Section 2
Buoyancy and Density

Key Concept Buoyant force and density affect whether an object will float or sink in a fluid.

What You Will Learn

- All fluids exert an upward buoyant force on objects in the fluid.
- The buoyant force on an object is equal to the weight of the fluid displaced by the object.
- An object will float or sink depending on the relationship between the object's weight, buoyant force, and overall density.
- Density can be calculated from measurements of mass and volume. The overall density of an object can be changed by changing the object's shape, mass, or volume.

Why It Matters

Understanding buoyant force and density will help you predict whether an object will float or sink in a fluid.

Why does ice float on water? Why doesn't it sink? Imagine that you use a straw to push an ice cube underwater. Then, you remove the straw. A force pushes the ice up to the water's surface. The force, called **buoyant force,** is the upward force that fluids exert on all matter.

Buoyant Force and Fluid Pressure

Look at **Figure 1.** Water exerts fluid pressure on all sides of an object. The pressure that is applied horizontally on one side of the object is equal to the pressure applied on the other side. These equal pressures balance one another. So, the only fluid pressures that may change the net force on the object are at the top and at the bottom. Pressure increases as depth increases. So, the pressure at the bottom of the object is greater than the pressure at the top. This difference in pressure is shown by the different lengths of the arrows in **Figure 1.** The water applies a net upward force on the object. This upward force, which is caused by differences in pressure, is buoyant force.

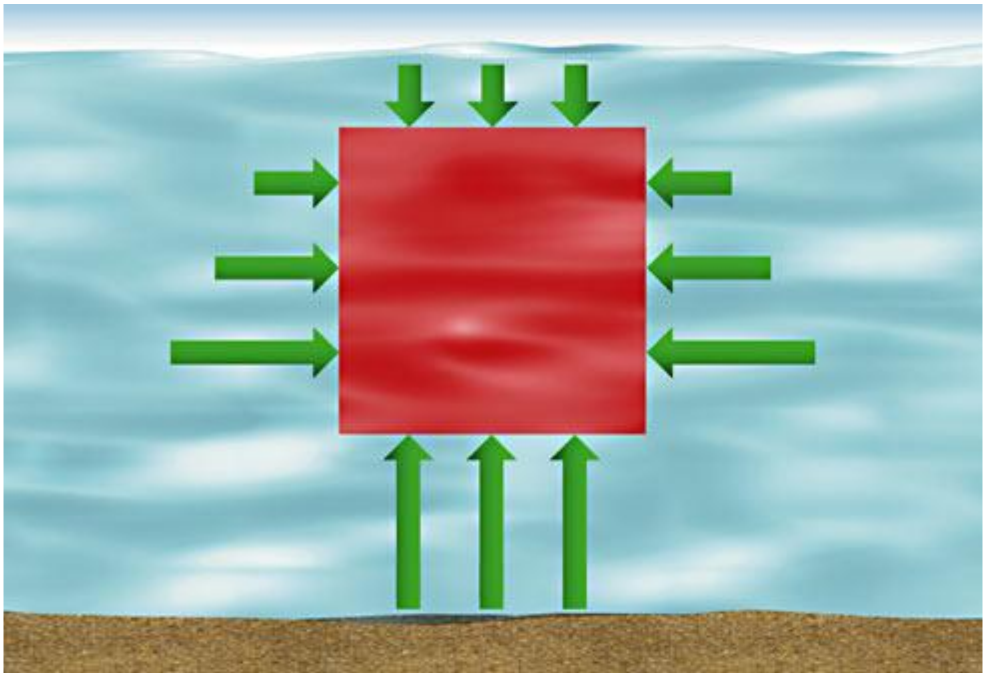

Figure 1 There is more pressure at the bottom of an object because pressure increases with depth. This difference in pressure results in an upward buoyant force on the object.

Standards Check Why is the pressure at the bottom of an object in a fluid greater than the pressure at the top of the object?

Determining Buoyant Force

Archimedes (AHR kuh MEE DEEZ) was a Greek mathematician who lived in the third century BCE. He discovered how to find buoyant force. **Archimedes' principle** states that the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid that the object takes the place of, or *displaces*. Suppose the block in **Figure 2** displaces 250 mL of water. The weight of 250 mL of water is about 2.5 N. The weight of the displaced water is equal to the buoyant force acting on the block. So, the buoyant force on the block is 2.5 N. Notice that you need to know only the weight of the water that is displaced to find the buoyant force. You do not need to know the weight of the block. But in order to predict if an object will float or sink, you need to consider the weights of both the displaced water and the object.

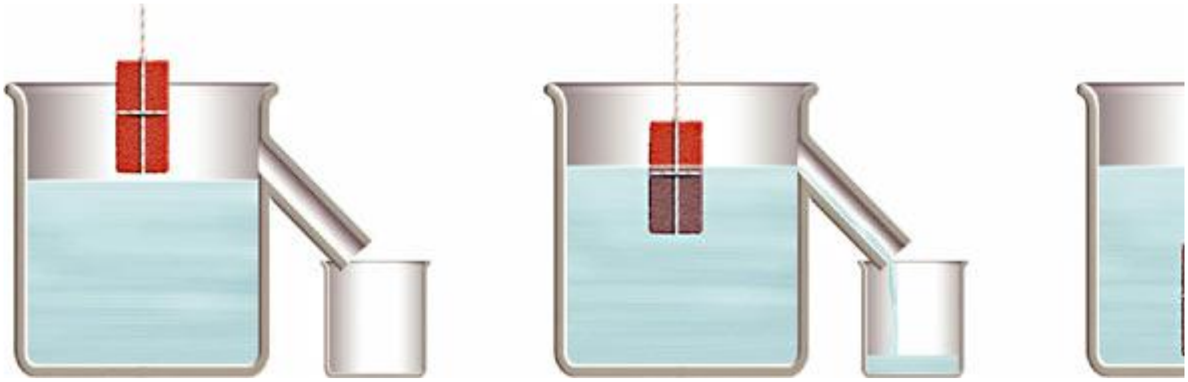

Figure 2 As a block is lowered into a container of water, the block displaces a certain volume of water. Then, this same volume of water flows into a smaller container. **What does the weight of displaced water in the smaller container represent?**

Standards Check Explain how displacement is used to determine buoyant force.

Weight Versus Buoyant Force

An object in a fluid will sink if the object's weight is greater than the buoyant force (the weight of the fluid that the object displaces). An object floats only when the buoyant force on the object is equal to the object's weight.

Sinking

The rock in **Figure 3** weighs 75 N. It displaces 5 L of water. Archimedes' principle states that the buoyant force is equal to the weight of the displaced water—about 50 N. The rock's weight is greater than the buoyant force. So, the rock sinks.

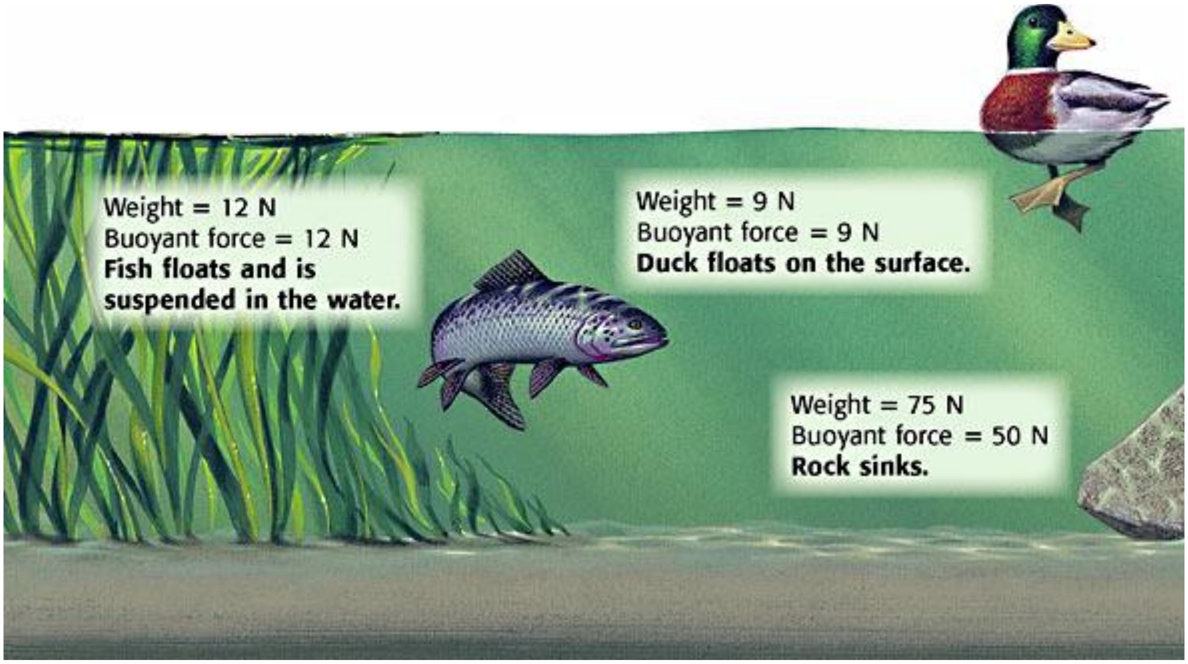

Figure 3 Will an object sink or float? The answer depends on the amount of buoyant force in relation to the object's weight.

Floating

The fish in **Figure 3** weighs 12 N. It displaces a volume of water that weighs 12 N. Because the fish's weight is equal to the buoyant force, the fish floats in the water. In fact, the fish is suspended in the water as it floats.

Now, look at the duck. The duck weighs 9 N. The duck floats. So, the buoyant force on the duck must equal 9 N. But only part of the duck has to be below the surface to displace 9 N of water. So, the duck floats on the surface of the water.

Buoying Up

If it dives underwater, the duck will displace more than 9 N of water. So, the buoyant force on the duck will be greater than the duck's weight. When the buoyant force on the duck is greater than the duck's weight, the duck is *buoyed up* (pushed rup). An object is buoyed up until the part of the object underwater displaces an amount of water that equals the object's entire weight. Thus, an ice cube pops to the surface when it is pushed to the bottom of a glass of water.

Standards Check What causes an object to buoy up?

Density and Floating

Think again about the rock in the lake. The rock displaces 5 L of water. But volumes of solids are measured in cubic centimeters (cm^3). Because 1 mL is equal to 1 cm^3, the volume of the rock is 5,000 cm^3. But 5,000 cm^3 of rock weighs more than an equal volume of water. So, the rock sinks. Because mass is proportional to weight, you can say that the rock has more mass per volume than water has. Mass per unit volume is density. The rock sinks because it is denser than water. The duck floats because it is less dense than water is. The density of the fish is equal to the density of the water.

Standards Check Explain why volume and mass affect whether an object will sink or float in water.

More Dense Than Air

Why does an ice cube float on water but not in air? An ice cube floats on water because ice is less dense than water. But most substances are *more* dense than air. So, there are few substances that float in air. An ice cube is more dense than air, so ice doesn't float in air.

Less Dense Than Air

One substance that is less dense than air is helium, a gas. In fact, helium has one-seventh the density of air under normal conditions. So, helium floats in air. Because it floats in air, helium is used in parade balloons, such as the one shown in **Figure 4.**

Figure 4 Helium in a balloon floats in air for the same reason that an ice cube floats on water: the helium is less dense than the surrounding fluid.

Determining Density

To determine the density of an object, you need to know the object’s mass and volume. You can use a balance to measure the mass of an object. But finding the volume of the object takes a little more work.

Volume of a Regular Solid

Some solids, such as cubes or rectangular blocks, have regular shapes. To find the volume of one of these objects, use a ruler to measure the length of each side. Then, multiply the three lengths together to find the volume of the object.

Volume of an Irregular Solid

Many things do not have a regular shape. So, you cannot easily calculate the volume of these objects. Instead, you can find the volume through water displacement. By measuring the volume of water that the object pushes aside, you find the volume of the object itself.

Standards Check Compare the methods for finding the volume of a regular solid and the volume of an irregular solid.

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Changing Overall Density

Steel is almost 8 times denser than water. Yet huge steel ships cruise the oceans with ease. But hold on! You just learned that substances that are denser than water will sink in water. So, how does a steel ship float?

Changing the Shape

The secret of how a ship floats is in the shape of the ship, as shown in **Figure 5**. What if a ship were just a big block of steel? If you put that block into water, the block would sink because it is denser than water. So, ships are built with a hollow shape. Imagine that the amount of steel in the ship is equal to the amount in the block. The hollow shape increases the volume of the ship. Remember that density is mass per unit volume. As volume increases, density decreases if the mass stays the same. So, an increase in the ship’s volume leads to a decrease in the ship’s density. Thus, ships made of steel float because their *overall density* is less than the density of water.

Figure 5 A block of steel is denser than water, so the block sinks. But shaping that block of steel into a hollow form results in less overall density. So, the ship floats.

Most ships are built to displace more water than is necessary for the ships to float. Ships are made this way so that they will not sink when people and cargo are loaded on the ships.

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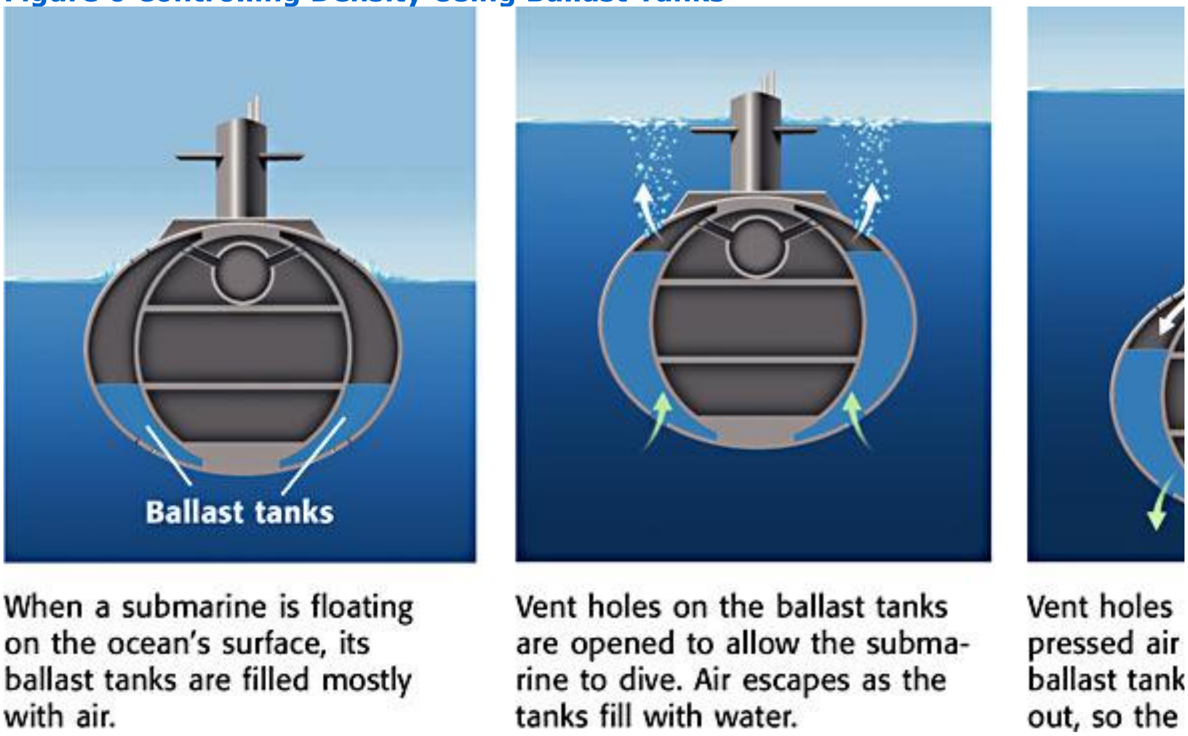
Changing the Mass

A submarine is a special kind of ship that can travel both on the surface of the water and underwater. Submarines have *ballast tanks* that can be opened to allow sea water to flow in. As water is added, the submarine's mass increases, but its volume stays the same. The submarine's overall density increases so that it can dive under the surface. Crew members control the amount of water taken in. In this way, they control how dense the submarine is and how deep it dives. Compressed air is used to blow the water out of the tanks so that the submarine can rise. Study **Figure 6** to learn how ballast tanks work.

Figure 6 Controlling Density Using Ballast Tanks



Changing the Volume

Like a submarine, some fish adjust their overall density to stay at a certain depth in the water. Most bony fishes have an organ called a *swim bladder,* shown in **Figure 7.** This swim bladder is filled with gases that are produced in a fish's blood. The inflated swim bladder increases the fish's volume, which decreases the fish's overall density. Thus, the fish does not sink in the water. The fish's nervous system controls the amount of gas in the bladder. Some fish, such as sharks, do not have a swim bladder. These fish must swim constantly to keep from sinking.

Figure 7 Most bony fishes have an organ called a swim bladder that allows them to adjust their overall density.

Standards Check How does a swim bladder enable a fish to float?

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Section Summary

- All fluids exert an upward force called *buoyant force*.
- Buoyant force is caused by differences in fluid pressure.
- Archimedes’ principle states that the buoyant force on an object is equal to the weight of the fluid displaced by the object.
- Any object that is denser than the surrounding fluid will sink. An object that is less dense than the surrounding fluid will float.
- The overall density of an object can be changed by changing the object’s shape, mass, or volume.

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Chapter Summary

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The Big Idea

Forces in fluids are related to pressure and density and can affect the motion of objects in the fluid.

Section 1
Fluids and Pressure

Key Concept Fluid is a nonsolid state of matter. All fluids can flow and exert pressure evenly in all directions.

- Pressure is the amount of force exerted on a given area.
- Fluid pressure increases as depth increases.
- Density is mass per unit volume. Because water is denser than air, water exerts more pressure than air does.
- Fluids flow from areas of high pressure to areas of low pressure.

Section 2
Buoyancy and Density

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- The buoyant force on an object is equal to the weight of the fluid displaced by the object.
- An object will float or sink depending on the relationship between the object’s weight, buoyant force, and overall density.
- Density can be calculated from measurements of mass and volume. The overall density of an object can be changed by changing the object’s shape, mass, or volume.

Submarines adjust their overall density by using ballast tanks. This change in density allows them to sink or float.

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