerged object produces an upward buoyant force.

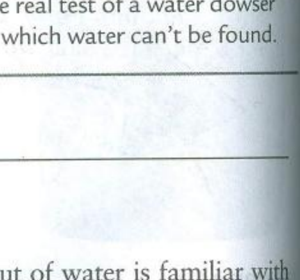

FIGURE 13.10
When a stone is submerged, it displaces water that has a volume equal to the volume of the stone.

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

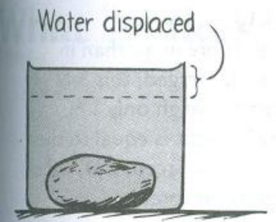

FIGURE 13.11
The increase in water level is the same as if you poured in a volume of water equal to the stone's volume.

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.*

CHECK YOURSELF

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

Archimedes' Principle

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

Insights

The relationship between buoyancy and displaced liquid was first discovered in the third 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 is true of liquids and gases, both of which are fluids. If an immersed object displaces 1 kilogram of fluid, the buoyant force acting on it is equal to the weight of 1 kilogram.[5] By *immersed,* we mean either *completely* or *partially submerged.* If we immerse a sealed 1-liter 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 equivalent to the weight of a full liter of water (1 kilogram of mass). If the container is fully submerged and doesn't compress, the buoyant force will equal the weight of 1 kilogram 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-kilogram object displaces 20 kilograms of fluid upon immersion, its apparent weight will be equal to the weight of 10 kilograms (98 newtons). Note that, in Figure 13.13, the 3-kilogram block has an apparent weight equal to the weight of 1 kilogram when submerged. The apparent weight of a submerged object is its usual weight in air minus the buoyant force.

FIGURE 13.12
A liter of water occupies a volume of 1000 cm^3, has a mass of 1 kg, and weighs 9.8 N. Its density may therefore be expressed as 1 kg/L and its weight density as 9.8 N/L. (Seawater is slightly denser, about 10.0 N/L).

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 watch 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 the volume of the butter.

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[5] In lab, you may find it convenient to express 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 9.8 N. Or we could as well say that the buoyant force is 1 *kilogram weight,* not simply 1 kg.

THE **Physics Place**
Archimedes' Principle

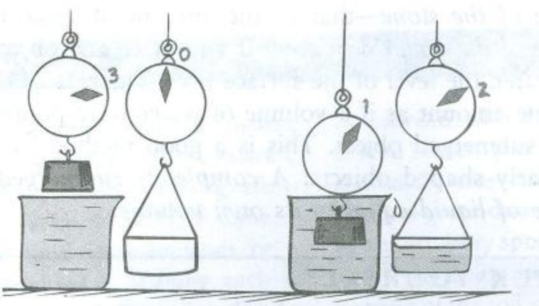

FIGURE 13.13
Objects weigh more in air than in water. When submerged, this 3-N block appears to weigh only 1 N. The "missing" weight is equal to the weight of water displaced, 2 N, which equals the buoyant force.

CHECK YOURSELF

1. Does Archimedes' principle tell us that, if an immersed object displaces liquid weighing 10 N, the buoyant force on the object is 10 N?
2. A 1-liter 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. A boulder is thrown into a deep lake. As it sinks deeper and deeper into the water, does the buoyant force upon it increase or decrease?
4. Since buoyant force is the net force that a fluid exerts on a body and, as we learned in Chapter 4, that net force produces acceleration, why doesn't a submerged body accelerate?

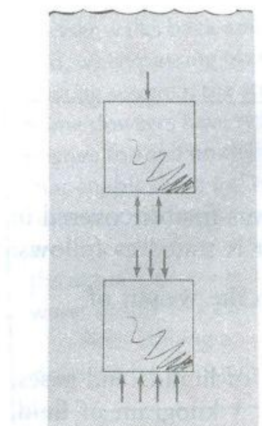

FIGURE 13.14
The difference in the upward and downward force acting on the submerged block is the same at any depth.

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. It makes no difference how deep the cube is placed because, 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.

CHECK YOUR ANSWERS

1. Yes. Looking at it another way, 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 is equal to the weight of the liter of water displaced. One L of water has a mass of 1 kg, and a weight of 9.8 N. So the buoyant force on it is 9.8 N. (The 11.3 kg of the lead is irrelevant; 1 L of anything submerged in water will displace 1 L and be buoyed upward with a force of 9.8 N, the weight of 1 kg.)
3. Buoyant force remains unchanged as the boulder sinks, because the boulder displaces the same volume of water at any depth.
4. A submerged body does accelerate if the buoyant force is not balanced by other forces acting on it—the force of gravity and fluid resistance. The net force on a submerged body is the result of the net force the fluid exerts (buoyant force), the weight of the body, and, if the submerged body is moving, the force of fluid friction.

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 having a density equal to the density of the fluid in which it is immersed will neither sink nor float.**

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

Insights

Rule 1 seems reasonable enough, for 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 to 5 kilograms 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).

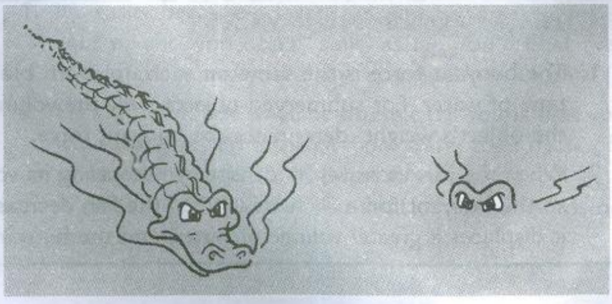

FIGURE 13.15
(*left*) A crocodile coming toward you in the water. (*right*) A stoned crocodile coming toward you in the water.

CHECK YOURSELF

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 buoyant force, why is this so?

Flotation

THE Physics Place

Flotation

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

Insights

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 eight times denser than water, it 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, it will sink no farther.

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

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

Every ship, every submarine, and every dirigible 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.

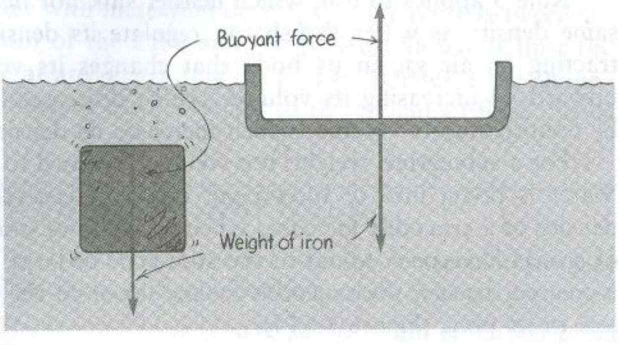

FIGURE 13.16
An iron block sinks, while the same quantity of iron shaped like a bowl floats.

CHECK YOUR ANSWERS

1. The buoyant force is the same on each, for both blocks displace the same volume of water. For submerged objects, only the volume of water displaced, not the object's weight, determines the buoyant force.
2. 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 a greater volume of water, and the buoyant force increases.

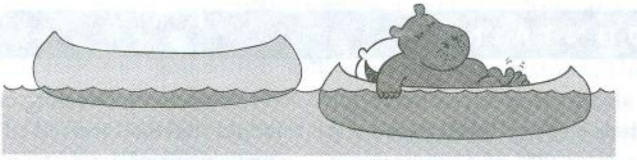

FIGURE 13.17
The weight of a floating object equals the weight of the water displaced by the submerged part.

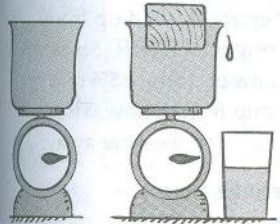

FIGURE 13.18
A floating object displaces a weight of fluid equal to its own weight.

The same holds true for vessels in air. A dirigible 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.

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 salt water than in freshwater because salt water is slightly denser. Similarly, a solid chunk of iron will float in mercury, even though it will sink in water.

CHECK YOURSELF

1. Why is it easier for you to float in salt water than in freshwater?
2. On a boat ride, the skipper gives you a 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 Styrofoam-filled life preservers. Is he being truthful?

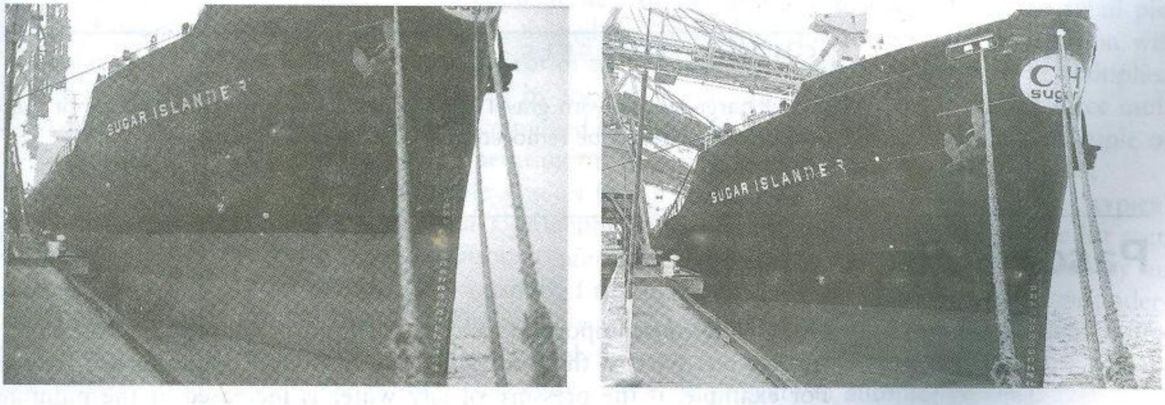

FIGURE 13.19
The same ship empty and loaded. How does the weight of its load compare with the weight of extra water displaced?

CHECK YOUR ANSWERS

1. It's easier because a lesser amount of your body is immersed when displacing your weight–you don't "sink" as far. You'd float even higher in mercury (density 13.6 g/cm^3), and you'd sink completely in alcohol (density 0.8 g/cm^3).
2. He's truthful. But what he doesn't tell you is that you'll drown! Your life preserver will submerge and displace more water than those of your friends who float at the surface. Although the buoyant force on you will be greater, your increased weight is greater still! Whether you float or sink depends on whether or not the buoyant force equals your weight.

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 the Earth's surface varies slightly with varying densities of underlying rock (which is valuable information to geologists and oil prospectors), and that 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 the 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.

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.

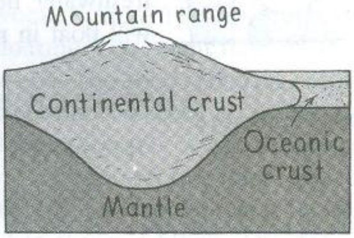

FIGURE 13.20
The continental crust is deeper beneath mountains.

CHECK YOURSELF

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?

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 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 (provided that the water is at rest). This rule 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.**

Pascal's principle was discovered in the seventeenth century by Blaise Pascal (who was an invalid at the age of 18 and remained so until his death at the age of 39), for whom the SI unit of pressure, the pascal (1 Pa = 1 N/m^2), was named.

DO YOU HAVE AN ANSWER?

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