Chapter 4

Density and Buoyancy

Will it float or will it sink? If you are designing ships this is a very important question. The largest ship in the world is the *Jahre Viking*, an oil-carrying tanker. This super-sized ship is 1,504 feet long and 264 feet wide, longer than 5 football fields laid end-to-end. If the Empire State building was laid on its side, the Jahre Viking would be longer by 253 feet! Crew members use bicycles to get from place to place on the ship. The ship is too large to fit through the Panama or Suez Canal, and it cannot dock in many of the world's seaports. The Jahre Viking is largely constructed of steel – so how can a big, heavy ship like this actually float? By the time you finish studying this chapter on density and buoyancy, you will be able to explain how ships and boats of all shapes and sizes can float.

Key Questions

1. ***What is density and how can you measure it?***
2. ***What two things does density depend on?***
3. ***How does a steel ship float, when a steel marble sinks?***

4.1 Density

When you think about the many kinds of matter you come into contact with every day, what properties come to mind? Some matter is solid and hard, like steel and wood. Some matter is liquid like water, or a gas like air. And in the category of solid matter, there are big differences. A block of wood and a block of steel may be the same size but one has a lot more mass than the other. Because of that difference in mass, wood floats in water and steel sinks. Whether an object floats or sinks in water is related to its density. This chapter will explain density, a property of all matter.

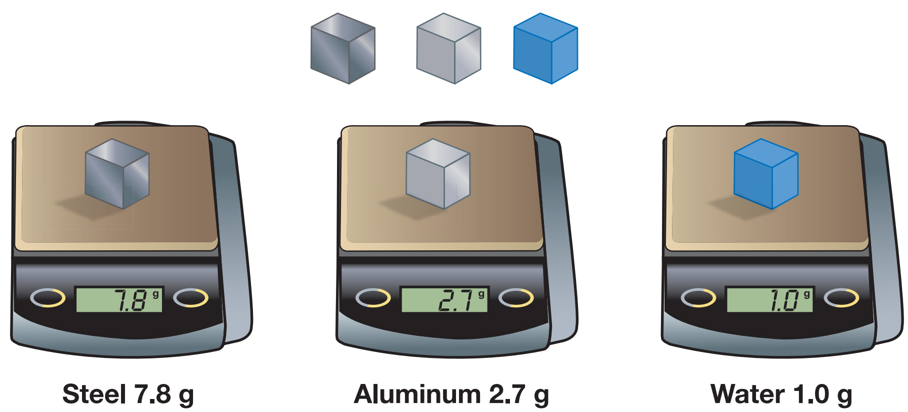
VOCABULARY

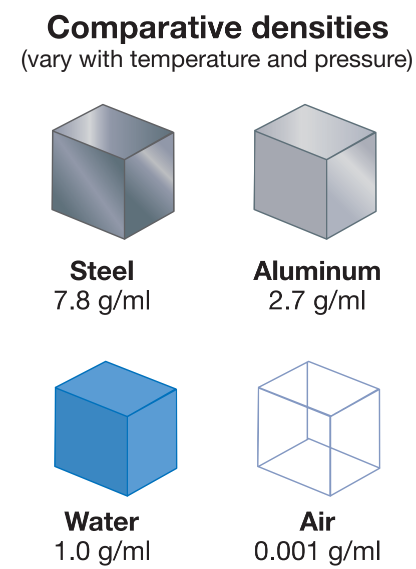
density - the mass of matter per unit volume; density is typically expressed in units of grams per milliliter (g/mL), grams per cubic centimeter (g/cm^3), or kilograms per cubic meter (kg/m^3).

Density is a property of matter

Density is mass per unit volume

Density describes how much mass is in a given volume of a material. Steel has high density; it contains 7.8 grams of mass per cubic centimeter. Aluminum, as you well might predict, has a lower density; a one-centimeter cube has a mass of only 2.7 grams.





The density of water and air

Liquids and gases are matter and have density. The density of water is about one gram per cubic centimeter. The density of air is lower, of course — much lower. The air in your classroom has a density of about 0.001 grams per cubic centimeter.

Figure 4.1: *The density of steel, aluminum, water, and air expressed in different units.*

Units of density

Density in units of grams per milliliter

Your laboratory investigations will typically use density in units of grams per milliliter (g/mL). The density of water is one gram per milliliter. That means one milliliter of water has a mass of one gram, and 100 milliliters of water a mass of 100 grams.

Density in g/cm^3 and kg/m^3

Some problems use density in units of grams per cubic centimeter (g/cm^3). Since one milliliter is exactly the same volume as one cubic centimeter, the units of g/cm^3 and g/mL are actually the same. For applications using large objects, it is more convenient to use density in units of kilograms per cubic meter (kg/m^3). Table 4.1 gives the densities of some common substances in both units.

Converting units of density

To convert from one to the other, remember that 1 g/cm^3 is equal to 1000 kg/m^3. To go from g/cm^3 to kg/m^3 you multiply by 1,000. For example, the density of ice is 0.92 g/cm^3. This is the same as 920 kg/m^3.

To go from kg/m^3 to g/cm^3 you divide by 1,000. For example, the density of aluminum is 2,700 kg/m^3. Dividing by 1,000 gives a density of 2.7 g/cm^3.

Convert between units of density

A reference book lists the density of ceramic tile as 2,650 kg/m^3. Estimate the mass of one cubic centimeter of tile.

1. Looking for: Mass of 1 cm^3, which is the density in g/cm^3
2. Given: Density of 2,650 kg/m^3
3. Relationships: 1 g/cm^3 = 1,000 kg/m^3
4. Solution: Divide by 1,000 to get the density in g/cm^3.
   2,650 ÷ 1,000 = 2.65 g

Your turn...

a. A bronze statue has a density of 6,000 kg/m^3. What is the density in g/mL?
   Answer: 6 g/mL

Table 4.1: Densities of common substances

Material	(kg/m^3)	(g/cm^3)
Platinum	21,500	21.5
Lead	11,300	11.3
Steel	7,800	7.8
Titanium	4,500	4.5
Aluminum	2,700	2.7
Glass	2,700	2.7
Granite	2,600	2.6
Concrete	2,300	2.3
Plastic	2,000	2.0
Rubber	1,200	1.2
Liquid water	1,000	1.0
Ice	920	0.92
Oak (wood)	600	0.60
Pine (wood)	440	0.44
Cork	120	0.12
Air (avg.)	0.9	0.0009

Figure 4.2: *The densities of some common materials.*

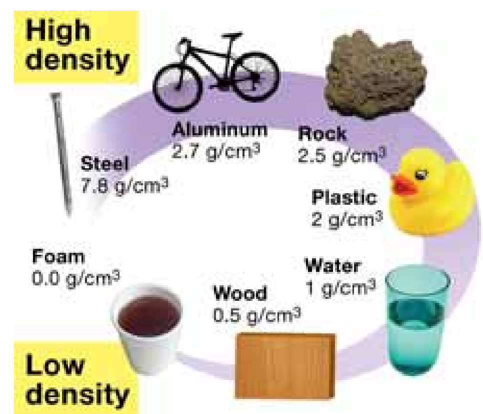


Figure 4.3: *The density range of common materials.*

Solving problems

A four-step technique

The method for solving problems has four steps. Follow these steps and you will be able to see a way to the answer most of the time and will at least make progress toward the answer almost every time. There is often more than one way to solve a problem. Sometimes you will have to use creativity to work with the given information to find the answer. Figure 4.4 shows the steps for solving problems.

Solved example problems are provided

Throughout this book you will find example problems that have been solved for you. Following each solved example, there are often practice problems. The answers to the practice problems are provided so that you can check your work while practicing your problem-solving skills. Always remember to write out the steps when you are solving problems on your own. If you make a mistake, you will be able to look at your work and figure out where you went wrong. Here is the format for example problems:

Calculating density

A wax candle has a volume of 1,000 ml. The candle has a mass of 1.4 kg (1,400 g). What is the density of the candle?

1. Looking for:	You are asked for the density.
2. Given:	You are given the mass and volume.
3. Relationships:	Density is mass divided by volume:
4. Solution:	density = (1,400 g) ÷ (1,000 ml) = 1.4 g/ml

Physics problems

Problem solving is important in all careers. For example, financial analysts are expected to look at information about businesses and figure out which companies are succeeding. Doctors collect information about patients and must figure out what is causing pain or an illness. Mechanics gather information about a car and have to figure out how to fix the engine. All these examples use problem-solving skills.

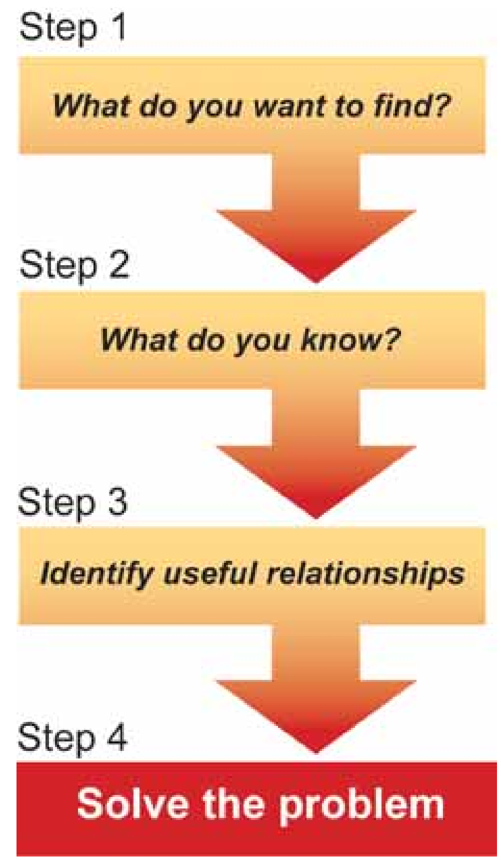


Figure 4.4: *Follow these steps and you will be able to see a way to the answer most of the time.*

Density of common materials

Material density is independent of shape

Density is a property of material independent of quantity or shape. For example, a steel nail and a steel cube have different amounts of matter and therefore different masses (Figure 4.5). They also have different volumes. However, if you calculate density by dividing mass by volume, the result is the same for both the nail and the cube.

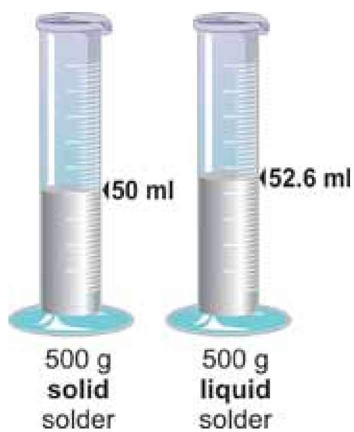
Strong solids typically have higher density

Solids that are strong, such as steel, typically have high density. High density means there are many atoms per cubic centimeter. Many atoms in a material means many bonds between atoms, and those bonds are what ultimately create strength. There are exceptions, however. Lead is very dense but not very strong because the bonds between lead atoms are relatively weak.

Soft materials typically have lower density

Solids with low density, such as cork or foam, are often used as cushioning material. Low density means there are relatively large spaces between atoms. That means materials may be compressed relatively easily, which is why foam and other low-density substances make good packing materials.

Liquids tend to be less dense than solids of the same material



The density of a liquid is usually close to solid density, surprisingly enough, but less. For example, the density of solder is 10 g/ml. The density of liquid solder is 9.5 g/ml. The liquid density is lower because the atoms are not packed as uniformly as they are in the solid. Picture a brand-new box of toy blocks. When you open the box, you see the blocks tightly packed in a repeating pattern, like the atoms in a solid. Now imagine dumping the blocks out of the box, and then trying to pour them back into the original tight packing pattern. The jumbled blocks take up more space, like the atoms in a liquid. Water is an exception to this rule. The density of solid water, or ice, is *less* than the density of liquid water.

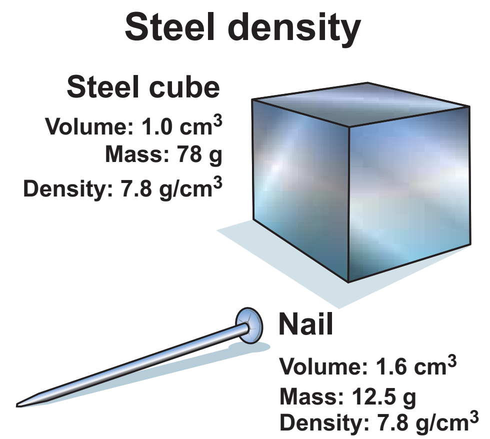


Figure 4.5: *The density of a steel nail is the same as the density of a solid cube of steel.*

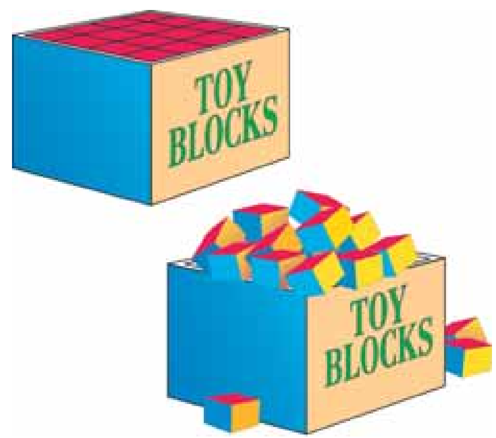


Figure 4.6: *The same number (or mass) of blocks arranged in a tight, repeating pattern take up less space than when they are jumbled up.*

Volume

Volume Volume is the amount of space an object takes up. The units used to measure volume depend on whether the object is solid or liquid. The volume of solids is measured in cubic centimeters (cm^3) or cubic meters (m^3). The volume of liquids is measured in milliliters (mL) or liters (L). One cubic centimeter is the same volume as one milliliter.

Measuring the volume of liquids Measuring the volume of liquids is easy. Pour the liquid into a marked container called a *graduated cylinder* and read the volume. There are two things to keep in mind to measure accurately. First, read the mark at eye level. Second, you will notice that the surface of the liquid forms a curve rather than a straight line (Figure 4.7). This curve is called the meniscus. Read the volume at the center of the meniscus.

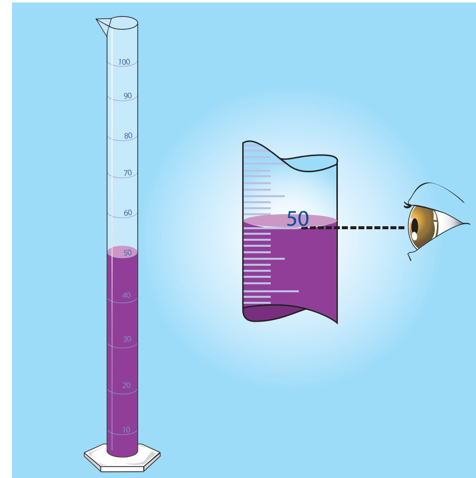


Figure 4.7: *The meniscus of water has a concave shape. Read the mark at the bottom of the curve.*

Volume of solids You have probably already learned to measure the volume of some solid shapes. The volume of a rectangular solid (a shoebox shape), for example, is found by multiplying length times width times height. The volume of a sphere is $4/3\pi r^3$, with r equal to the radius of the sphere.

The displacement method You can find the volume of an irregular shape using a technique called displacement. To displace means to "take the place of" or to "push aside." You can find the volume of an irregularly shaped object by putting it in water and measuring the amount of water displaced.

How you make the measurement You can use the displacement method to find the volume of an ordinary item like a house key. Fill a 100-milliliter graduated cylinder with 50 mL of water (Figure 4.7). Gently slide the key into the water. The water level in the container will rise, because the key displaced, or pushed aside, some water. If the level now reads 53.0 mL, you know that the key displaced 3.0 mL of water. The volume of the key, or of any object you measured in this way, is equal to the volume of the water it displaced. The key has a volume of 3.0 milliliters, or 3.0 cubic centimeters (cm^3).

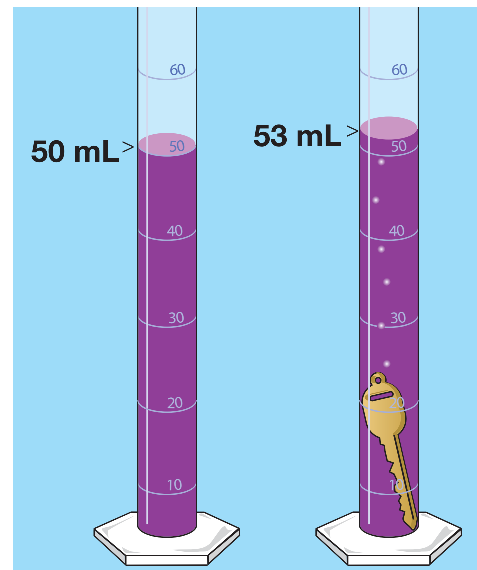


Figure 4.8: *The key displaced 3.0 milliliters of water.*

Determining density

Measuring density

To find the density of a material, you need to know the mass and volume of a solid sample of the material. You can calculate the density from the formula below.

DENSITY

$$\underset{(\text{kg/m}^3 \text{ or g/cm}^3)}{\textit{Density}} \longrightarrow D = \frac{m}{V} \begin{array}{l} \longleftarrow \textit{Mass} \text{ (kg or g)} \\ \longleftarrow \textit{Volume} \text{ (m}^3 \text{ or cm}^3\text{)} \end{array}$$

Mass is measured with a balance or scale. For irregular objects (Figure 4.10) the displacement method can be used to find the volume.

Calculating volume

For simple shapes you can calculate the volume. The volume of spheres, cylinders, and rectangular solids is given in the diagram in Figure 4.9. When calculating volume, all of the units of length involved in the calculation must be the same. For example, if you want volume in cubic centimeters, all of the measurements in the calculation must be in centimeters.

Calculate density from mass and volume

A student measures the mass of five steel nuts to be 96.2 grams. The nuts displace 13 mL of water. Calculate the density of the steel in the nuts.

1. Looking for: Density
2. Given: Mass (96.2 g) and volume (13 mL)
3. Relationships: Density = mass ÷ volume
4. Solution: D = 96.2g ÷ 13 mL = 7.4 g/mL

Your turn...

a. A solid brass block measures 2 cm × 2 cm × 3 cm and has a mass of 48 g. What is its density? **Answer**: 4 g/cm^3

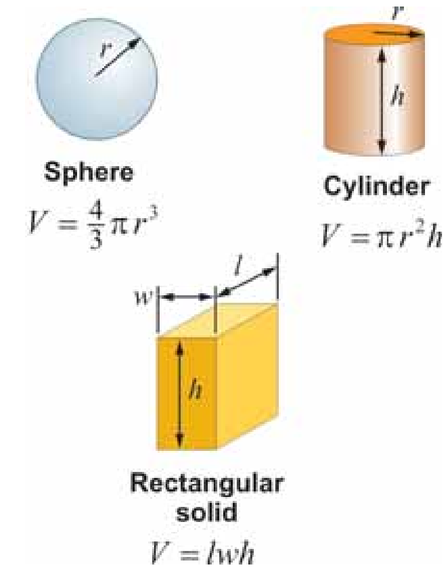


Figure 4.9: *The volume of some simple geometric shapes.*

Figure 4.10: *Use the displacement method to find the volume of irregular objects. Use a scale to find the mass.*

Why density varies

Atoms have different masses

The density of a material depends on two things. First is the individual mass of each atom or molecule. Solid lead is denser than solid aluminum mostly because a single atom of lead has 7.7 times more mass than a single aluminum atom.

Atoms may be "packed" tightly or loosely

Second, density depends on how tightly the atoms are packed. A diamond is made of carbon atoms and has a density of 3,500 kg/m^3. The carbon atoms in diamonds are closely packed. Paraffin wax is mostly carbon, but the density of paraffin is only 870 kg/m^3. The density of paraffin is low because the carbon atoms are mixed with hydrogen atoms in long molecules that take up a lot of space.

Solving density problems

Density problems usually ask you to find one of the three variables (mass, volume, density), given the other two. Figure 4.12 shows three forms of the density equation you can use. Which one you choose depends on what you are asked to find.

Using the density equation

A 4,500-gram cube of titanium is 10 centimeters on each side. Calculate its volume in cm^3, and then calculate its density in g/cm^3.

1. Looking for: You are looking for the volume of a solid and its density.
2. Given: You are given the size and mass.
3. *Relationships:* V = *length x width x height* $\quad D = m/V$
4. Solution: V = 10 cm x 10 cm x 10 cm = 1,000 cm^3
   D = 4,500 g ÷ 1,000 cm^3 = 4.5 g/cm^3

Your turn...

a. Calculate the volume and density of a block that has the dimensions 10 cm x 5 cm x 4 cm and a mass of 400 grams. **Answer:** 200 cm^3**,** 2 g/cm^3

b. A 6-gram marble put in a graduated cylinder raises the water from 30 mL to 32 mL. Calculate the marble's volume and density. **Answer:** 2 cm^3**,** 3 g/cm^3

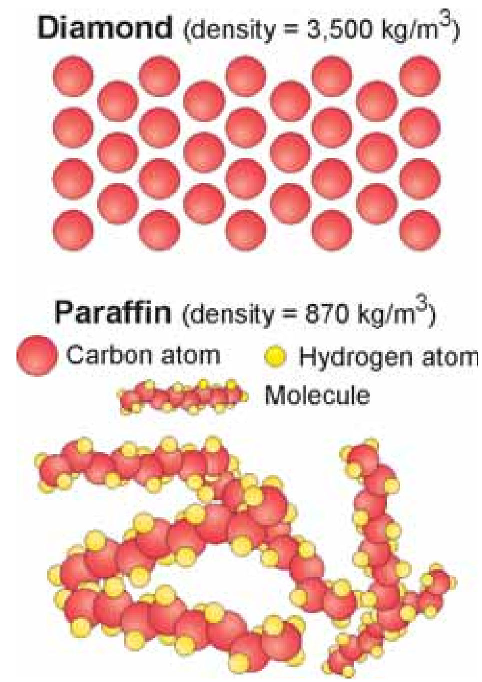


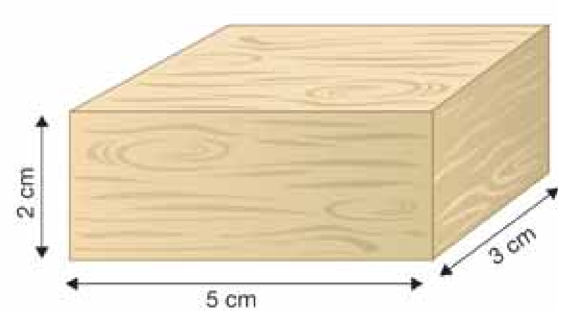
Figure 4.11: *The carbon atoms in diamonds are packed tightly while the carbon atoms in paraffin are not.*

Use. . .	. . . if you know . . .	. . . and want to find . . .
$D = m \div V$	mass and volume	density
$m = D \times V$	volume and density	mass
$V = m \div D$	mass and density	volume

Figure 4.12: *Relationships to use when solving density problems.*

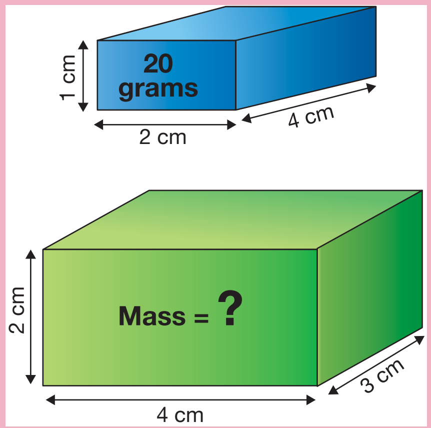
4.1 Section Review

1. List three physical properties of a piece of wood.
2. One cubic centimeter is the same volume as one _______.
3. Explain two ways to find the volume of a plastic cube.
4. A certain material has a density of 0.2 g/mL. Is this material good for building a bridge or for making cushions for a couch?
5. The density of a gas is lower than the density of a liquid because:
   a. gas atoms are smaller than liquid atoms.
   b. gas atoms are larger than liquid atoms
   c. atoms in a gas are farther apart than atoms in a liquid.
   d. atoms in a gas are closer together than atoms in a liquid
6. Density is a _______ property of matter.
7. Density is the _______ per unit volume of a substance.
8. What measurements must be known in order to find the density of a substance?



9. The piece of wood shown above has a mass of 18 grams. Calculate it volume and density. Then use the table in Figure 4.2 to determine which type of wood it is. What are the two factors that determine a material's density?

CHALLENGE



Two toy blocks are made of the same type of material. One has a mass of 20 grams and its dimensions are 2 centimeters x 4 centimeters x 1 centimeter. The other is 4 cm x 3 cm x 2 cm. Calculate the mass of the second block.

4.2 Buoyancy

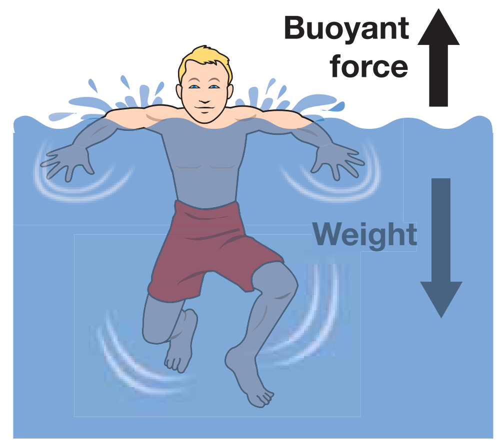


Figure 4.13: *The water in the pool exerts an upward force on your body, so the net force on you is lessened.*

VOCABULARY

weight - the downward force of gravity acting on mass.

buoyancy - the measure of the upward force a fluid exerts on an object that is submerged.

If you drop a steel marble into a glass of water, it sinks to the bottom. The steel does not float because it has a greater density than the water. And yet many ships are made of steel. How does a steel ship float when a steel marble sinks? The answer has to do with gravity and weight.

Weight and buoyancy

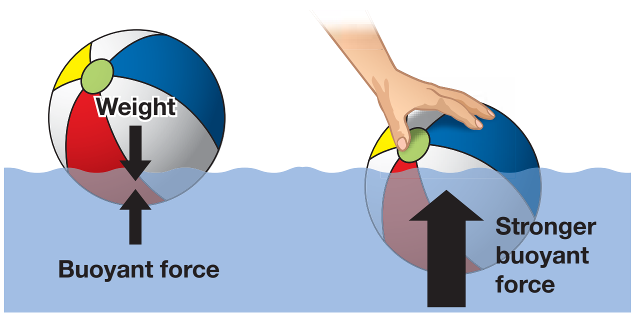
Weight and mass are not the same

We all tend to use the terms *weight* and *mass* interchangeably. In science however, *weight and mass are not the same thing*. Mass is a fundamental property of matter. **Weight** is a force, like any other pushing or pulling force, and is caused by Earth's gravity. It is easy to confuse mass and weight because heavy objects (more weight) have lots of mass and light objects (less weight) have little mass.

Buoyancy is a force

It is much easier to lift yourself in a swimming pool than to lift yourself on land. That is because the water in the pool exerts an upward force on you that acts in a direction opposite to your weight (Figure 4.13). We call this force **buoyancy**. Buoyancy is a measure of the upward force a fluid exerts on an object that is submerged.

Pushing a ball underwater

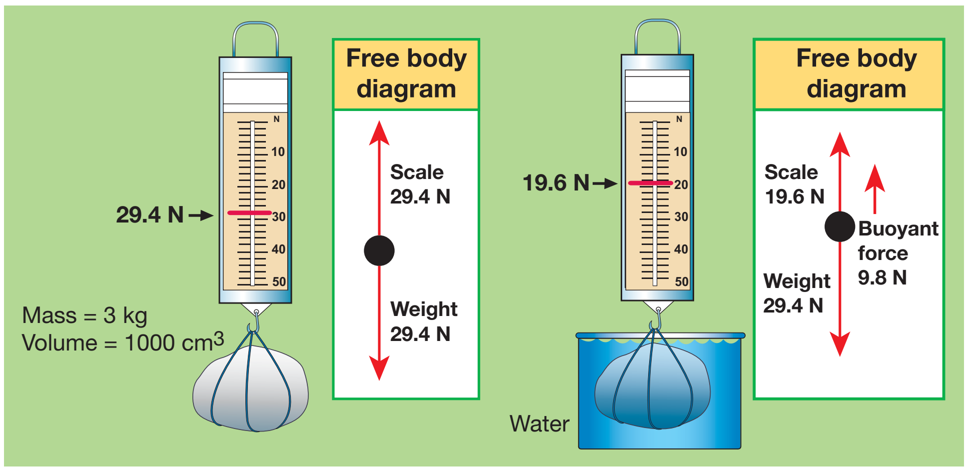


The strength of the buoyant force on an object in water depends on the volume of the object that is underwater. Suppose you have a large beach ball you want to submerge in a pool. As you keep pushing downward on the ball, you notice the buoyant force getting stronger and stronger. The greater the part of the ball you manage to push underwater, the stronger the force trying to push it back up. The strength of the buoyant force is proportional to the volume of the part of the ball that is submerged.

Archimedes' principle

Archimedes' principle

In the third century BC, a Greek mathematician named Archimedes realized that buoyant force is equal to the weight of fluid displaced by an object. We call this relationship **Archimedes' principle**. For example, suppose a rock with a volume of 1,000 cubic centimeters is dropped into water (Figure 4.14). The rock displaces 1,000 cm^3 of water, which has a mass of 1 kilogram. The buoyant force on the rock is the weight of 1 kilogram of water, which is 9.8 newtons.



A simple buoyancy experiment

A simple experiment can be done to measure the buoyant force on a rock (or any object) with a spring scale. Suppose you have a rock with a volume of 1,000 cubic centimeters and a mass of three kilograms. In air, the scale shows the rock's weight as 29.4 newtons. The rock is then gradually immersed in water, but not allowed to touch the bottom or sides of the container. As the rock enters the water, the reading on the scale decreases. When the rock is completely submerged, the scale reads 19.6 newtons.

Calculating the buoyant force

Subtracting the two scale readings, 29.4 newtons and 19.6 newtons, results in a difference of 9.8 newtons. This is the buoyant force exerted on the rock, and it is the same as the weight of the 1,000 cubic centimeters of water the rock displaced.

VOCABULARY

Archimedes' principle - states that the buoyant force is equal to the weight of the fluid displaced by an object.

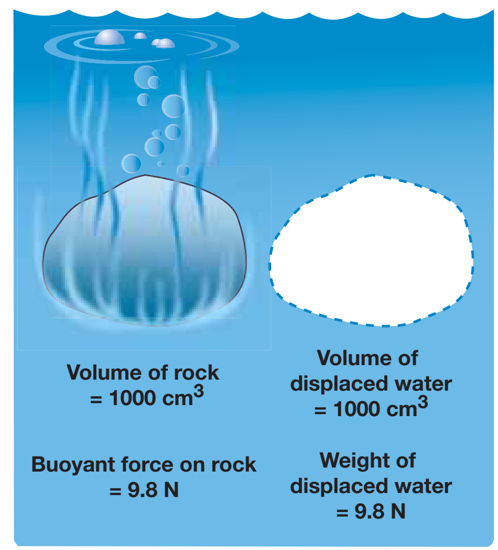
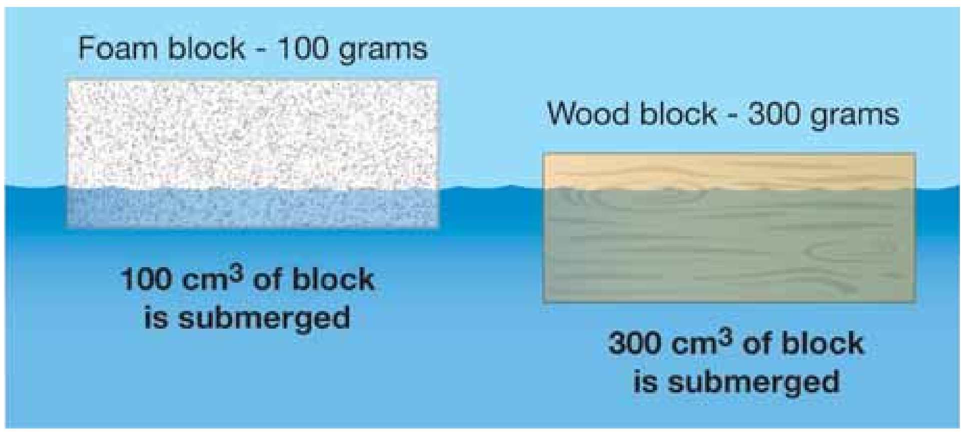


Figure 4.14: *A rock with a volume of 1,000 cm^3 experiences a buoyant force of 9.8 newtons.*

Sinking and floating

Comparing buoyant force and weight Buoyancy explains why some objects sink and others float. A submerged object floats to the surface if the buoyant force is greater than its weight (Figure 4.15). If the buoyant force is less than its weight, then the object sinks.

Equilibrium Suppose you place a block of foam in a tub of water. The block sinks partially below the surface. Then it floats without sinking any farther. The upward buoyant force perfectly balances the downward force of gravity (the block's weight). But how does the buoyant force "know" how strong to be to balance the weight?



Denser objects float lower in the water You can see the answer to this question in the pictures above. If a foam block and a wood block of the same size are both floating, the wood block sinks farther into the water. Wood has a greater density, so the wood block weighs more. A greater buoyant force is needed to balance the wood block's weight, *so the wood block displaces more water*. The foam block has to sink only slightly to displace water with a weight equal to the block's weight. A floating object displaces just enough water to make the buoyant force equal to the object's weight.

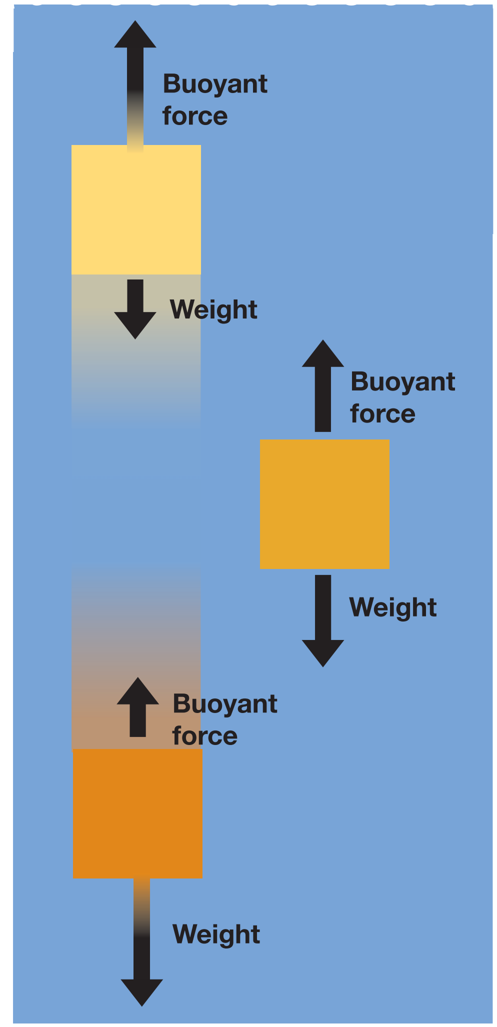


Figure 4.15: *Whether an object sinks or floats depends on how the buoyant force compares with the weight.*

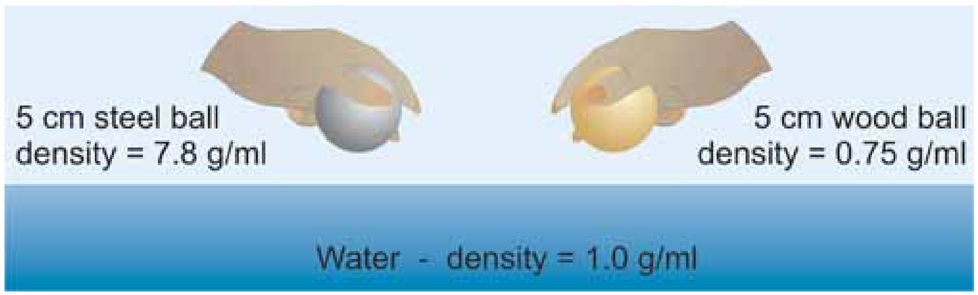
Density and buoyancy

Comparing densities

If you know an object's density, you can immediately predict whether it will sink or float — without measuring its weight. An object sinks if its density is greater than that of the liquid. It floats if its density is less than that of the liquid.

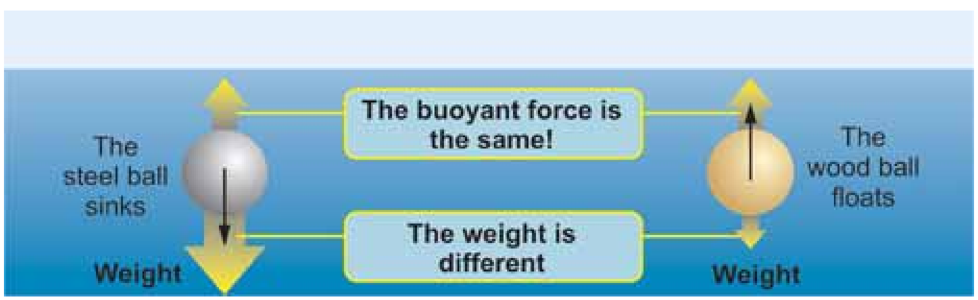
Two balls with the same volume but different density

To see why, picture dropping two balls in a pool of water. The balls have the same size and volume but have different densities. The steel ball has a density of 7.8 g/ml which is greater than the density of water (1.0 g/ml). The wood ball has a density of 0.75 g/ml, which is less than the density of water.



Why one sinks and the other floats

When they are completely underwater, both balls have the same buoyant force because they displace the same volume of water. However, the steel ball has more weight since it has a higher density. The steel ball sinks because steel's higher density makes the ball heavier than the same volume of water. The wood ball floats because wood's lower density makes the wood ball lighter than the same volume of displaced water.



An object with an average density GREATER than the density of water will sink

An object with an average density LESS than the density of water will float.

Average density

Average density is the total mass divided by the total volume.

Figure 4.16: *The meaning of average density.*

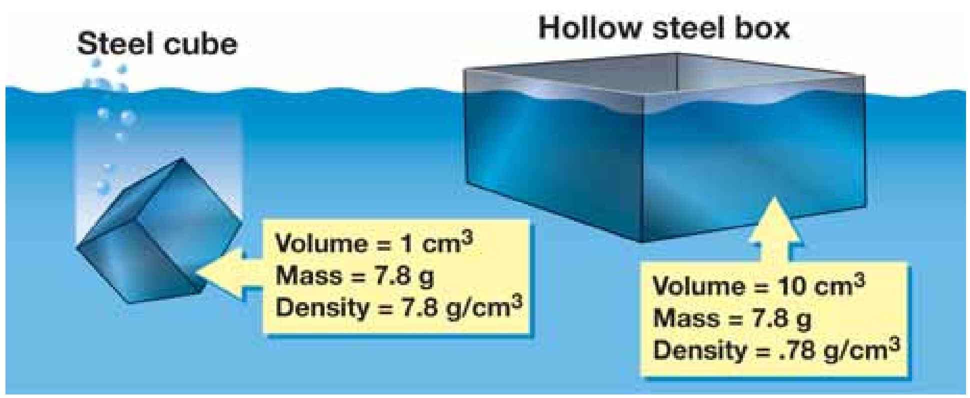
Boats and average density

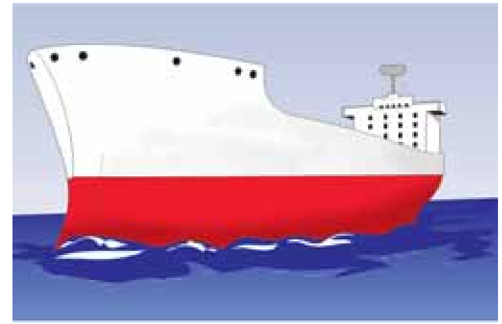
How do steel boats float?

If you place a solid chunk of steel in water, it immediately sinks because the density of steel (7.8 g/cm^3) is much greater than the density of water (1.0 g/cm^3). So how is it that thousands of huge ships made of steel are floating around the world? The answer is that it is the *average density* that determines whether the object sinks or floats.

Solid steel sinks because it is denser than water

To make steel float, you have to reduce the *average* density somehow. Making the steel hollow does exactly that. Making a boat hollow expands its volume a tremendous amount without changing its mass. Steel is so strong that it is quite easy to reduce the average density of a boat to 10 percent of the density of water by making the shell of the boat relatively thin.





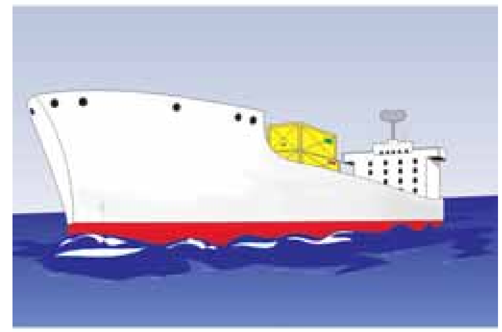


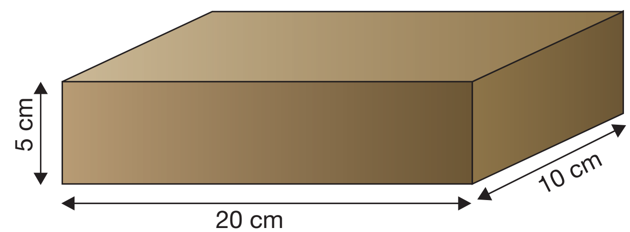
Figure 4.17: *A full ship has more mass than an empty ship. This means a full ship must displace more water (sink deeper) to make the buoyant force large enough to balance the ship's weight.*

Increasing volume decreases density

Ah, you say, but that is an empty ship. True, so the density of a new ship must be designed to be under 1.0 g/cm^3 to allow for cargo. When objects are placed in a boat, of course its average density increases. The boat must sink deeper to displace more water and increase the buoyant force (Figure 4.17). If you have seen a loaded cargo ship, you might have noticed that it sat lower in the water than an unloaded ship nearby. In fact, the limit to how much a ship can carry is set by how low in the water the ship can get before rough seas cause waves to break over the side of the sip.

4.2 Section Review

1. The buoyant force on an object depends on the _______ of the object that is underwater.
2. What happens to the buoyant force on an object as it is lowered into water? Why?
3. The buoyant force on an object is equal to the weight of the water it ________________.
4. When the buoyant force on an object is greater than its weight, the object ___________.



5. A rectangular object is 10 centimeters long, 5 centimeters high, and 20 centimeters wide. Its mass is 800 grams.
   a. Calculate the object’s volume in cubic centimeters.
   b. Calculate the object’s density in g/cm^3.
   c. Will the object float or sink in water? Explain.
6. Solid iron has a density of 7.9 g/cm3. Liquid mercury has a density of 13.6 g/cm^3. Will iron float or sink in mercury? Explain.
7. Why is it incorrect to say that heavy objects sink in water?
8. Steel is denser than water and yet steel ships float. Explain.

CHALLENGE

Legend has it that Archimedes added to his fame by using the concepts of volume and density to figure out whether a goldsmith had cheated Hiero II, the king of Syracuse. The goldsmith had been given a piece of gold of a known weight to make the crown. Hiero suspected the goldsmith had kept some of the gold for himself and replaced it with an equal weight of another metal. Explain the steps you could follow to determine whether or not the crown was pure gold.

PHYSICS CONNECTION

Airships in the Sky

What do televised football, baseball, and auto racing all have in common? You might think of sports, dedicated fans, and athletes. While these similarities are true, one common feature is that blimps provide video coverage for each of these events. Large, oval shaped airships hover over stadiums providing aerial shots of the action. Television cameras attached to the blimp's underside take wide-angle pictures. In addition, blimps provide advertising for major corporations. You have probably seen one in a sports telecast.

Hot air balloons

Anything that flies is an aircraft. In fact, the hot air balloon was the first aircraft invented, dating back to the early 1700s almost 200 years before the Wright brothers tested their first successful powered airplane. A hot air balloon depends on buoyancy forces for lift. Air in the balloon is kept hot by a burner. Hot air has a lower density than cold air. As long as the air inside the balloon is significantly hotter than the air outside, the balloon floats.

The density of air decreases with altitude. A hot air balloon floats upward until its average density matches the average density of the surrounding air. To go up father, the balloon pilot makes the air hotter inside the balloon, decreasing the average density. To go down, the pilot releases some hot air, making the balloon smaller and decreasing its average density.

The problem with hot air balloons is how to steer! With a hot air balloon you can only control motion up or down. The only way to steer is to change your altitude in hopes that the wind will be blowing the way you want to go at *some* altitude. This is all right if you are ballooning for fun. However, the direction of the wind is not reliable enough to use hot air balloons for travel or for shipping.

Blimps

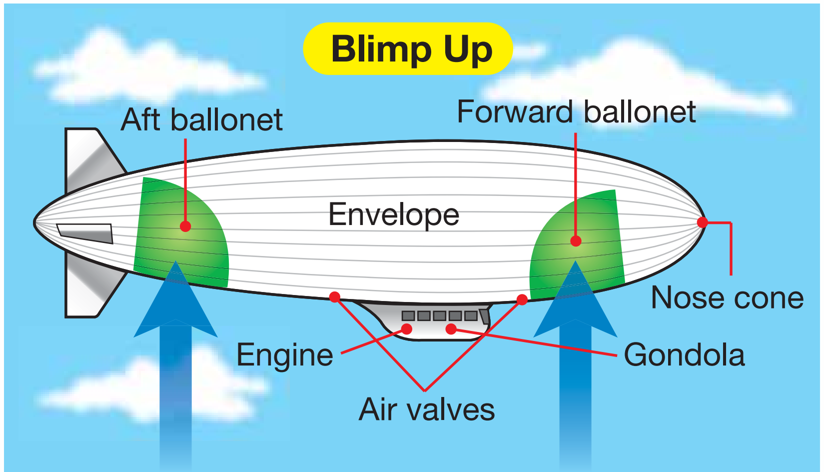
A blimp is a type of *airship*, like a hot air balloon. Like a hot air balloon, a blimp also gets its lift from buoyancy of surrounding air. However, a blimp is filled with helium, a gas that is lighter than air. Unlike a balloon, a blimp keeps its helium gas at the same temperature as the surrounding air.

A blimp has four major parts: the envelope, gondola, engines, and controls. The envelope is the large cavity filled with helium. Made of polyester fabric similar to spacesuits, the envelope is a cigar-shaped, aerodynamic design. The gondola carries passengers and pilots and contains the engines and controls. Gasoline powered engines move blimps an average of 35 miles per hour.

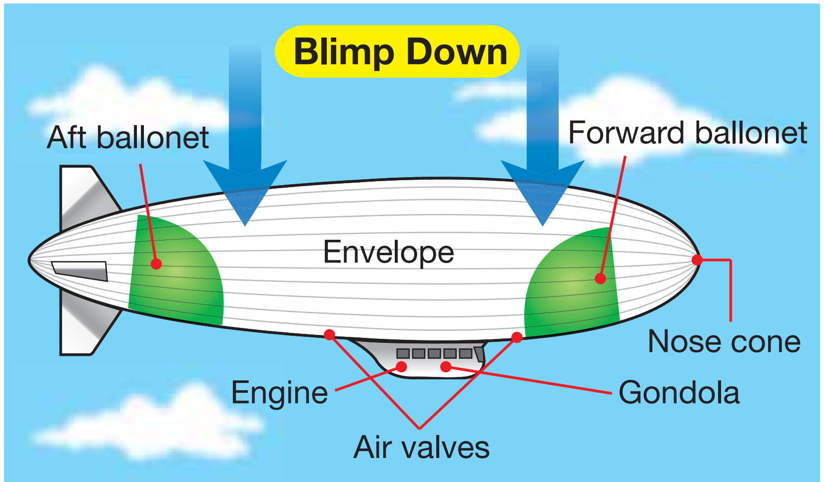
Because the blimp has a motor, it can steer with a rudder, like a boat. Controls allow the pilot to steer the blimp up, down, right, or left. This is a big advantage over a hot air balloon.

Henri Giffard invented the first powered airship in 1852. In 1900, Count Ferdinand von Zeppelin invented the first rigid airship with a metal structure providing its shape. For buoyancy, early blimps used hydrogen. Hydrogen is very light bit also very explosive! In fact, the famous Hindenburg blimp, filled with hydrogen, exploded and burned during an accident in New Jersey in 1937.

Today, blimps are filled with helium instead of hydrogen, and do not have a rigid steel structure. Instead, modern blimps are nothing more than a large, strong, gas balloons. The aerodynamic shape is maintained by keeping the pressure of the helium in the blimp greater than the pressure of the air outside, just like the balloons you get at a party.



1. Air is released from the ballonets through air vents controlled by air valves
2. Ballonets deflate causing the envelope to fill with **HELIUM**
3. Envelope air becomes lighter and less dense
4. Outside air becomes heavier and more dense
5. Positive buoyancy causes blimp to rise



1. Air fills ballonets through air vents controlled by air valves
2. Ballonets inflate causing the envelope to fill with **AIR**
3. Envelope air becomes heavier and denser
4. Outside air becomes lighter and less dense
5. Negative buoyancy causes blimp to descend

Controlling altitude in a blimp

Inside a blimp's envelope there are two compartments called ballonets. These are bags filled with relatively heavy air (not helium). The pilot controls the amount of air in the ballonets through air valves. Since air is heavier than helium, the pilot deflates or inflates the ballonets to make the blimp rise or fall. Changing the proportions of air and helium changes the blimp's average density. Just like a hot air balloon, the blimp rises or falls until its average density matches the surrounding air.

Blimps in science

Today blimps are used for more than just sporting events and advertising. The U.S. Geological Survey has used blimps to fly over volcanoes. A blimp is less likely to be damaged by ash than a helicopter or plane.

Blimps are also used to study whales and their behavior. One research blimp is outfitted with cameras and equipment for tracking whales. Picture taking is much more stable from a blimp than from an airplane. The stability allows cameras with high-power zoom lenses to take highly detailed pictures from far above the ocean surface.

Questions:

1. What is a blimp?
2. What is buoyancy and how does it affect a blimp
3. What are negative, positive, and neutral buoyancy, and how do they affect a blimp?

CHAPTER ACTIVITY

Will it Float or Will it Sink?

Background

Why do some objects sink while other float? During this activity you will predict whether a variety of objects will sink or float. You will then test your predictions and calculate the density of each object. You will look at the relationship between a material's density and its ability to float.

Materials:

Graduated cylinder, balance or scale, plastic cup
An assortment of small objects made of materials such as wood, various types of plastic, foam, steel, glass, cork, and aluminum

What you will do

1. Find the mass of an empty plastic cup. Pour exactly 50 mL (50 cm^3) of water into the cup. Measure the mass of the water and cup together, and subtract to find the mass of the water alone. Record your result in the data table below.

Description of object	Prediction: Sink or float?	Result: Sink or float?	Mass (g)	Volume (cm^3)	Density (g/cm^3)
water	X	X		50	

2. Calculate the density of the water.
3. Select one of the objects that you wish to test. Predict whether it will sink or float. Record your prediction in the data table.
4. Use a balance or scale to record the mass of the object in grams.
5. Fill the graduated cylinder halfway with water. Place the object in the water and observe whether it sinks or floats. Record the result in your data table.
6. Use the displacement method to find the volume of the object in cubic centimeters.
7. Calculate the density of the object in grams per cubic centimeter.
8. Repeat steps 3-7 using the other objects.

Applying your knowledge

a. Explain how you found the volume of the various objects you tested.
b. List the objects in order of density, starting with the least dense material. Circle each object that floats.
c. What is the pattern between the density of an object and the ability of the object to sink or float?
d. Suppose you were to do this experiment using other liquids instead of water. Which of the objects would float in each of the liquids listed below? Explain how you found your answer.

Liquid	Density (g/cm^3)
corn syrup	1.4
mercury	13.6
cooking oil	0.91

Vocabulary

Select the correct term to complete the sentences.

density	buoyancy	Archimedes' principle
weight		

Section 4.1

1. The mass of matter per unit of volume is known as ____.

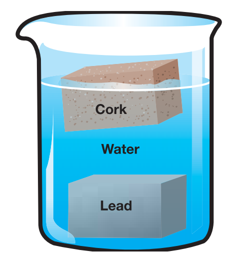
Section 4.2

2. The upward force exerted by a fluid on an object submerged in the fluid is called ____.
3. The idea that the buoyant force exerted on an object is equal to the weight of the fluid displaced by the object is known as ____.
4. The force exerted on an object by the gravity of Earth is called ____.

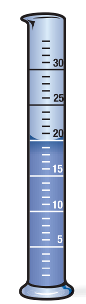
Concepts

Section 4.1

1. Which has a greater weight, 1.0 gram of steel or 1.0 gram of aluminum?
2. Which has a greater density, 1.0 gram of steel or 1.0 kilogram of aluminum?
3. Which has a greater volume, 1.0 gram of steel or 1.0 gram of aluminum?
4. Name three units that can be used to represent density.
5. When comparing solids, liquids, and gases:
   a. Which phase generally has the greatest density?
   b. Which phase has the lowest density?
6. The density of ice is less than the density of water. How does this affect life in a pond over a long, cold winter?
7. Using Table 4.1 on page 75, which material might be used to make an object with a density of 0.60 g/cm^3?
8. A glass block has a density of 2.7 g/cm^3. If the same type of glass was used to make a 2-liter water pitcher, what would be the density of the pitcher?
9. By adding more lead to a bar of lead you:
   a. increase the bar's density.
   b. decrease the bar's density.
   c. do not change the bar's density.
10. If you know the mass and density of a material, how would you find its volume?
11. Based upon the diagram to the right, arrange the three materials, cork, water, and lead in order from most to least dense.



12. A graduated cylinder contains 25 mL of water. An object placed in the cylinder causes the water level to rise to 43 mL. What is the volume of the object?
13. What is the name of the dark, curved "band" at the top of the column of water pictured in the graduated cylinder to the right?



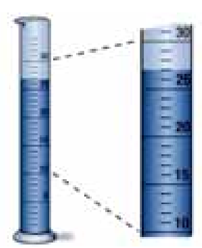
Section 4.2

14. How does the buoyant force of a rock submerged in water compare to the weight of the water displaced by the rock?
15. Why does ice float in a glass of water? Explain in terms of density and buoyancy.
16. What property of an object determines the strength of buoyant force that will be exerted on it when submerged in water?
17. A cargo barge weighs 200,000 N when empty. Cargo weighing 50,000 N is loaded onto the barge. What is the total weight of water displaced by the loaded barge?
18. What is the maximum average density that a fully loaded cargo ship may have?
19. Why do helium balloons float in air? Use the terms *buoyancy* and *density* in your answer.

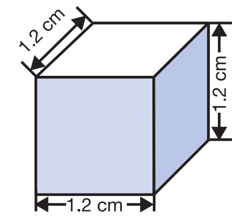
Problems

Section 4.1

1. A piece of granite has a mass of 26 grams. The granite is placed in a graduated cylinder containing 10 mL of water. What is the reading of the water level in the graduated cylinder after the granite is fully submerged? Granite has a density of 2.6 g/cm^3.
2. Convert a density of 123 kg/m^3 to units of g/cm^3.
3. What is the volume of the liquid in the graduated cylinder pictured in the diagram?



4. A rubber ball has a radius of 2.5 cm. The density of rubber is 1.2 g/cm^3.
   a. What is the volume of the ball?
   b. What is the mass of the ball?
5. The density of ice is 0.92 g/cm^3. What is the volume of 1 kg of ice? If that 1 kg of ice completely melted, what would the volume of water be? The density of water is 1 g/cm^3.
6. Your teacher gives you two stainless steel balls. The larger has a mass of 25 grams and a volume of 3.2 cm^3. The smaller has a mass of 10 grams. Calculate the volume of the smaller ball.
7. The cube in the diagram has a mass of 7.8 grams and measures 1.2 centimeters on an edge.
   a. Find the density of the cube. Show your work, including an equation.
   b. Will the cube float in water? Explain.



Section 4.2

8. An object weighing 45 newtons in air is suspended from a spring scale. The spring scale reads 22 newtons when the object is fullly submerged. Calculate the buoyant force on the object.
9. A stone that weighs 6.5 newtons in air weighs only 5.0 newtons when submerged in water. What is the buoyant force exerted on the rock by the water?
10. A 100 mL oak object is placed in water. What volume of water is displaced by the oak object? The density of oak is 0.60 g/cm^3.
11. A 100 mL steel object is placed in water. What volume of water is displaced by the steel object? The density of steel is 7.8 g/cm^3.