Chapter 3, Lesson 1: What is Density?

Key Concepts

- Density is a characteristic property of a substance.
- The density of a substance is the relationship between the mass of the substance and how much space it takes up (volume).
- The mass of atoms, their size, and how they are arranged determine the density of a substance.
- Density equals the mass of the substance divided by its volume; D = m/v.
- Objects with the same volume but different mass have different densities.

Summary

Students will observe a copper and an aluminum cube of the same volume placed on a balance. They will see that the copper has a greater mass. Students will try to develop an explanation, on the molecular level, for how this can be. Students are then given cubes of different materials that all have the same volume. Students determine the density of each cube and identify the substance the cube is made from.

Objective

Students will be able to calculate the density of different cubes and use these values to identify the substance each cube is made of. Students will be able to explain that the size, mass, and arrangement of the atoms or molecules of a substance determines its density.

Evaluation

The activity sheet will serve as the "Evaluate" component of each 5-E lesson plan. The activity sheets are formative assessments of student progress and understanding. A more formal summative assessment is included at the end of each chapter.

Safety

Make sure you and your students wear properly fitting goggles.

Materials for Each Group

- Cubes marked A–H that you will share with other groups
- Balance that can measure in grams
- Calculator

Materials for the Demonstration

- Copper cube and aluminum cube of the same volume
- Balance

Notes about the materials

Cubes
For this lesson, you will need a set of cubes of different materials that are all the same volume. These sets of cubes are available from a variety of suppliers. Flinn Scientific sells a Density Cube Set, Product #AP6058. This set comes with 10 cubes—4 metal, 3 plastic, and 3 wood. It is easier for students if you reduce the number to 8 by using all the samples of metal but only two wood and two plastic cubes. We suggest using the nylon (off-white, least dense) plastic cube and the PVC (gray, most dense) plastic cube. For the wood, we suggest using the oak (darker and most dense) and either the pine or poplar (paler, less dense). In the activity, each group will need to measure the mass of each of the eight cubes. Groups will need to measure and record their data for a cube and pass it along to another group until each group has used each of the cubes.

Balances
Use a simple, plastic, two-sided balance that looks like a see-saw for the demonstration. One of the least expensive is Delta Education, Stackable Balance (21-inch) Product #WW020-0452. Have students use any balance that can measure in grams.

Metric ruler
Students will use a metric ruler in the engage portion of the activity when they measure the length, width, and height of a cube along with you.

About this Lesson
This is the first lesson in which students see models of molecules that are more complex than a water molecule. Some of these molecules may look a little intimidating. Let students know that they do not need to memorize or draw these molecules. For the purpose of this chapter, students only need to think about the size and mass of the atoms that make up the molecule and how they are arranged in the substance.

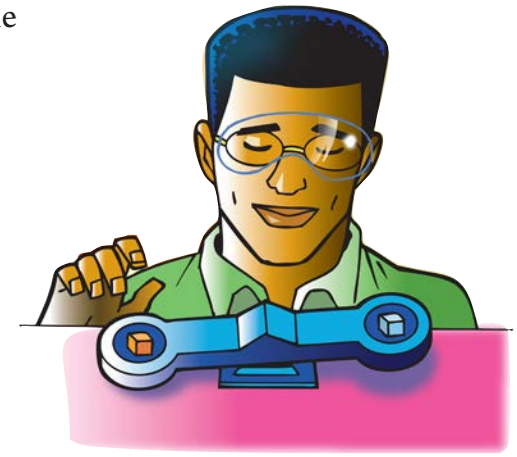
ENGAGE

1. **Do a demonstration to show that cubes of the same volume but made of different metals have different masses.**

Question to investigate
Do cubes of exactly the same size and shape, have the same mass?

Materials for the demonstration

- Copper cube and aluminum cube of the same volume
- Balance



Procedure

Place the copper and aluminum cube on opposite sides of a simple balance.

Expected results

The copper cube will have a greater mass than the aluminum cube.

2. Lead a discussion about why the copper cube has a greater mass than the aluminum cube.

Tell students that both cubes are exactly the same size and both are solid with no hollow spots. Explain that the aluminum cube is made of only aluminum atoms and the copper cube is made of only copper atoms.

Ask students:

- **How can two objects, which are exactly the same size and shape, have a different mass?**

  Help students understand that the difference in mass must have something to do with the atoms in each cube. There are three possible explanations about the copper and aluminum atoms in the cubes that could explain the difference in mass.

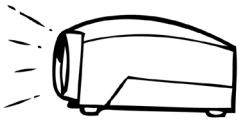
  - Copper atoms might have more mass than aluminum atoms.
  - Copper atoms might be smaller so more can fit in the same volume.
  - Copper and aluminum atoms might be arranged differently so more copper atoms fit in the same size cube.

Explain that any one of these explanations alone, or two or three together, could be the reason why the copper cube has more mass.

Give each student an activity sheet.

Students will record their observations and answer questions about the activity on the activity sheet. The *Explain It with Atoms & Molecules* and *Take It Further* sections of the activity sheet will either be completed as a class, in groups, or individually, depending on your instructions. Look at the teacher version of the activity sheet to find the questions and answers.

3. Project an illustration and use the pictures of the copper and aluminum atoms to introduce the concept of density.

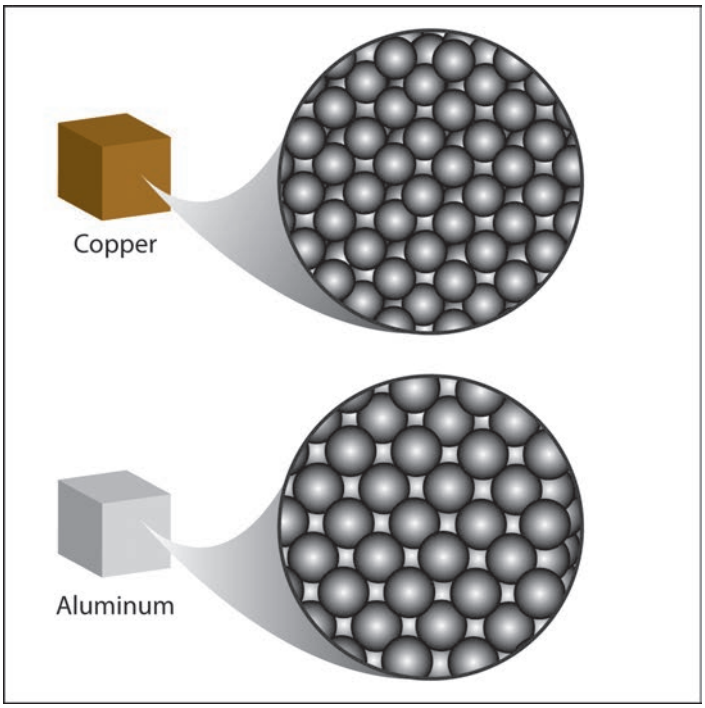


Have students turn to the illustration of copper and aluminum cubes and their atoms on their activity sheet.

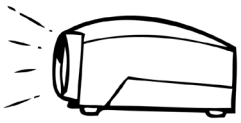
Show students the image *Aluminum and Copper Atoms*
www.middleschoolchemistry.com/chapter3/lesson1#aluminum_and_copper

Point out that the copper atoms are slightly smaller than aluminum atoms. This smaller size means that more copper atoms can fit in the same amount of space. So, the copper cube contains more atoms than the aluminum cube. Although they are smaller, individual copper atoms actually have more mass than individual aluminum atoms. The combination of more atoms, each with a greater mass, makes a copper cube weigh more than an aluminum cube of the same size and shape.

Explain to students that this idea of how heavy something is compared to the amount of space it takes up is called *density*. The density of an object is the mass of the object compared to its volume. The equation for density is: *Density = mass/volume* or $D = m/v$. Each substance has its own characteristic density because of the size, mass, and arrangement of its atoms or molecules.



4. Show animations and demonstrate how to measure volume and mass of a cube.



Explain to students that volume is a measure of the amount of space an object takes up. It is always in three dimensions. To find the volume of an object like a cube or a box, you measure the length, width, and height and then multiply them ($V = l \times w \times h$). If measured in centimeters, the answer will be in cubic centimeters (cm^3).

***Note**: Students often confuse volume and area. Check their understanding to make sure they know the difference. Make sure they understand that area is measured in two dimensions (length × width) with an answer in cm^2. Area is a measure of the amount of surface. But volume is measured in three dimensions (length × width × height) with an answer in cm^3. Volume is a measure of the entire object, including the surface and all the space the object takes up.*

Show the animation *Cube*.
www.middleschoolchemistry.com/chapter3/lesson1#cube
While the animation is playing, you can demonstrate the measuring process with a cube and ruler. Have students measure along with you to confirm the volume of the cubes.

Volume

The cubes are 2.5 centimeters on each side. Show students that in order to calculate the volume, you multiply the length (2.5 cm) × width (2.5 cm) × height (2.5 cm) to get 15.625 cm^3. Rounding this number to 15.6 cm^3 is accurate enough and will make the density calculations easier. Record the volume of the cube in cubic centimeters (cm^3).

Mass

Demonstrate how to use the balance that students will be using to measure the mass of the cube. Record the mass of the cube in grams (g).

Density

Show students how to calculate density by dividing the mass by the volume. Point out that the answer will be in grams per cubic centimeter (g/cm^3).

EXPLORE

5. Have students calculate the density of eight different cubes and use the characteristic property of density to correctly identify them.

Student groups will not need to measure the volume of the cubes. The volume of each cube is the same, 15.6 cm^3, and is given in their chart on the activity sheet. They will need to measure the mass of each of the eight different cubes and calculate their densities. Students will use their values for density to identify each cube.

***Note**: The densities students calculate may not be exactly the same as the given densities in this chart. However, their calculations will be close enough that they should be able to identify most of the cubes.*

Question to investigate
Can you use density to identify eight cubes made of different materials?

Materials for the class
- Set of eight cubes of equal volume
- Calculator

Teacher preparation
Use a piece of masking tape and a permanent marker to mark the eight cubes with the letters A–H.

Materials for each group
- Cubes marked A–H that you will share with other groups
- Balance that can measure in grams
- Calculator

Procedure
1. The volume of each cube is given in the chart. It is 15.6 cm^3.
2. Find the mass in grams of each cube using a scale or balance. Record this mass in the chart.
3. Trade cubes with other groups until you have measured the mass of all eight cubes.
4. Calculate the density using the formula $D = m/v$ and record it in the chart.

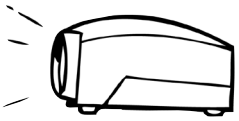
Sample	Volume (cm^3)	Mass (g)	Density (g/cm^3)	Material
A	15.6			
B	15.6			
C	15.6			
D	15.6			
E	15.6			
F	15.6			
G	15.6			
H	15.6			

Material	Approximate density (g/cm^3)
Aluminum	2.9
Brass	8.8
Copper	9.3
Steel	8.2
PVC	1.3
Nylon	1.2
Oak	0.7–0.9
Pine or poplar	0.4–0.6

5. Compare the value you found for density with the given value in the chart below to identify which cube is made out of which material. Write the name of the material in your chart for cubes A–H.

Expected results: Student values for density for each cube will not be exact, but will be close enough that they should be able to identify each of the cubes. You may notice that the approximate densities given for each cube in this lesson are slightly different than those given in the cube set. Most of this difference is probably due to the value for the volume of each cube. Since it is likely that these are 1-inch cubes, each side should be 2.54 cm. We rounded to 2.5 cm because students can make this measurement more easily.

EXPLAIN

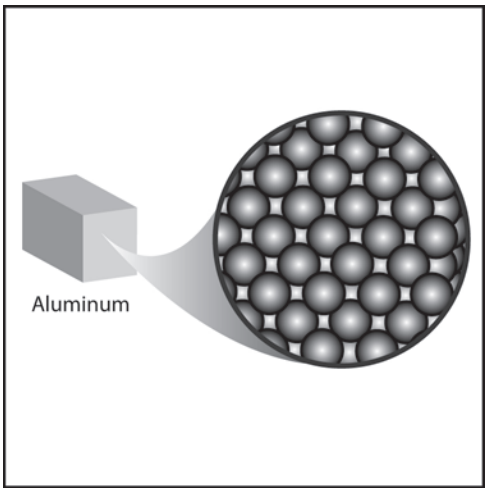


6. Discuss how the mass, size, and arrangement of atoms and molecules affect the densities of metal, plastic, and wood

Explain to students that each substance has its own density because of the atoms and molecules it is made from. The metal, plastic, and wood cubes that students measured each have their own unique density. In general, the density of metal, plastic, and wood can be explained by looking at the size and mass of the atoms and how they are arranged.

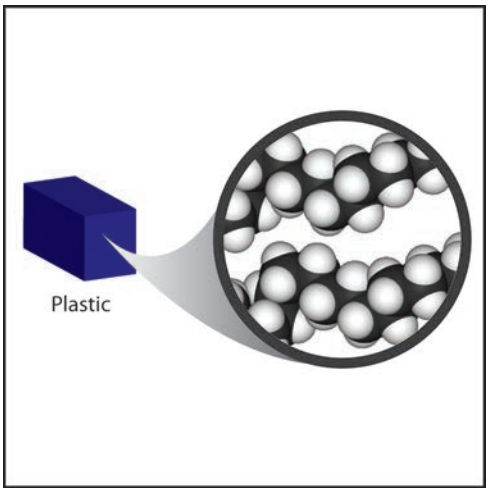
Project the image *Metal.*
www.middleschoolchemistry.com/multimedia/chapter3/lesson1#metal

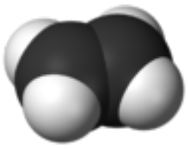
Most common metals like aluminum, copper, and iron are more dense than plastic or wood. The atoms that make up metals are generally heavier than the atoms in plastic and wood and they are packed closer together. The difference in density between different metals is usually bsed on the size and the mass of the atoms but the arrangement of the atoms in most metals is mostly the same.



Project the image *Plastic.*
www.middleschoolchemistry.com/multimedia/chapter3/lesson1#plastic

Most plastics are less dense than metal but can have similar density to wood. Plastics are mde from individual molecules bonded together into long chains called *polymers*. These polymer chains are arranged and pakced together to make the plastic. One common plastic, *polyethylene*, is made up of many individual molecules called *ethylene* which bonded together to make the long polymer chains. Like most plastics, the polymers in polyethylene are made of carbon and hydrogen atoms.



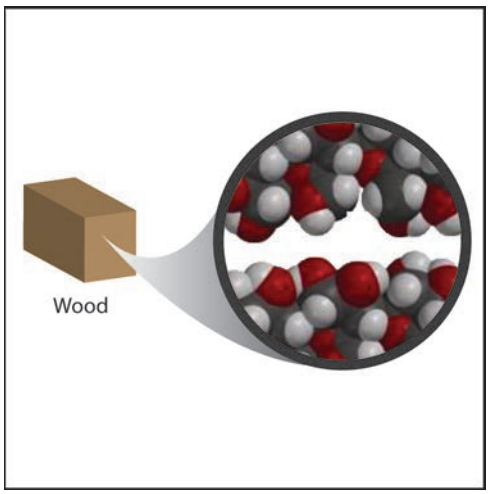


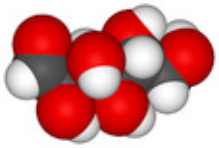
Ethylene molecule

The carbon and hydrogen atoms are very light, which helps give plastics their relatively low density. Plastics can have different densities because different atoms can be attached to the carbon-hydrogen chains. The density of different plastics also depends on the closeness of packing of these polymer chains.

Project the image *Wood.*
www.middleschoolchemistry.com/multimedia/chapter3/lesson1#wood

Wood is made mostly from carbon, hydrogen, and oxygen atoms bonded together into a molecule called *glucose*. These glucose molecules are bonded together to form long chains called *cellulose*. Many cellulose molecules stacked together give wood its structure and density.





Glucose molecule

In general, the density of wood and plastic are similar because they are made of similar atoms arranged in long chains. The difference in density is mostly based on the arrangement and packing of the polymer chains. Also, since wood is from a living thing, its density is affected by the structure of plant cells and other substances that make up wood.

Ask students:
The size, mass, and arrangement of atoms affect the density of a substance.

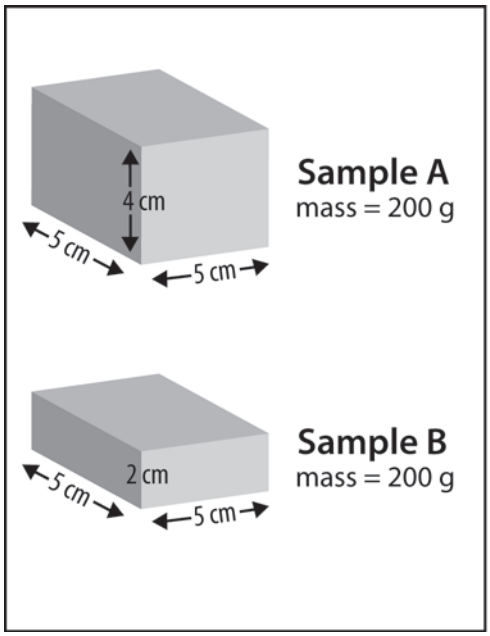
- **How might these factors work together to cause a substance to have a *high density*?**
  A substance with smaller more massive atoms that are close together is going to have a higher density.
- **How might these factors work together to cause a substance to have a *low density*?**
  A substance with larger, lighter atoms that are farther apart is going to have a lower density.

EXTEND

7. Have students explain on the molecular level why two blocks of different materials that have the same mass can have different densities.

Remind students that they looked at cubes that had the *same volume* but *different masses*. Point out that their activity sheet has drawings of two blocks (Sample A and Sample B) made of different substances that both have the *same mass*, but *different volumes*.

Ask students:



- **What is the density of Sample A?**
  Volume = 5 × 5 × 4 = 100 cm^3
  Mass = 200 g
  Density = 200 g/100 cm^3 = 2g/ cm^3

- **What is the density of Sample B?**
  Volume = 5 × 5 × 2 = 50 cm^3
  Mass = 200 g
  Density = 200 g/50 cm^3 = 4g/ cm^3
  Give two possible explanations for why one sample is more dense than the other.

  Hint: The size, mass, and arrangement of molecules affect the density of a substance. There are several possible answers for why sample B is more dense than sample A.

  - Sample B atoms might have more mass than Sample A atoms.
  - Sample B atoms might be smaller than Sample A atoms so more can fit in the same volume.
  - Sample B atoms might be arranged differently so more Sample B atoms than Sample A atoms fit in the same size cube.

  Any one of these explanations alone, or any combination, could be the reason why Sample B is more dense than Sample A.

Activity Sheet
Chapter 3, Lesson 1
What is Density?

Name _____

Date _____

DEMONSTRATION

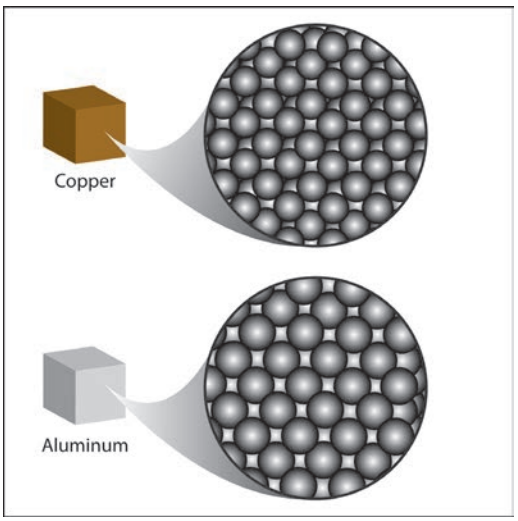
Your teacher placed a copper and an aluminum cube on a balance. Even though the cubes are the same size and shape, the copper has a greater mass than the aluminum. Both cubes are solid and are not hollowed out anywhere inside. The copper cube is made up of only copper atoms and the aluminum cube is made up of only aluminum atoms.

1. Look at the drawing of the copper and aluminum cubes and their atoms. What are two possible explanations for why the copper cube has a greater mass than the aluminum cube?

   Hint: Just because the aluminum atoms are larger, they are not necessarily heavier.

   Explanation 1:

   Explanation 2:



2. The density of a substance like copper or aluminum is its mass divided by its volume (how much space it takes up).
   Density = mass/volume or D = m/v.

   Which is more dense, copper or aluminum?

   How do you know?

You saw an animation about how to find the volume, mass, and density of a cube.

3. How do you find the volume of a cube?

4. How do you find the mass of a cube?

5. Once you know the volume and mass of a cube, how do you find the density of the cube?

6. Calculate the density of a cube using the following information:

   - Each side is 4 cm long.
   - The mass of the cube is 128 g.

ACTIVITY

Your group will work with eight cubes each with the same volume, but made of a different material. Carefully measure the mass of each cube and calculate the density. Then use density to correctly identify each of the 8 cubes.

Question to investigate
Can you use density to identify eight cubes made of different materials?

Materials for the class
- Set of eight cubes of equal volume
- Calculator

Teacher preparation
Use a piece of masking tape and a permanent marker to mark the eight cubes with the letters A–H.

Materials for each group
- Cubes marked A–H that you will share with other groups
- Balance that can measure in grams
- Calculator

Procedure
1. The volume of each cube is given in the chart. It is 15.6 cm^3.
2. Find the mass in grams of each cube using a scale or balance. Record this mass in the chart.
3. Trade cubes with other groups until you have measured the mass of all eight cubes
4. Calculate the density using the formula D = m/v and record it in the chart.

Sample	Volume (cm^3)	Mass (g)	Density (g/cm^3)	Material
A	15.6			
B	15.6			
C	15.6			
D	15.6			
E	15.6			
F	15.6			
G	15.6			
H	15.6			

7. Compare the value you found for density with the given value in the chart below to identify which cube is made out of which material. Write the name of the material in your chart for cubes A–H.

Material	Approximate Density (g/cm^3)
Aluminum	2.9
Brass	8.8
Copper	9.3
Steel	8.2
PVC	1.3
Nylon	1.2
Oak	0.7–0.9
Pine or poplar	0.4–0.6

EXPLAIN IT WITH ATOMS & MOLECULES

7. The size, mass, and arrangement of atoms affect the density of a substance.

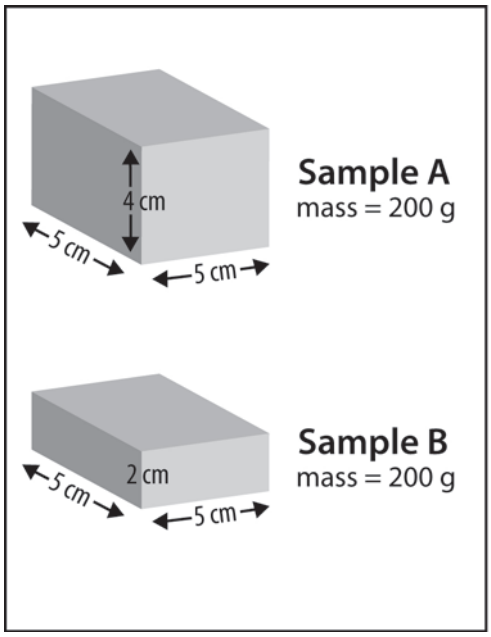
   If a substance has a *high density*, what can you guess about the size, mass, and arrangement of the atoms that make up the substance?

   If a substance has a *low density*, what can you guess about the size, mass, and arrangement of the atoms that make up the substance?

TAKE IT FURTHER

In this activity, you investigated cubes made out of different substances. The cubes had the same volume, but different masses. When you calculated the density of each cube, you found that this was different, too.

8. Now imagine two blocks (Sample A and Sample B) made of different substances that both have the *same mass*, but *different volumes*.



   a. What is the density of Sample A?

   b. What is the density of Sample B?

   c. Give two possible explanations for why one sample is more dense than the other.

   Hint: The size, mass, and arrangement of molecules affect the density of a substance.

Chapter 3, Lesson 2:
Finding Volume—The Water Displacement Method

Key Concepts

- A submerged object displaces a volume of liquid equal to the volume of the object.
- One milliliter (1 mL) of water has a volume of 1 cubic centimeter ($1cm^3$).
- Different atoms have different sizes and masses.
- Atoms on the periodic table are arranged in order according to the number of protons in the nucleus.
- Even though an atom may be smaller than another atom, it might have more mass.
- The mass of atoms, their size, and how they are arranged determine the density of a substance.
- Density equals the mass of the object divided by its volume; D = m/v.
- Objects with the same mass but different volume have different densities.

Summary

Students use the water displacement method to find the volume of different rods that all have the same mass. They calculate the density of each rod, and use the characteristic density of each material to identify all five rods. Then students consider the relationship between the mass, size, and arrangement of atoms to explain why different rods have different densities. Students will be briefly introduced to the periodic table.

Objective

Students will be able to explain that materials have characteristic densities because of the different mass, size, and arrangement of their atoms. Students will be able to use the volume displacement method to find the volume of an object.

Evaluation

The activity sheet will serve as the "Evaluate" component of each 5-E lesson plan. The activity sheets are formative assessments of student progress and understanding. A more formal summative assessment is included at the end of each chapter.

Safety

Make sure you and your students wear properly fitting goggles.

Materials for Each Group

- Set of 5 different rods that all have the same mass
- Graduated cylinder, 100 mL
- Water in a cup
- Calculator

Notes about the materials:
For this lesson you will need a set of five solid rods, each with the same mass, same diameter, but a different volume. Each rod is made of a different material. There are several versions of these rods available from different suppliers. This activity uses a set from Flinn Scientific, Equal Mass Kit, Product # AP 4636 but can be adapted to any set of equal mass rods. Since there are only five samples in the Equal Mass kit, you may need two kits so that each group can work with a sample.

This chart will help you identify each rod. Do not reveal this information to the students. They will discover the identity of each rod and the inverse relationship between the density and the length of each rod later in this lesson.

Sample	Material	Approximate density (g/cm^3)	Relative length
Smallest metal	Brass	7.5	shortest
Shiny gray metal	Aluminum	3.0	
Dark gray	PVC	1.4	
Tall off-white	Nylon	1.1	
Tallest white	Polyethylene	0.94	longest

ENGAGE

1. Show students five rods that have the same mass but different volumes.

Show students the five rods and explain that they all have the same mass. Then hold up the longest, middle-sized, and shortest rods and remind students that they have the same mass.

Ask students to make a prediction:

- **Which rod is the most dense? Least dense? In between?**

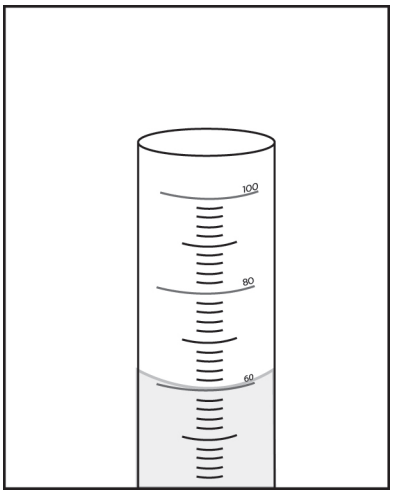
Students may reason that since the mass of each rod is the same, the volume of each rod must have something to do with its density. Some may go so far as to say that the rod with the smallest volume must have the highest density, because the same mass is packed into the smallest volume. Or that the rod with the largest volume must have the lowest density, because the same mass is spread out over the largest volume.

Tell students that like the cubes in the previous activity, they will need to know the volume and mass of each of the samples. They will also calculate the density of each sample and use this value to figure out which material each rod is made of.

2. Show an animation and demonstrate how to measure volume using the water displacement method.

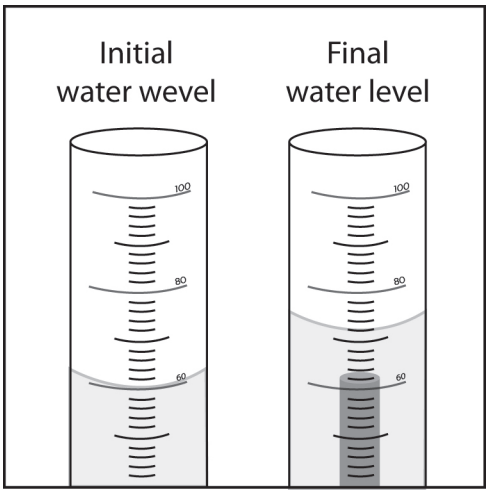
Project the animation *Water Displacement*.
www.middleschoolchemistry.com/multimedia/chapter3/lesson2#warer_displacement
Play the animation as you demonstrate the water displacement method using a cup of water, a graduated cylinder, and a rod, the way students will do in the activity. Use the dark gray plastic sample so that students can see it better.

Volume



1. Demonstrate what students will do by pouring water from a cup into a 100-mL graduated cylinder until it reaches a height that will cover the sample. This is the "initial water level."
2. Tell students that the surface of water in a tube may not be completely flat. Instead, the surface may curve in a shallow U-shape called the *meniscus*. When measuring, read the line just at the bottom of the meniscus.
3. Tilt the graduated cylinder and slowly slide the sample into the water. Hold the graduated cylinder upright. Record the level of the water. Point out that this is the "final water level."

4. Tell students that you want to find out how much the water level changed. Subtract the initial water level from the final water level to find the volume of the rod.
   - Volume of sample = final water level – initial water level



Students may be confused that the unit for volume in the graduated cylinder is milliliters (mL), when in the previous lesson students calculated volume in cubic centimeters (cm^3). Explain to students that 1 ml is the same as 1 cm^3. Click on the oval-shaped button on the first screen of the animation marked "1 mL = 1 cm^3."

Ask students:

- **When you place a sample in the water, why does the water level go up?**
  The volume that the rod takes up pushes or displaces the water. The only place for the water to go is up. The amount or volume of water displaced is equal to the volume of the sample.
- **Is the volume of the sample equal to the final water level?**
  No. Students should realize that the volume of the rod is not equal to the level of the water in the graduated cylinder. Instead, the volume of the rod equals the amount that the water went up in the graduated cylinder (the amount displaced). To find the amount of water displaced, students should subtract the initial level of the water (60 mL) from the final level of the water.
- **What units should you use when you record the volume of the sample?**
  Because they will be using the volume to calculate density, students should record the volume of the sample in cm^3.

Mass

Student groups will not need to measure the mass of the rods. The mass of each rod is the same, 15 grams, and is given in their chart on the activity sheet. They will need to measure the volume of each of the five different rods and calculate their densities. Students will use their values for density to identify each rod.

Density

Demonstrate how to calculate density (D = m/v) by dividing the mass by the volume. Point out that that the answer will be in grams per cubic centimeter (g/cm^3).

Give one activity sheet to each student.

Students will record their observations and answer questions about the activity on the activity sheet. The *Explain It with Atoms and Molecules* and *Take It Further* sections of the activity sheet will either be completed as a class, in groups, or individually, depending on your instructions. Look at the teacher version of the activity sheet to find the questions and answers.

Give students time to answer questions 1–5 on the activity sheet before starting the activity.

EXPLORE

3. Have students calculate the density of five different rods and use the characteristic property of density to correctly identify them.

***Note**: The densities for the three plastics are similar, so students need to be very careful when measuring their volume using the water displacement method. Also, it is difficult to measure the volume of the smallest rod. Give students a hint that it is between 1.5 and 2.0 mL.*

Question to investigate

Can you use density to identify all five rods?

Materials for each group

- Set of five different rods that all have the same mass
- Graduated cylinder, 100 mL
- Water in a cup
- Calculator

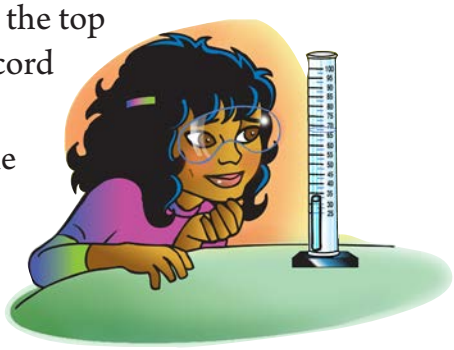
Teacher preparation

- Use a permanent marker to mark the five rods with letters A, B, C, D, and E. Keep track of which letter corresponds to which sample without letting students know. If you are using two or more sets of rods, be sure to mark each sample of the same material with the same letter.
- After a group finds the volume of a sample, they should then pass that sample to another group until all groups have found the volume of all five rods.
- For the longest sample, which floats, students can use a pencil to gently push the sample just beneath the surface of the water to measure its full volume.

Procedure

Volume

1. Pour enough water from your cup into the graduated cylinder to reach a height that will cover the sample. Read and record the volume.
2. Slightly tilt the graduated cylinder and carefully place the sample into the water.
3. Place the graduated cylinder upright on the table and look at the level of the water. If the sample floats, use a pencil to gently push the top of the sample just under the surface of the water. Record the number of milliliters for this final water level.
4. Find the amount of water displaced by subtracting the initial level of the water from the final level. This volume equals the volume of the cylinder in cm^3.
5. Record this volume in the chart on the activity sheet.
6. Remove the sample by pouring the water back into your cup and taking the sample out of your graduated cylinder.



Density

7. Calculate the density using the formula D = m/v. Record the density in (g/cm^3).
8. Trade samples with other groups until you have measured the volume and calculated the density of all five samples.

Sample	Initial water level (mL)	Final water level (mL)	Volume of the rods (cm^3)	Mass (g)	Density (g/cm^3)
A				15.0	
B				15.0	
C				15.0	
D				15.0	
E				15.0	

Identify the samples

9. Compare the values for density you calculated to the values in the chart. Then write the letter name for each sample in the chart.

***Note**: The densities students calculate may not be exactly the same as the given densities in the chart. As students are working, check their values for volume to be sure that they are using the difference between the final and initial water levels, not just the final level.*

Material	Approximate density (g/cm^3)	Sample (Letters A–E)
Brass	8.8	
Aluminum	2.7	
PVC	1.4	
Nylon	1.2	
Polyethylene	0.94	

4. Discuss whether students' values for density support their predictions from the beginning of the lesson.

Discuss student values for density for each of the samples. Point out that different groups may have different values for density, but that most of the values are close to the values in the chart.

Ask students:

- **Each group measured the volume of the same samples. What are some reasons that groups might have different values for density?**
  Students should realize that small inaccuracies in measuring volume can account for differences in density values. Another reason is that the graduated cylinder, itself, is not perfect. So there is always some uncertainty in measuring.

Remind students that in the beginning of the lesson they made a prediction about the density of the small, medium, and long sample. Students should have predicted that the longest cylinder has the lowest density, the shortest cylinder has the highest density, and the middle is somewhere in between.

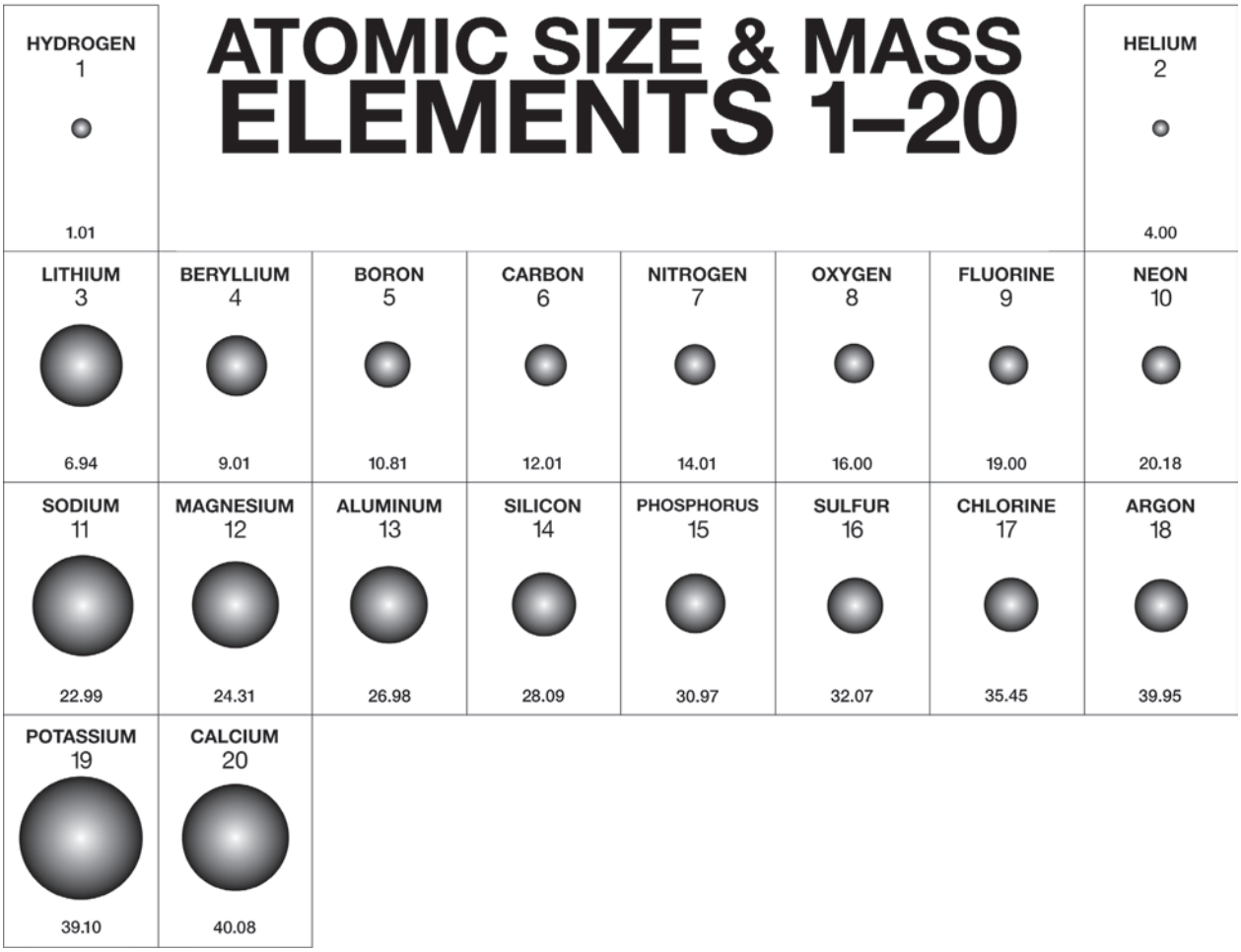
Ask students:

- **Was your prediction about the density of these three samples correct?**
  Have students look at their chart with the values for mass, volume, and density for each cylinder. Have them look for a relationship between the volume and the density. Students should realize that the shortest cylinder has the greatest density and the longest cylinder has the lowest density.
- **Is it fair to say that if two samples have the same mass that the one with the larger volume will have a lower density?** Yes. **Why?** Because the samples have the same mass, their volumes will give you an idea about their densities according to the equation $D = m/v$. If a larger number for volume is in the denominator, the density will be lower.
- **Is it fair to say that the one with the smaller volume will have a higher density?** Yes. **Why?** If a smaller number for volume is in the denominator, the density will be higher.

EXPLAIN

5. **Have students look at the size and mass of atoms to help explain why each sample has a different density.**

   Project the image *Atomic Size and Mass*.
   www.middleschoolchemistry.com/multimedia/chapter3/chapter2#atomic_size_and_mass



Tell students that this chart is based on the periodic table of the elements but that it only includes the first 20 elements out of about 100. A representation of an atom for each element is shown. For each element, the atomic number is above the atom and the atomic mass is below. This chart is special because it shows both the size and mass of atoms compared to other atoms.

***Note**: Students may want to know more about why atoms have different atomic numbers and different sizes. These questions will be covered in later chapters but you can tell them that the atomic number is the number of protons in the center or nucleus of the atom. Each element has a certain number of protons in its atoms, so each element has a different atomic number. The dif-*

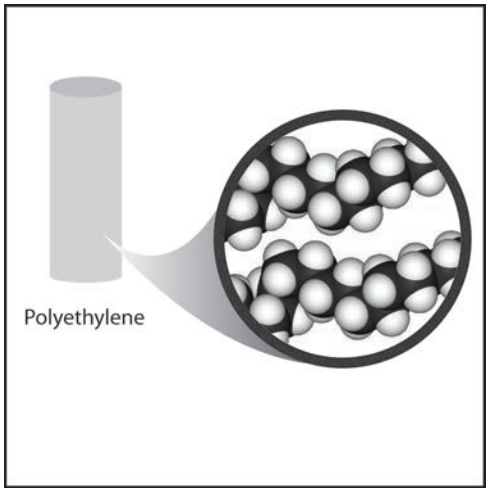
ference in size is a little harder to explain. Atoms have positively charged protons in the nucleus and negatively charged electrons moving around the nucleus. It's really the space the electrons occupy that makes up most of the size of the atom. As the number of protons in the atom increases, both its mass and the strength of its positive charge increases. This extra positive charge pulls electrons closer to the nucleus, making the atom smaller. The atoms get bigger again in the next row because more electrons are added in a space (energy level) further from the nucleus.

Let students know that they will learn more about the periodic table and atoms in Chapter 4. For now, all students need to focus on is the size and mass of the atoms.

Tell students that the difference in density between the small, medium, and large samples that they measured can be explained based on the atoms and molecules they are made from.

Project the image *Polyethylene* (longest rod).
www.middleschoolchemistry.com/multimedia/chapter3/lesson2#polyethylene

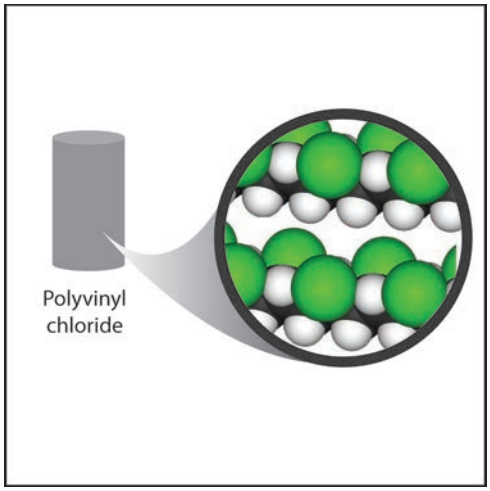
Polyethylene is made of long molecules of only *carbon* and *hydrogen* atoms. In the *Atomic Size and Mass* chart, the mass of carbon is pretty low, and the mass of hydrogen is the lowest of all the atoms. These low masses help explain why polyethylene has a low density. Another reason is that these long, skinny molecules are loosely packed together.



Project the image *Polyvinyl Chloride* (medium-length rod).
www.middleschoolchemistry.com/multimedia/chapter3/lesson2#polyvinyl_chloride

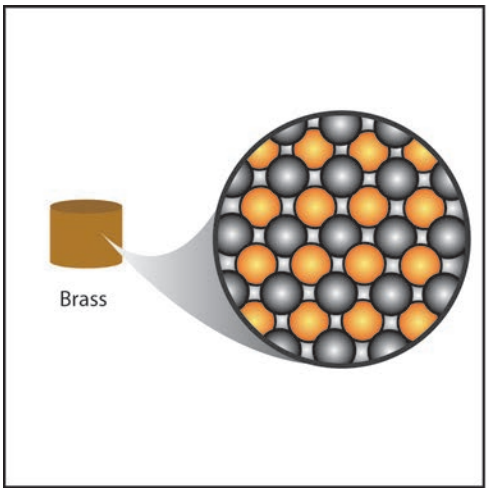
Polyvinyl chloride is made up of *carbon, hydrogen,* and *chlorine* atoms. If you compare polyvinyl chloride to polyethylene, you will notice that there are chlorine atoms in some places where there are hydrogen atoms in the polyethylene. In the chart, chlorine has a

large mass for its size. This helps make polyvinyl chloride more dense than polyethylene. The density of different plastics is usually caused by the different atoms that can be connected to the carbon–hydrogen chains. If they are heavy atoms for their size, the plastic tends to be more dense; if they are light for their size, the plastic tends to be less dense.



Project the image *Brass* (shortest rod).
www.middleschoolchemistry.com/multimedia/chapter3/lesson2#brass

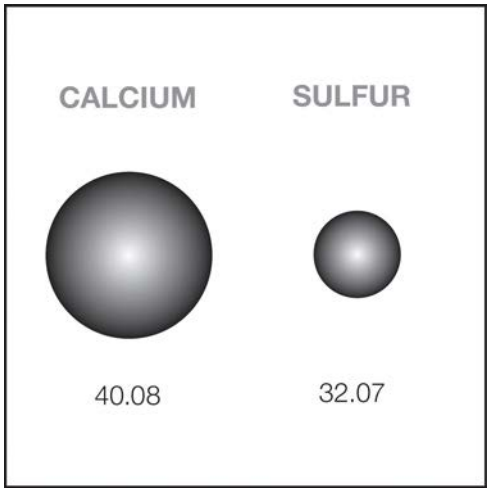
Brass is a combination of *copper* and *zinc* atoms. Copper and zinc come up later in the periodic table, so they are not shown in the chart, but they are both heavy for their size. The atoms are also packed very closely together. For these reasons, brass is more dense than either polyethylene or polyvinyl chloride.



EXTEND

6. Discuss the density of calcium compared to the density of sulfur.

Have students refer to the illustration of Calcium and Sulfur on their activity sheets. Explain that a calcium atom is both bigger and heavier than a sulfur atom. But a piece of solid sulfur is more dense than a solid piece of calcium. The density of sulfur is about 2 g/cm^3 and the density of calcium is about 1.5 g/cm^3.



Ask students:

- **Based on what you know about the size, mass, and arrangement of atoms, explain why a sample of sulfur is more dense than a sample of calcium.**
  Even though a sulfur atom has less mass than a calcium atom, many more sulfur atoms can pack together in a certain amount of space. This gives sulfur more mass per volume than calcium, making it more dense.

Activity Sheet
Chapter 3, Lesson 2
Finding Volume—The Water Displacement Method

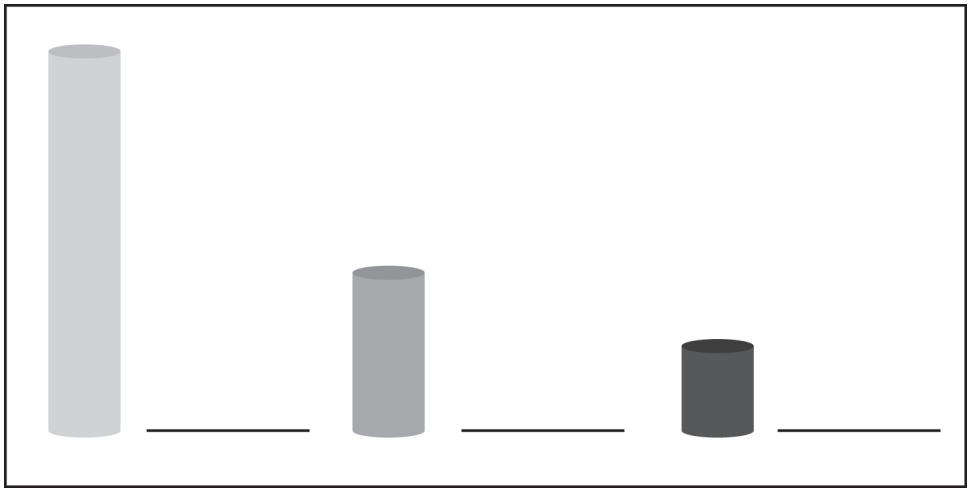
Name _____

Date _____

DEMONSTRATION

Think about the longest, middle-sized, and shortest rods your teacher showed you. All of these samples have the same mass, but their volumes are different.

1. Predict the densities of each sample by writing a phrase from the box on the line next to each sample.

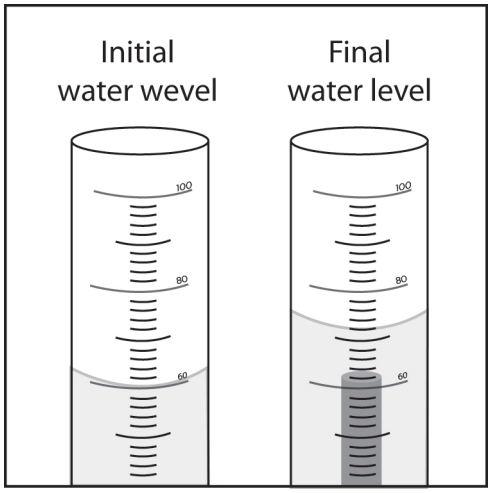


Least dense Medium dense Most dense

2. Explain why you think each rod is either the most, medium, or least dense.

3. The animation showed you how to find the volume of a sample using the water displacement method.

   Look at the illustrations showing the water level in a graduated cylinder before and after a sample is submerged in water. What does this difference in water level tell you about the sample?



   How much would the water level rise if you submerged a cube with a volume of 1 cm^3 in a graduated cylinder filled with 40 mL of water?

4. What is the density of the sample described below?
   Be sure to write the units in g/cm^3.

   - Water level rose from 60 mL to 85 mL
   - Mass = 50 g

ACTIVITY

Your group will work with five rods each with the same mass, but made of a different material. Carefully measure the volume of each sample and calculate the density. Then use density to correctly identify each of the five samples.

Question to investigate
Can you use density to identify all five rods?

Materials for each group

- Set of five different rods that all have the same mass
- Graduated cylinder, 100 mL
- Water in a cup
- Calculator

Hint: the volume of the smallest rod is between 1.5–2.0 cm^3.

Procedure

Volume

1. Pour enough water from your cup into the graduated cylinder to reach a height that will cover the sample. Read and record the volume.
2. Slightly tilt the graduated cylinder and carefully place the sample into the water.
3. Place the gradated cylinder upright on the table and look at the level of the water. If the sample floats, use a pencil to gently push the top of the sample just under the surface of the water. Record the number of milliliters for this final water level.

4. Find the amount of water displaced by subtracting the initial level of the water from the final level. This volume equals the volume of the cylinder in cm^3.
5. Record this volume in the chart on the activity sheet.
6. Remove the sample by pouring the water back into your cup and taking the sample out of your graduated cylinder.

Density

7. Calculate the density using the formula D = m/v. Record the density in (g/cm^3).
8. Trade samples with other groups until you have measured the volume and calculated the density of all five samples.

Sample	Initial water level (mL)	Final water level (mL)	Volume of the rods (cm^3)	Mass (g)	Density (g/cm^3)
A				15.0	
B				15.0	
C				15.0	
D				15.0	
E				15.0	

Identify the samples

9. Compare the values for density you calculated to the values in the chart. Then write the letter name for each sample in the chart.

Material	Approximate density (g/cm^3)	Sample (Letters A–E)
Brass	8.8	
Aluminum	2.7	
PVC	1.4	
Nylon	1.2	
Polyethylene	0.94	

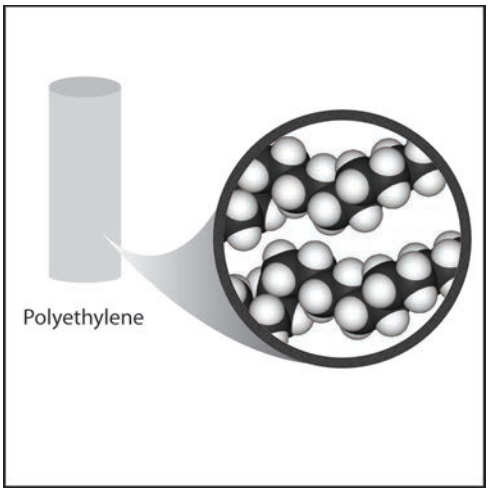
5. On the first page of this activity sheet, you made a prediction about the density of a small, medium, and long rod. Based on your calculations for density in your chart, were your predictions correct? If a short rod and a long rod have the same mass, explain why the short one will be more dense than the long one.

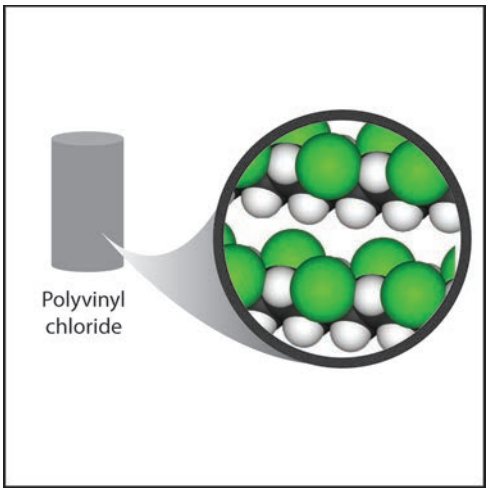
EXPLAIN IT WITH ATOMS & MOLECULES

The difference in density between the small, medium, and large rods can be explained based on the atoms and molecules they are made from. Refer to the chart of atomic size and mass to answer the following question about each substance.

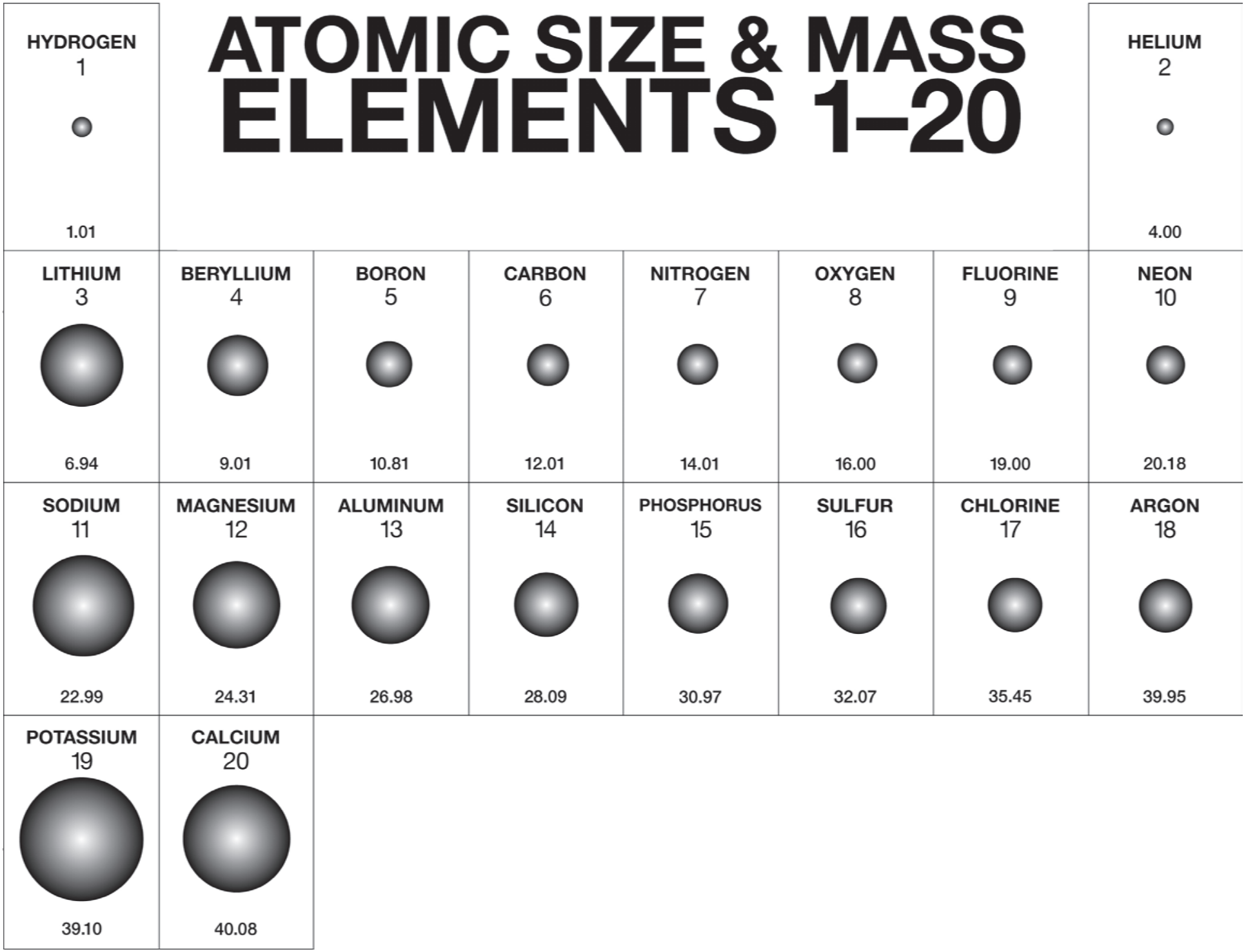
6. Polyethylene is made of carbon and hydrogen atoms. Polyvinyl chloride is also made of carbon and hydrogen atoms, but also has chlorine atoms.

   Look at the size and mass of these atoms in the chart to explain why polyvinyl chloride is more dense than polyethylene.

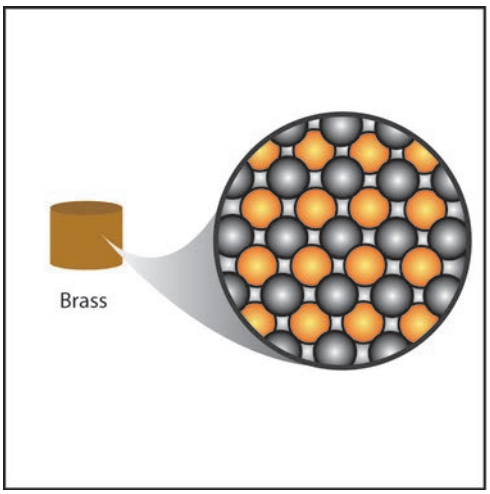




ATOMIC SIZE & MASS
ELEMENTS 1–20

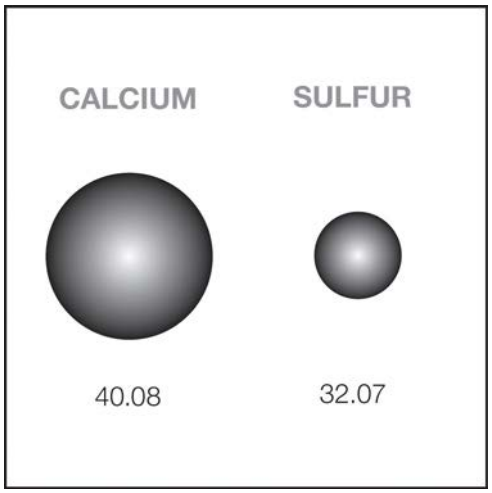


7. Brass is made of copper and zinc atoms. These atoms are pretty heavy for their size, but they are also packed together differently than the molecules of the plastics. How does the way these atoms pack together help make the brass more dense than the plastics?



TAKE IT FURTHER

8. Based on the *Atomic Size and Mass* chart, a calcium atom is both bigger and heavier than a sulfur atom. But a piece of solid sulfur is more dense than a solid piece of calcium. In fact, sulfur is about 2 g/cm^3, and calcium is about 1.5 g/cm^3.



Based on what you know about the size, mass, and arrangement of atoms, explain why a sample of sulfur is more dense than a sample of calcium.

Chapter 3, Lesson 3: Density of Water

Key Concepts

- Just like solids, liquids also have their own characteristic density.
- The volume of a liquid can be measured directly with a graduated cylinder.
- The molecules of different liquids have different size and mass.
- The mass and size of the molecules in a liquid and how closely they are packed together determine the density of the liquid.
- Just like a solid, the density of a liquid equals the mass of the liquid divided by its volume; $D = m/v$.
- The density of water is 1 gram per cubic centimeter.
- The density of a substance is the same regardless of the size of the sample.

Summary

Students measure the volume and mass of water to determine its density. Then they measure the mass of different volumes of water and discover that the density is always the same. Students make a graph of the relationship between the volume and the mass of water.

Objective

Students will be able to measure the volume and mass of water and calculate its density. Students will be able to explain that since any volume of water always has the same density, at a given temperature, that density is a characteristic property of water.

Evaluation

The activity sheet will serve as the "Evaluate" component of each 5-E lesson plan. The activity sheets are formative assessments of student progress and understanding. A more formal summative assessment is included at the end of each chapter.

Safety

Make sure you and your students wear properly fitting goggles.

Materials for Each Group

- Graduated cylinder, 100 ml
- Water
- Balance that measures in grams (able to measure over 100 g)
- Dropper

Materials for the Demonstration

- Water
- Two identical buckets or large containers

ENGAGE

1. Do a demonstration to introduce the idea that water has density.

Materials

- Water
- Two identical buckets or large containers

Teacher preparation

- Half-fill one bucket and add only about 1 cup of water to the other.

Procedure

1. Select a student to lift both buckets of water.
2. Ask the student volunteer which bucket appears to have more mass.

Expected results

The bucket containing more water has more mass.

Ask students:

- **In Lessons 1 and 2, you found the density of solids, by measuring their mass and volume. Do you think a liquid, like water can have a density?**
  Students should realize that water has volume and mass. Because D=m/v, water must also have density.
- **How do you think you can find the density of a liquid like water?**
  Students are not expected to be able to fully answer this question at this point. It is meant as a lead-in to the investigation. But students may realize that they should somehow find the mass and volume of the water first.
- **Could both the small and large amounts of water your classmate lifted have the same density?**
  Students may point out that the bucket with more water has more mass but a greater volume. The bucket with less mass has less volume. So it is possible that different amounts of water could have the same density.

Give each student an activity sheet.

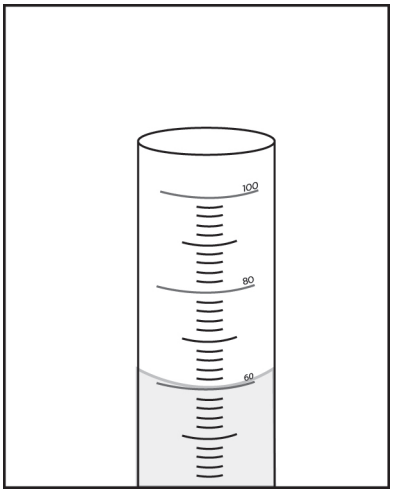
Students will record their observations and answer questions about the activity on the activity sheet. The *Explain It with Atoms and Molecules* and *Take It Further* sections of the activity sheet will either be completed as a class, in groups, or individually depending on your instructions. Look at the teacher version of the activity sheet to find the questions and answers.

EXPLORE

2. Discuss with students how to find the volume and mass of water.

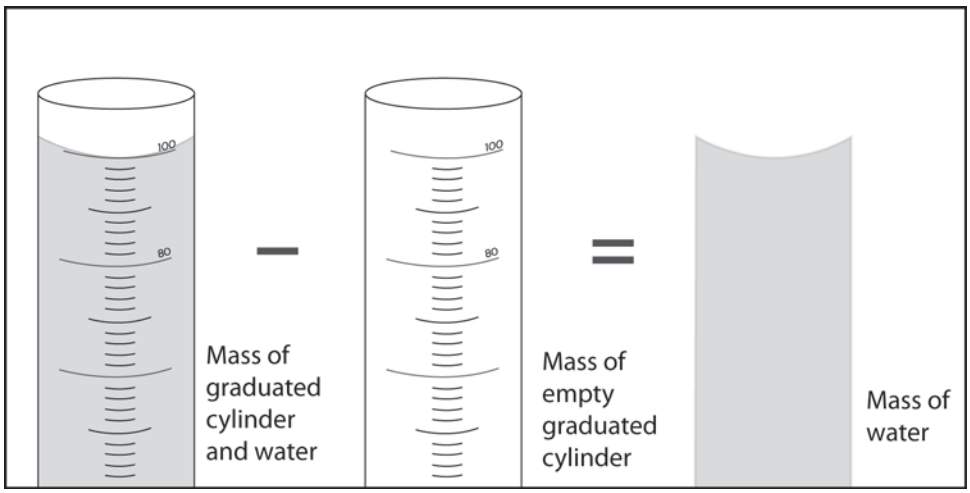
Tell students that they are going to try to find the density of water.

Ask students:



- **What two things do you need to know in order to find the density of water?**
  Students should realize that they need both the volume and mass of a sample of water to find its density.
- **How can you measure a *volume* of water?**
  Suggest that students use a graduated cylinder to measure volume in milliliters. Remind students that each milliliter equals 1 cm^3.
- **How can you measure the *mass* of water?**
  Suggest that students use a balance to measure the mass in grams. Tell students that they can find mass by weighing the water. However, since water is a liquid, it needs to be in some sort of container. So in order to weigh the water, they have to weigh the container, too. Explain to students that they will have to subtract the mass of an empty graduated cylinder from the mass of the cylinder and water to get the mass of just the water.

Measuring the mass of water



2. Have students find the mass of different volumes of water to show that the density of water does not depend on the size of the sample.

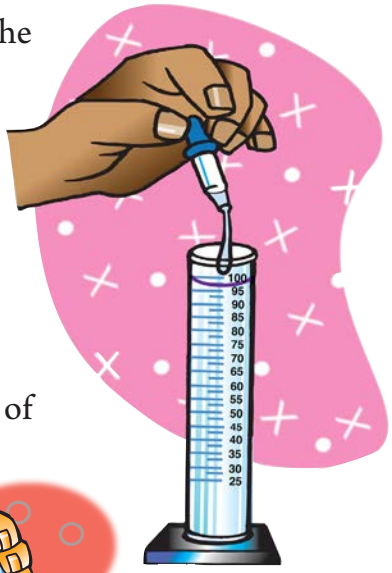
Question to investigate

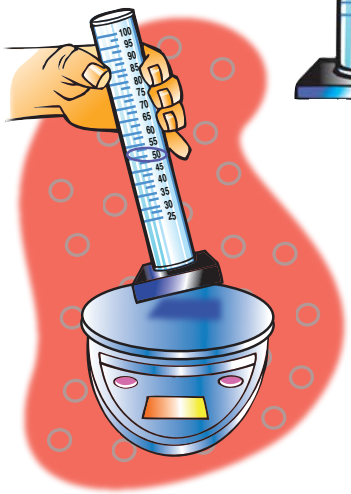
Do different amounts of water have the same density?

Materials for each group

- Graduated cylinder, 100 ml
- Water
- Balance that measures in grams (able to measure over 100 g)
- Dropper

Procedure





1. Find the mass of an empty graduated cylinder. Record the mass in grams in the chart on the activity sheet.
2. Pour 100 mL of water into the graduated cylinder. Try to be as accurate as possible by checking that the meniscus is right at the 100-mL mark. Use a dropper to add or remove small amounts of water.
3. Weigh the graduated cylinder with the water in it. Record the mass in grams.
4. Find the mass of only the water by subtracting the mass of the empty graduated cylinder. Record the mass of 100 mL of water in the chart.
5. Use the mass and volume of the water to calculate density. Record the density in g/cm^3 in the chart.
6. Pour off water until you have 50 mL of water in the graduated cylinder. If you accidentally pour out a little too much, add water until you get as close as you can to 50 mL.
7. Find the mass of 50 mL of water. Record the mass in the activity sheet. Calculate and record the density.
8. Next, pour off water until you have 25 mL of water in the graduated cylinder. Find the mass of 25 mL of water and record it in the chart. Calculate and record the density.

Finding the density of different volumes of water			
Volume of water	100 milliliters	50 milliliters	25 milliliters
Mass of graduated cylinder + water (g)			
Mass of empty graduated cylinder (g)			
Mass of water (g)			
Density of water (g/cm^3)			

Expected results
The density of water should be close to 1 g/cm^3. This is true for 100, 50, or 25 mL.

Ask students:

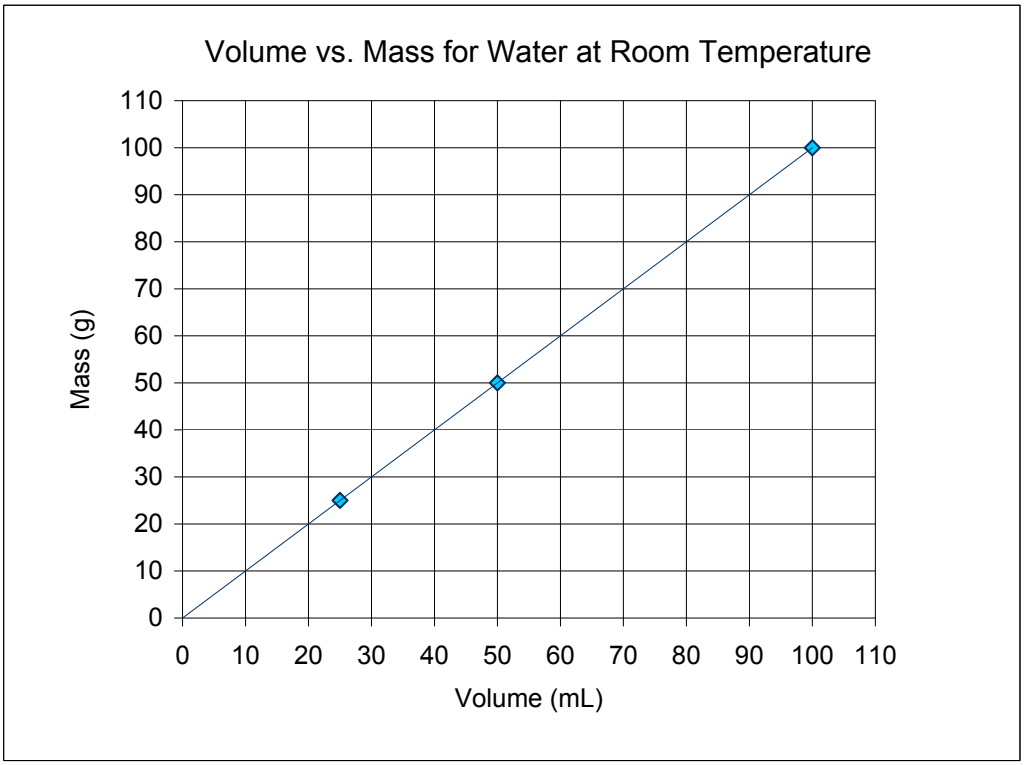
- **Look at your values for density in your chart. Does the density of the different volumes of water seem to be about the same?**
  Help students see that most of the different values for density are near 1 g/cm^3. They may wonder why their values are not all exactly 1 g/cm^3. One reason could be inaccuracies in measuring. Another reason is that the density of water changes with temperature. Water is most dense at 4 °C and at that temperature has a density of 1 g/cm^3. At room temperature, around 20–25 °C, the density is about 0.99 g/cm^3.

- **What is the density of water in g/cm^3?**
  Students answers will vary, but their values should mostly be around 1 g/cm^3.

4. Have students graph their results.

Help students make a graph of the data on their activity sheet. The x-axis should be volume and the y-axis should be mass.

When students plot their data, there should be a straight line showing that as volume increases, mass increases by the same amount.



5. Discuss student observations, data, and graphs.

Ask students:

- **Use your graph to find the mass of 40 mL of water. What is the density of this volume of water?**
  The mass of 40 mL of water is 40 grams. Since D = m/v and mL = cm^3, the density of water is 1 g/cm^3.
- **Choose a volume between 1 and 100 mL. Use your graph to find the mass. What is the density of this volume of water?**
  Whether students weigh 100, 50, 25 mL or any other amount, the density of water will always be 1 g/cm^3.

Tell students that density is a characteristic property of a substance. This means that the density of a substance is the same regardless of the size of the sample.

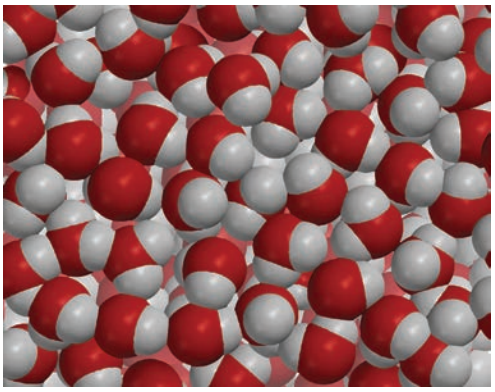
Ask students:

- **Is density a characteristic property of water? How do you know?**
  Density is a characteristic property of water because the density of any sample of water (at the same temperature) is always the same. The density is 1 g/cm^3.

EXPLAIN

6. Explain why the density of any size sample of water is always the same.

Project the image *Density of Water*.
www.middleschoolchemistry.com/multimedia/chapter3/lesson3#density_of_water



Water molecules all have the same mass and size. Water molecules are also packed pretty close together. They are packed the same way throughout an entire sample of water. So, if a volume of water has a certain mass, twice the volume will have twice the mass, three times the volume has three times the mass, etc. No matter what size sample of water you measure, the relationship between the mass and volume will always be the same. Because D=m/v, the density is the same for any amount of water.

Project the animation *Liquid Water*.
www.middleschoolchemistry.com/multimedia/chapter3/lesson3#liquid_water
Water molecules are always moving. But on the average they are packed the same throughout. Therefore, the ratio between the mass and volume is the same, making the density the same. This is true no matter the size of the sample or where you select your sample from.

EXTEND

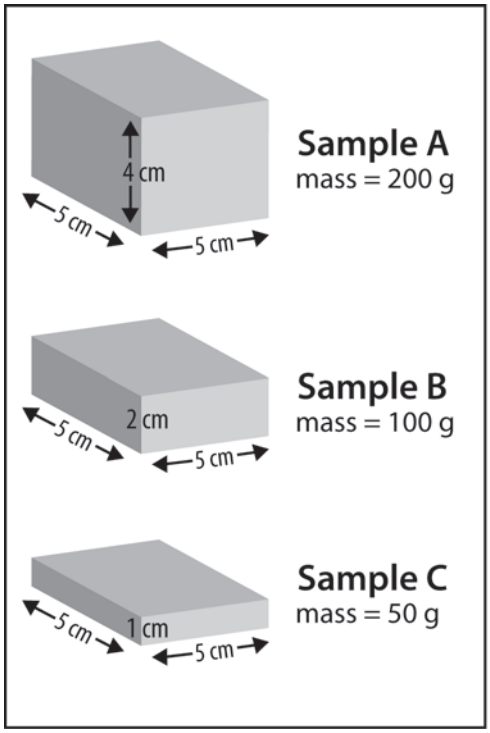
7. Have students consider whether the density of a large piece of a solid substance is the same as the density of a smaller piece.

Give students time to calculate the density of each of the three samples drawn on their activity sheet and answer the related questions.

Ask students:

- **The density of a liquid is the same no matter what the size of the sample. Could this be true for solids, too? Calculate the density of each of the three samples to find out.**
  Yes. The density of a solid substance is the same no matter how big or small the sample.

- **Sample A has a mass of 200 g. What is the density of Sample A?**
  D = m/v
  D = 200g/100cm^3
  D = 2 g/cm^3
- **If you cut Sample A in half and looked at only one half, you would have Sample B. What is the density of Sample B?**
  If students do not know what the mass is, tell them that it is half the mass of Sample A. Because Sample A was 200 g, Sample B is one half the volume and therefore one half the mass (100 g).
  D = m/v
  D = 100g/50 cm^3
  D = 2 g/cm^3
- **If you cut Sample B in half you would have Sample C. What is the density of Sample C?**
  D = m/v
  D = 50g/25 cm^3
  D = 2 g/cm^3



Activity Sheet
Chapter 3, Lesson 3
Density of water

Name _____

Date _____

DEMONSTRATION

1. One of your classmates lifted different amounts of water. The largest amount of water also had the most mass.

   You know how to find the density of solids. Do you think a liquid, like water, can have a density?

   How do you think you could find the density of a liquid like water?

   Could both the small and large amounts of water your classmate lifted have the same density?

   Explain.

ACTIVITY

Question to investigate
Do different amounts of water have the same density?

Materials for each group

- Graduated cylinder, 100 mL
- Water
- Balance that measures in grams (able to measure over 100 g)
- Dropper

Procedure

1. Find the mass of an empty graduated cylinder. Record the mass in grams in the chart on the activity sheet.
2. Pour 100 mL of water into the graduated cylinder. Try to be as accurate as possible by checking that the meniscus is right at the 100 mL mark. Use a dropper to add or remove small amounts of water.

3. Weigh the graduated cylinder with the water in it. Record the mass in grams.
4. Find the mass of only the water by subtracting the mass of the empty graduated cylinder. Record the mass of 100 mL of water in the chart.
5. Use the mass and volume of the water to calculate density. Record the density in g/cm^3 in the chart.
6. Pour off water until you have 50 mL of water in the graduated cylinder. If you accidentally pour out a little too much, add water until you get as close as you can to 50 mL.
7. Find the mass of 50 mL of water. Record the mass in the activity sheet. Calculate and record the density.
8. Next, pour off water until you have 25 mL of water in the graduated cylinder. Find the mass of 25 mL of water and record it in the chart. Calculate and record the density.

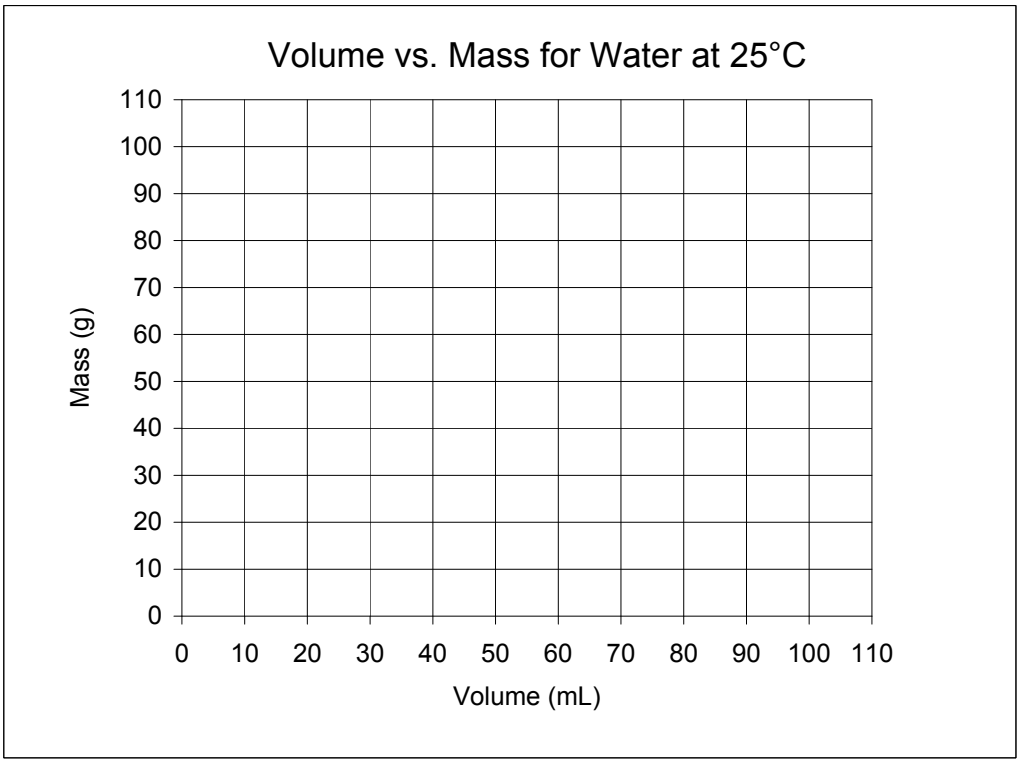
Finding the density of different volumes of water			
Volume of water	100 milliliters	50 milliliters	25 milliliters
Mass of graduated cylinder + water (g)			
Mass of empty graduated cylinder (g)			
Mass of water (g)			
Density of water (g/cm^3)			

2. Look at your values for density in your chart. Does the density of the different volumes of water seem to be about the same?

3. What do you think is the density of water in g/cm^3?

4. Using the data from your chart, graph the volume and mass for 100 mL, 50 mL, and 25 mL.

Volume vs. Mass for Water at Room Temperature



5. Look at the graph you made.
   If you measured 40 milliliters of water, what do you think its mass would be? What would its density be?

   Volume: 40 mL
   Mass _____
   Density _____

6. Choose any volume of water between 1 and 100 milliliters. Based on the graph, what would its mass be? What would its density be?

   Volume _____
   Mass _____
   Density _____

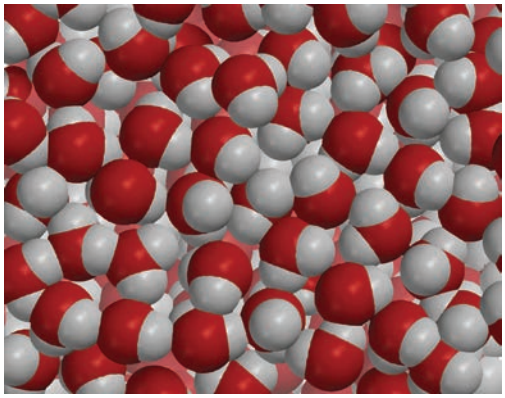
7. Density is a "characteristic property" of a substance. This means that the substance will have the same density no matter how big or small the sample is. Would you say that density is a characteristic property of water? Why or why not?

EXPLAIN IT WITH ATOMS & MOLECULES

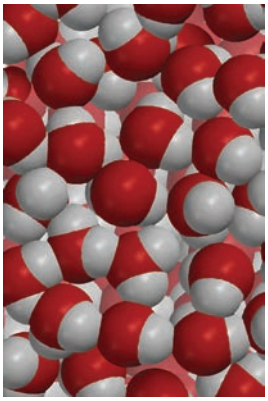
Each individual molecule has the same size and mass. The water molecules are packed very close together the same way throughout an entire sample of water.

8. Sample B is half the volume of Sample A.

   Do the samples have the same mass?



Sample A



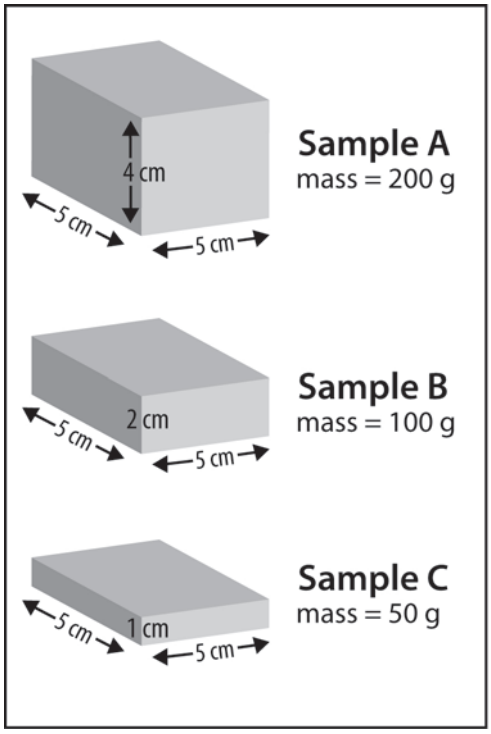
Sample B

   Do the samples have the same density?

TAKE IT FURTHER

9. The density of a liquid is the same no matter the size of the sample. Could this be true for solids, too? Calculate the density of each of the three samples to find out.

   Sample A has a mass of 200 g. What is the density of Sample A?



   If you cut Sample A in half and looked at only one half you would have Sample B. What is the density of this Sample B?

   If you cut Sample B in half you would have Sample C. What is the density of Sample C?

Chapter 3, Lesson 4: Density: Sink and Float for Solids

Key Concepts

- The density of an object determines whether it will float or sink in another substance.
- An object will float if it is less dense than the liquid it is placed in.
- An object will sink if it is more dense than the liquid it is placed in.

Summary

Students will investigate a wax candle and a piece of clay to understand why the candle floats and the clay sinks even though the candle is heavier than the piece of clay. Students will discover that it is not the weight of the object, but its density compared to the density of water, that determines whether an object will sink or float in water.

Objective

Students will be able to determine whether an object will sink or float by comparing its density to the density of water.

Evaluation

The activity sheet will serve as the "Evaluate" component of each 5-E lesson plan. The activity sheets are formative assessments of student progress and understanding. A more formal summative assessment is included at the end of each chapter.

Safety

Make sure you and your students wear properly fitting goggles.

Materials for Each Group

- 2 tea light candles in their metal containers
- Clay
- Water in cup
- Small balance
- Tape
- Dropper

Notes About the Materials

A simple balance is required for the demonstration. One of the least expensive is Delta Education, Stackable Balance (21-inch) Product # 020-0452-595. Students can use the smaller version of the same balance, Delta Education, Stackable Balance (12-inch), Product # 023-0724-595. You will need tea light candles for the demonstration and for each student group. Look for candles in which the wax completely fills the metal container.

ENGAGE

1. Do a demonstration to show that the wax is heavier than the clay but that the wax floats and the clay sinks.

Materials for the demonstration

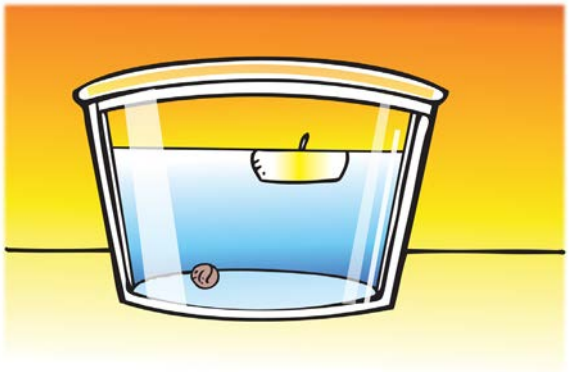
- 1 tea light candle
- Clay
- Clear plastic container
- Water
- Large balance

Teacher preparation

- Use a small enough piece of clay so that you are sure that the candle weighs more than the clay.
- Pour water into a clear plastic container (or large cup) until it is about ½-full.

Procedure

1. Place a piece of clay that weighs less than a tea light candle on one end of a balance.
2. Remove the candle from its metal container and place the candle on the other end of the balance.
3. Ask students which is heavier, the clay or the candle. Ask them to predict which will sink and which will float. Then, place the clay and candle in a clear container of water.



Expected results

Even though the candle weighs more than the clay, the candle floats and the clay sinks.

2. Discuss students' ideas about why the heavier candle floats and the lighter clay sinks.

Ask students:

- **Why do you think the bigger, heavier candle floats and the smaller, lighter clay sinks?**

Students may say that the clay is more dense than wax. Tell students that the density of the objects is important, but that in sinking and floating, the density of the *water* matters, too. In fact, by comparing the density of an object to the density of water, you can predict whether an object will sink or float. One way to compare them is to weigh equal volumes of each.

Give an activity sheet to each student.
Students will record their observations and answer questions about the activity on the activity sheet. The *Explain It with Atoms and Molecules* and *Take It Further* sections of the activity sheet will either be completed as a class, in groups, or individually depending on your instructions. Look at the teacher version of the activity sheet to find the questions and answers.

EXPLORE

3. Have students compare the density of water, wax, and clay.

Question to investigate
Why does a heavier candle float and a lighter piece of clay sink?

Materials for each group

- 2 tea light candles in their metal containers
- Clay
- Water in cup
- Small balance
- Tape
- Dropper

Procedure
Compare the density of wax and water

1. Roll two pieces of tape and stick them to the center of the pan at each end of the balance.
2. Attach each tea light candle to the tape so that each candle is in the center of the pan.
3. Use the wick to pull one candle out of its container.
4. Carefully pour water into the empty metal container until it fills the container to the same level as the candle in the other container. You may use a dropper to add the last bit of water and prevent spilling. The goal is to compare the mass of equal volumes of wax and water.

Expected results
The water has a greater mass than an equal volume of wax. So, the density of water must be greater than the density of wax.

Ask students:

- **Which weighs more, wax or an equal volume of water?**
  Water weighs more than an equal volume of wax.
- **Which is more dense, wax or water?**
  Water is more dense.

If students have trouble understanding this relationship between the mass and density of equal volumes, have them think about the demonstration from Chapter 3, Lesson 1 with the aluminum and copper cubes. Both had the same volume, but the copper cube weighed more. Because the copper had more mass, it also had a greater density.

Compare the density of clay and water

1. Make sure you have one piece of tape in the center of each pan on the balance.
2. Fill one container with clay and place it on the tape so that it is in the center of the pan.
3. Place an empty container on the tape at the opposite end of the balance.
4. Slowly and carefully add water to the empty container until it is full.

Expected results
The clay has a greater mass than an equal volume of water. So, the density of clay is greater than the density of water.

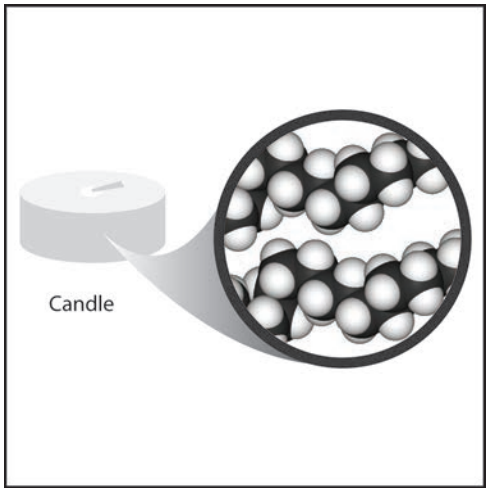
Ask students:

- **Which weighs more, the clay or an equal volume of water?**
  The clay weighs more than an equal volume of water.
- **Which is more dense, clay or water?**
  Clay is more dense.
- **Knowing the density of an object can help you predict if it will sink or float in water.**
  - **If an object is more dense than water, would you expect it to sink or float?**
    Objects that are more dense than water sink.
  - **If an object is less dense than water, would you expect it to sink or float?**
    Objects that are less dense than water float.

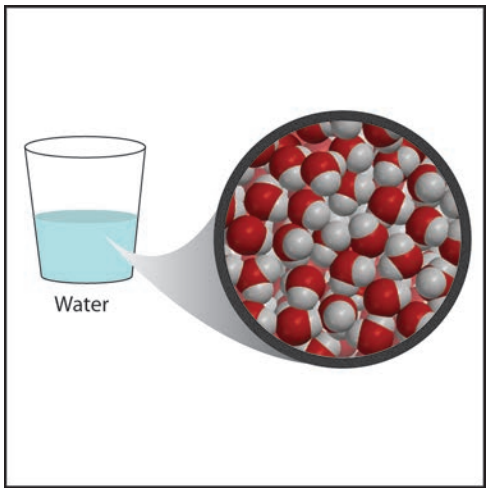
EXPLAIN

4. Compare the density of wax, water, and clay on the molecular level.

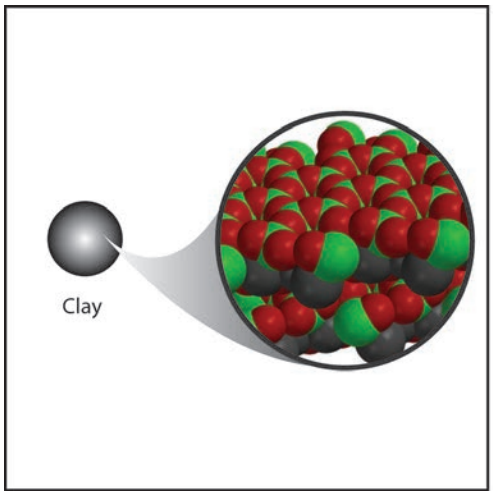
Project the image *Wax*.
www.middleschoolchemistry.com/multimedia/chapter3/lesson4#wax
Wax is made of carbon and hydrogen atoms connected together in long chains. These long chains are tangled and intertwined and packed together to make the wax.



Project the image *Water*.
www.middleschoolchemistry.com/multimedia/chapter3/lesson4#water
Even though they both have lots of hydrogen atoms, water is more dense than wax because the oxygen in water is heavier and smaller than the carbon in the wax. Also, the long chains of the wax do not pack as efficiently as the small water molecules.



Project the image *Clay.*
www.middleschoolchemistry.com/multimedia/chapter3/lesson4#clay
Clay has oxygen atoms like water, but it also has heavier atoms like silicon and aluminum. The oxygen atoms are bonded to the silicon and aluminum to make molecules with a lot of mass. These are packed closely together, which makes the clay more dense than water.



EXTEND

5. **Have students explain, in terms of density, why a very heavy object like a big log floats and why a very light object like a tiny grain of sand sinks.**

Ask students:

- **A giant log can float on a lake, while a tiny grain of sand sinks to the bottom. Explain why a heavy object like the log floats while a very light grain of sand sinks.**
  Students should recognize that a log will float because wood is less dense than water. If you could weigh a large amount of water that has the same volume as the log, the log will weigh less than the water. Therefore, the log floats. A grain of sand will sink because sand is more dense than water. If you could weigh a small amount of water that has the same volume as the grain of sand, the sand will weigh more than the water. Therefore, the sand sinks.

  Students should realize that if an object weighs more than an equal volume of water, it is more dense and will sink, and if it weighs less than an equal volume of water, it is less dense and will float.

  - Remember that the density of water is about 1 g/cm^3. Predict whether the following objects will sink or float.

Will these objects sink or float?		
Object	Density (g/cm^3)	Sink or float
Cork	0.2–0.3	Float
Anchor	7.8	Sink
Spruce wood oar	0.4	Float
Apple	0.9	Float
Orange	0.84	Float
Orange without peel	1.16	Sink

Ask students:

- **If a peach has a volume of 130 cm^3 and sinks in water, what can you say about its mass?**
  Its mass must be more than 130 grams.

- **If a banana has a mass of 150 grams and floats in water, what can you say about its volume?**
  Its volume must be more than 150 cm^3.

Read more about sinking and floating in the additional teacher background section at the end of this lesson.

***Note**: Students may wonder why boats made out of dense material like steel can be made to float. This is a good question and there are several ways of answering it. A key to understanding this phenomenon is that the density of the material and the density of an object made of that material are not necessarily the same. If a solid ball or cube of steel is placed in water, it sinks. But if that same steel is pounded and flattened thin and formed into a big bowl-like shape, the overall volume of the bowl is much greater than the volume of the steel cube. The mass of the steel is the same but the big increase in volume makes the density of the bowl less than the density of water so the bowl floats. This is the same reason why a steel ship is able to float. The material is shaped in such a way so that the density of the ship is less than the density of water.*

Activity Sheet
Chapter 3, Lesson 4
Density—Sink and Float for Solids

Name _____

Date _____

ACTIVITY

Question to investigate
Why does a heavier candle float and a lighter piece of clay sink?

Materials for each group

- 2 tea light candles in their metal containers
- Clay
- Water in cup
- Small balance
- Tape
- Dropper

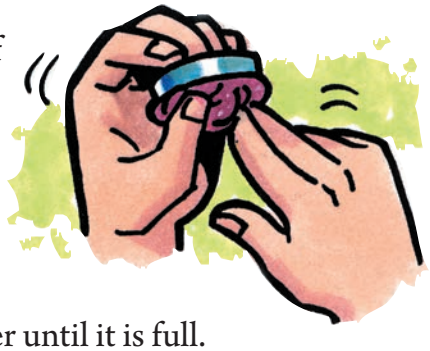
Procedure
Compare the density of wax and water

1. Roll two pieces of tape and stick them to the center of the pan at each end of the balance.
2. Attach each tea light candle to the tape so that each candle is in the center of the pan.
3. Use the wick to pull one candle out of its container.
4. Carefully pour water into the empty metal container until it fills the container to the same level as the candle in the other container. You may use a dropper to add the last bit of water and prevent spilling. The goal is to compare the mass of equal volumes of wax and water.

1. Which weighs more, wax or an equal volume of water?

   Which is more dense, wax or water?

Compare the density of clay and water



1. Make sure you have one piece of tape in the center of each pan on the balance.
2. Fill one container with clay and place it on the tape so that it is in the center of the pan.
3. Place an empty container on the tape at the opposite end of the balance.
4. Slowly and carefully add water to the empty container until it is full.

2. Which weighs more, clay or an equal volume of water?
   Which is more dense, clay or water?

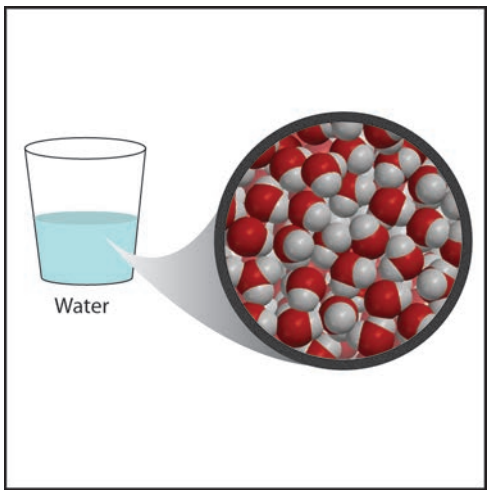
3. Knowing the density of an object can help you predict if it will sink or float in water.

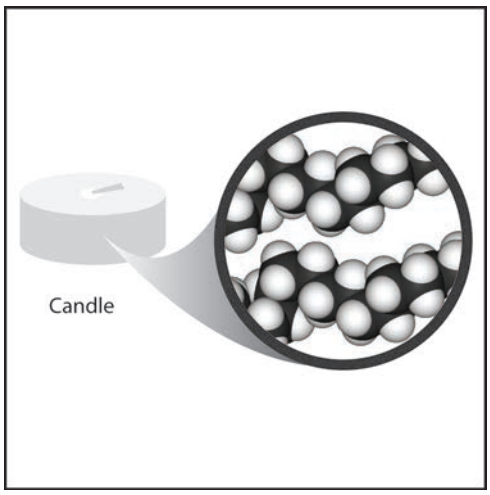
   If an object is *more dense* than water, would you expect it to sink or float?

   If an object is *less dense* than water, would you expect it to sink or float?

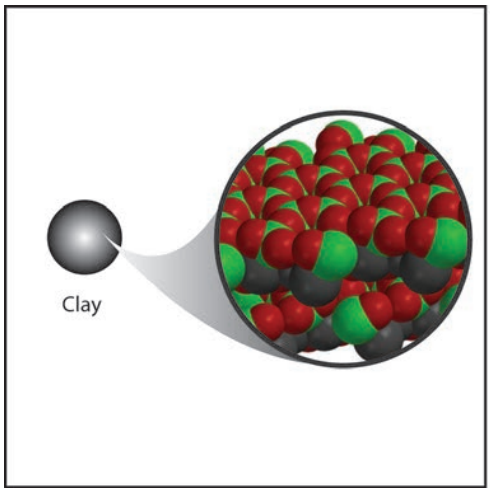
EXPLAIN IT WITH ATOMS & MOLECULES

4. Water is made up of small molecules of oxygen and hydrogen. Water molecules are closely packed together. Wax is made of carbon and hydrogen atoms connected together in long chains. Explain on the molecular level why wax is less dense than water.





Clay is made of oxygen and heavier atoms such as silicon and aluminum. Explain on the molecular level why clay is more dense than water.



TAKE IT FURTHER

5. A giant log can float on a lake while a tiny grain of sand sinks to the bottom. Explain why a heavy object like the log floats while a very light grain of sand sinks.

6. Remember that the density of water is 1 g/cm^3. Predict whether the following objects will sink or float.

Will these objects sink or float?		
Object	Density (g/cm^3)	Sink or float
Cork	0.2–0.3	
Anchor	7.8	
Wooden oar	0.4	
Apple	0.9	
Orange	0.84	
Orange without peel	1.16	

7. If a peach has a volume of 130 cm^3 and sinks in water, what can you say about its mass?

8. If a banana has a mass of 150 grams and floats in water, what can you say about its volume?

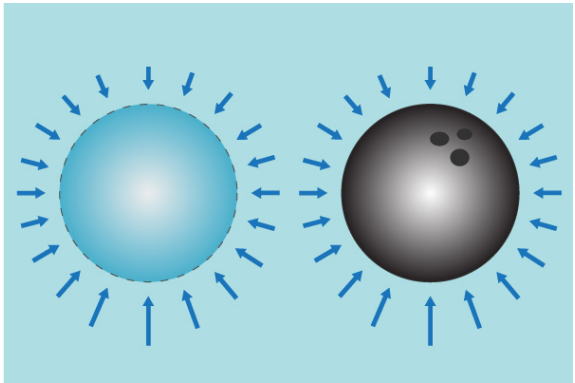
Additional Teacher Background
Chapter 3, Lesson 4, p. 205

Another way to analyze the floating ship question is based on comparing the mass of the ship to the mass of water it displaces. When an object floats, the weight of the object equals the weight of the water that the object displaces. Even though a ship is very massive, the volume is so huge that the weight of water displaced by the ship is equal to the weight of the ship.

For example, a solid cube of steel displaces a volume of water equal to the volume of the cube. But since steel is more dense than water, the weight of the cube is greater than the weight of the displaced water, and the cube sinks. But if the cube is flattened and shaped into a large enough boat and placed in water, the boat will displace more water. Its weight hasn't changed, but the volume of water it displaces has increased. When the weight of the water displaced by the boat is equal to the weight of the boat, the boat floats.

But why does the weight of the water matter and what *really* is making the boat float? This question requires a more physics-like analysis. There is a force that makes objects float called the *buoyant force*. Some curricula attempt to teach aspects of density using the concept of buoyant force but we do not recommend it for middle school students. Here is a short explanation for you:

An object in a fluid is acted on by the pressure (force /unit area) exerted by the fluid surrounding it. Because the pressure (force) is greater the deeper you go, there is more force beneath the object pushing up than the force above the object pushing down. Therefore, the buoyant force on an object is a net upward force.



In the diagram, an imaginary ball of water (on the left) is suspended or floating in the water surrounding it. Since water has a particular density, this volume of water has a certain mass and weight. The net upward force due to the buoyant force of the surrounding water is strong enough to counteract the weight of the ball of water and keep it suspended or floating in place. This means that the buoyant force is equal to the weight of the ball of water.

But what happens if the ball of water is replaced by an object that is more dense than water, like a bowling ball?

Since the bowling ball is more dense, it weighs more than the ball of water of the same volume. The buoyant force of the surrounding water is not strong enough to support this extra weight and the bowling ball sinks.

If the ball of water is replaced by a ball that is less dense than water, that ball must weigh less than the ball of water. That ball will be pushed up by the buoyant force and will float to the surface.

Chapter 3, Lesson 5: Density: Sink and Float for Liquids

Key Concepts

- Since density is a characteristic property of a substance, each liquid has its own characteristic density.
- The density of a liquid determines whether it will float on or sink in another liquid.
- A liquid will float if it is less dense than the liquid it is placed in.
- A liquid will sink if it is more dense than the liquid it is placed in.

Summary

Students will observe three household liquids stacked on each other and conclude that their densities must be different. They will predict the relative densities of the liquids and then measure their volume and mass to see if their calculations match their observations and predictions.

Objective

Students will be able to determine whether a liquid will sink or float in water by comparing its density to the density of water.

Evaluation

The activity sheet will serve as the "Evaluate" component of each 5-E lesson plan. The activity sheets are formative assessments of student progress and understanding. A more formal summative assessment is included at the end of each chapter.

Safety

Make sure you and your students wear properly fitting goggles. When using isopropyl alcohol, read and follow all warnings on the label. Isopropyl alcohol is flammable. Keep it away from any flames or spark sources. Have students wash hands after the activity.

Materials for Each Group

- Balance
- Isopropyl alcohol, 70% or higher
- Water
- Graduated cylinder
- 2 identical tall clear plastic cups
- 2 tea light candles

Materials for the Demonstration

- Balance
- Isopropyl alcohol, 70% or higher
- Water
- Graduated cylinder
- 2 identical tall clear plastic cups
- 2 tea light candles

Notes about the Materials

Isopropyl alcohol

The demonstrations and activity work best with 91% isopropyl alcohol solution, which is available in many grocery stores and pharmacies. If you can't find 91% solution, 70% will work, but your candle might not sink in it. If that happens, do not do that demonstration. Although the isopropyl alcohol solution is 91% alcohol and 9% water, you can disregard the small amount of water for the purpose of this lesson.

Balance
A simple balance is all that is required for the second demonstration. One of the least expensive is Delta Education, Stackable Balance (21-inch) Product # 020-0452-595. Students can use the smaller version of the same balance, Delta Education, Stackable Balance (12-inch), Product # 023-0724-595.

ENGAGE

1. Do two demonstrations to show that different liquids have different densities.

Materials

- Balance
- Isopropyl alcohol, 70% or higher
- Water
- Graduated cylinder
- 2 identical tall clear plastic cups
- 2 tea light candles

Teacher preparation

- Use a graduated cylinder to measure 50 mL of water and pour it into a clear plastic cup.
- Measure 50 mL of isopropyl alcohol and pour it into another identical clear plastic cup.

Procedure

Demonstrate the density of two liquids with sinking and floating

1. Place a tea light candle in a cup with water and another tea light candle in a cup with alcohol.
2. Hold up the two cups.

Expected results

The candle will float on water and sink in alcohol.

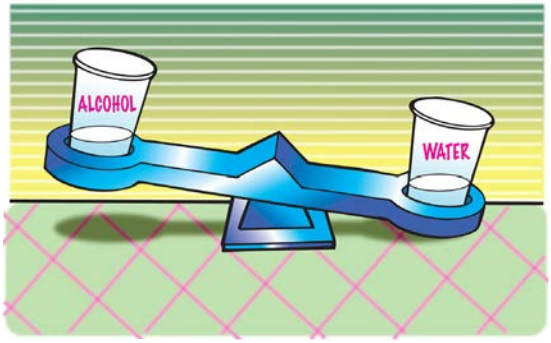
Ask students:

- **What might be causing one candle to float and the other to sink?**
  Explain that the two candles are the same. Students should reason that the liquids must be different and have different densities. Explain that the cup with the floating candle contains water and the cup with the sinking candle contains isopropyl alcohol.

- **Do you think these two liquids have the same or different densities?**
  Students should conclude that the liquids must have different densities. They may even realize that water is more dense and alcohol is less dense than the wax candle.

Procedure

Demonstrate the density of two liquids by comparing the mass of equal volumes



3. Remove the candles from each liquid and tell students that each cup contains the same volume of liquid.
4. Carefully place the cups of water and alcohol on opposite ends of a balance.

Expected results

The water will weigh more than the alcohol.

Ask students:

- **Which liquid is more dense?**
  Students should agree that the water is more dense than the alcohol.
- **How do you know?**
  Since the water has more mass than an equal volume of alcohol, water must be more dense.

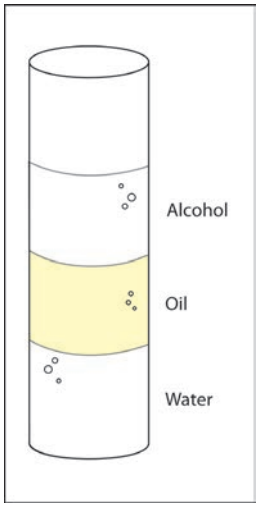
EXPLORE

2. Demonstrate that liquids can float or sink in other liquids by making a density column with water, oil, and alcohol.

Materials for the demonstration

- Graduated cylinder
- Water
- Vegetable oil
- Isopropyl alcohol, 70% or higher

***Note**: If you would like the liquids to be more visible, add 1 drop of food coloring to the water and another drop of a different color to the alcohol.*



Procedure

1. Pour about 15 mL of water into the graduated cylinder. Gradually add about 15 mL of oil. Then slowly pour about 15 mL of alcohol on top. The liquids should form layers in the graduated cylinder.
2. Show students the layered liquids in the graduated cylinder and point out that the alcohol floats on the oil while the water sinks.

Expected results
Alcohol floats on oil and water sinks in oil. Water, alcohol, and oil layer well because of their densities, but also because the oil layer does not dissolve in either liquid. The oil keeps the water and alcohol separated so that they do not dissolve in one another.
Ask students:

- **Why does the alcohol float on the oil?**
  They should conclude that the alcohol floats because it is less dense than the oil.
- **Why does the water sink in the oil?**
  Water sinks because it is more dense than oil. Explain that, just like solids, liquids are made from atoms and molecules, which have a certain mass and size. Depending on the mass of the molecules that make up a liquid and how closely they pack together, liquids have their own densities.
- **In the activity, you will compare the mass of equal volumes of each liquid. Which liquid do you think will have the most mass? The least mass? In between?**
  Students should predict that the water will weigh the most, the alcohol will weigh the least, and the vegetable oil will weigh somewhere in between.

Give each student an activity sheet.
Students will record their observations and answer questions about the activity on the activity sheet. *The Explain It with Atoms and Molecules* and *Take It Further* sections of the activity sheet will either be completed as a class, in groups, or individually depending on your instructions. Look at the teacher version of the activity sheet to find the questions and answers.

Give students time to answer the questions about the demonstration before conducting the activity.

2. Calculate the density of water, alcohol, and oil.

Question to investigate
Why does water sink in oil and alcohol float in oil?

Materials for each group

- Water
- Vegetable oil
- Isopropyl alcohol (70% or higher)
- Graduated cylinder
- Balance that measures in grams

This activity is written for students to make actual measurements of the mass and volume and to calculate the density of each liquid. Emphasize to students that they should be sure to accurately measure the volume and mass of each liquid.

Procedure

1. Find the mass of an empty graduated cylinder. Record the mass in grams in the chart on the activity sheet.
2. Pour 20 mL of water into the graduated cylinder. Try to be as accurate as possible by checking that the meniscus is right at the 20 mL mark.
3. Weigh the graduated cylinder with the water in it. Record the mass in grams.
4. Find the mass of only the water by subtracting the mass of the empty graduated cylinder. Record the mass of 20 mL of water in the chart.
5. Use the mass and volume of the water to calculate density. Record the density in g/cm^3 in the chart.
6. Follow steps 2–5 for alcohol and then oil. Be sure to measure the oil last because it does not rinse easily from the graduated cylinder.

	Water	Alcohol	Oil
Mass of graduated cylinder + liquid (g)			
Mass of empty graduated cylinder (g)			
Mass of liquid (g)			
Density of liquid (g/cm^3)			

4. Discuss whether the calculated densities support the order the liquids layer in the graduated cylinder.

Ask students:

- **Do the densities you calculated explain why liquids float and sink in one another? Explain.**
  Yes, the water is the most dense and sinks in the oil. The alcohol is the least dense and floats on the oil.

EXPLAIN

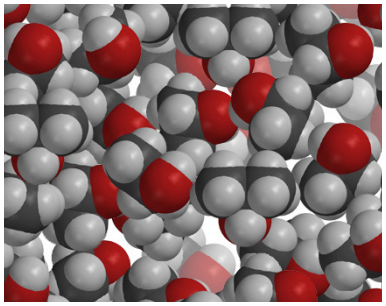
5. Compare the density of water, alcohol, and oil on the molecular level.

Depending on the mass and size of the molecules that make up different liquids and how closely they pack together, liquids have their own characteristic densities.

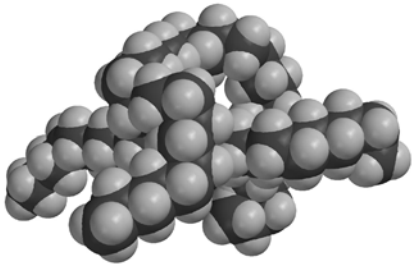
Project the image *Oil*
www.middleschoolchemistry.com/multimedia/chapter3/lesson5#oil
Tell students that molecules of oil are mostly made of carbon and hydrogen atoms bonded together.

Project the image *Water*
www.middleschoolchemistry.com/multimedia/chapter3/lesson5#water
Water molecules are made up of oxygen and hydrogen atoms bonded together. Oxygen is heavier and smaller than carbon, so a volume of water molecules is heavier than the same volume of oil molecules. This makes water more dense than oil. Also, water molecules are very attracted to each other and pack very close together. This is another reason why water is more dense than oil.

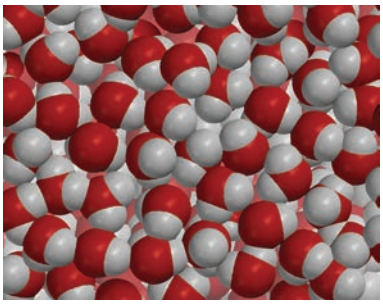
Project the image *Alcohol*
www.middleschoolchemistry.com/multimedia/chapter3/lesson5#alcohol
Alcohol is less dense than oil. Alcohol molecules are mostly carbon and hydrogen atoms so they are similar to oil. But they also contain an oxygen atom, which makes them a little heavy. For this reason, you might think that alcohol would be more dense than oil. But alcohol molecules do not pack very tightly together. Because of their shape and size, alcohol molecules do not pack as efficiently as oil molecules, making alcohol less dense than oil.



Alcohol



Oil



Water

EXTEND

6. As a demonstration, change the density of water so that a sinking carrot slice floats.

You may choose to do the following either as a demonstration or as an activity that students can do.

Materials

- Tall clear plastic cup
- Water
- Carrot slice about ¼ inch thick
- Salt
- Spoon

Procedure

1. Pour water into a clear tall plastic cup until it is about ½-filled.
2. Place a slice of carrot in the water.

Ask students:

Is the carrot more or less dense than the water?

Since the carrot sinks, students should conclude that the carrot is *more* dense than water.

3. Add about 1 teaspoon of salt to the water and stir. Continue to stir until the carrot floats to the surface of the salt water. If the carrot does not float to the surface, add more salt and stir.

Expected results

The slice of carrot should float in the saltwater.

Ask student:

- **Is it more or less dense than saltwater?**
  Since the carrot floats in saltwater, students should conclude that the carrot is less dense than saltwater.
- **How does adding salt change the density of the water?**
  Dissolving salt in water increases both the mass and volume of the water, but it increases the mass more. Because D = m/v, increasing the mass more than the volume results in an increase in density.
- **What would you expect if you placed equal volumes of water and saltwater on opposite ends of a balance?**
  If equal volumes of water and saltwater were placed on a balance, the saltwater would be heavier.

Activity Sheet
Chapter 3, Lesson 5
Density: Sink and Float for Liquids

Name _____

Date _____

DEMONSTRATION

1. Your teacher showed you one candle floating in water and another identical candle sinking in alcohol.

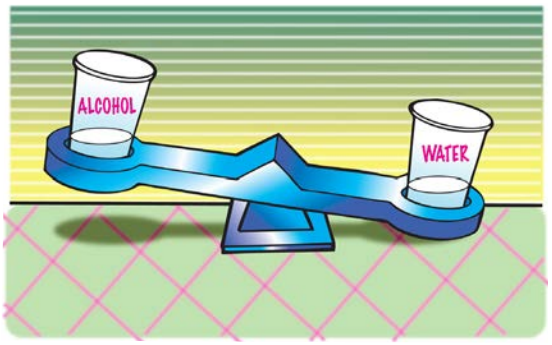
   Do water and alcohol have the same or different densities?

   Which liquid is more dense?

   How do you know?

2. Your teacher placed equal volumes of water and alcohol on a balance.

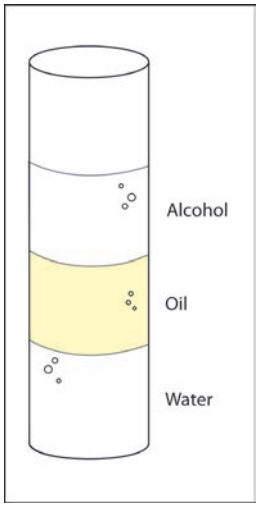
   Explain how this demonstration proves that water is more dense than alcohol. Be sure to mention both volume and mass.



3. Your teacher showed you a graduated cylinder with alcohol, oil, and water.

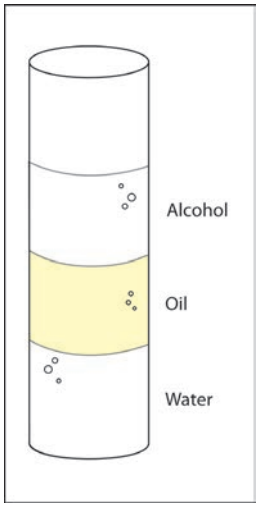
   Why does the alcohol float on the oil?

   Why does the water sink in the oil?



ACTIVITY

Question to investigate
Why does water sink in oil, and alcohol float in oil?



Materials for each group

- Water
- Vegetable oil
- Isopropyl alcohol
- Graduated cylinder
- Balance that measures in grams

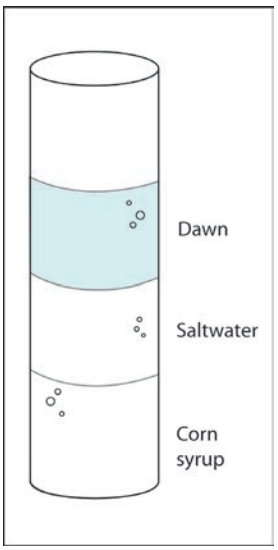
Procedure

1. Find the mass of an empty graduated cylinder. Record the mass in grams in the chart on the activity sheet.
2. Pour 20 mL of water into the graduated cylinder. Try to be as accurate as possible by checking that the meniscus is right at the 20-mL mark.
3. Weigh the graduated cylinder with the water in it. Record the mass in grams.
4. Find the mass of only the water by subtracting the mass of the empty graduated cylinder. Record the mass of 20 mL of water in the chart.
5. Use the mass and volume of the water to calculate density. Record the density in g/cm^3 in the chart.
6. Follow steps 2–5 for alcohol and then oil. Be sure to measure the oil last because it does not rinse easily from the graduated cylinder.

	Water	Alcohol	Oil
Mass of graduated cylinder + liquid (g)			
Mass of empty graduated cylinder (g)			
Mass of liquid (g)			
Density of liquid (g/cm^3)			

4. How do the densities you calculated explain why water sinks in oil and alcohol floats on oil?

5. Look at the layered liquids in the illustration. Write *most*, *least*, or *in-between* in the chart below to describe the density of each liquid.



Liquid	Density
Dawn	
Saltwater	
Corn syrup	

EXPLAIN IT WITH ATOMS & MOLECULES

6. Water molecules are smaller and have less mass than alcohol and oil molecules. Explain why water is more dense than alcohol and oil.

TAKE IT FURTHER

4. A carrot slice sinks in water and floats in saltwater.

   Is the carrot more dense or less dense than *water*?

   Is the carrot more dense or less dense than *saltwater*?

5. Does adding salt change the density of the water?

   How do you know?

6. What would you expect if you placed equal volumes of water and saltwater on opposite ends of a balance?

7. Adding salt to water increases both its mass and volume; which do you think it increases more, the mass of the water or the volume?

Chapter 3, Lesson 6: Temperature Affects Density

Key Concepts

- Heating a substance causes molecules to speed up and spread slightly further apart, occupying a larger volume that results in a decrease in density.
- Cooling a substance causes molecules to slow down and get slightly closer together, occupying a smaller volume that results in an increase in density.
- Hot water is less dense and will float on room-temperature water.
- Cold water is more dense and will sink in room-temperature water.

Summary

Students place hot and cold colored water into room-temperature water. They observe that the hot water floats on the room-temperature water and the cold water sinks. Students will combine the concepts of temperature, molecular motion, and density to learn that hot water is less dense than room-temperature water and that cold water is more dense.

Objective

Students will be able to explain, on the molecular level, how heating and cooling affect the density of water.

Evaluation

The activity sheet will serve as the "Evaluate" component of each 5-E lesson plan. The activity sheets are formative assessments of student progress and understanding. A more formal summative assessment is included at the end of each chapter.

Safety

Make sure you and your students wear properly fitting goggles. Use caution when handling hot water.

About this Lesson

In this lesson, you can help students connect some of the concepts about density to ideas from Chapter 1. In Chapter 1, students saw that heat increases molecular motion. This increased motion competes with the attractions between molecules, causing the molecules to move a little further apart. They also saw that as a substance is cooled, molecules slow down and their attractions bring them closer together. These ideas can also be applied to the concept of density.

Materials for Each Group

- Cold water (colored blue) in foam cup
- Hot water (colored yellow) in foam cup
- Room temperature water in clear plastic cup (colorless)
- 2 droppers

Materials for the Demonstration

- Hot water (colored yellow)
- Cold water (colored blue)
- 2 identical clear baby food jars
- Water-resistant card (from a deck of cards or laminated index card)
- Paper towels

ENGAGE

1. Do a demonstration to show that hot water floats on cold water.

Tell students that in Chapter 3, they have seen that different substances have different densities. In this activity, they will see that the *same* substance can have *different* densities at different temperatures.

Tell students that you are going to try to place one jar filled with hot colored water upside down over another jar with cold colored water.
Ask students to make a prediction:

- **Do you think the hot and cold water will mix or stay separate?**

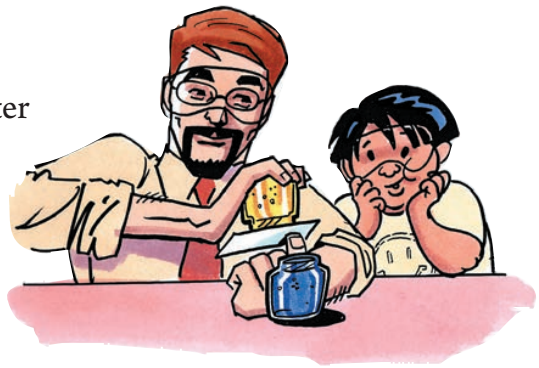
Either follow the procedure below or project the video for students. If you decide to do the demonstration, you may want to watch the video first in order to see how to set the jars up.

Project the video *Hot Water on Cold Water.*
www.middleschoolchemistry.com/multimedia/chapter3/lesson6#hot_water_on_cold water

Materials

- Hot water (about 50 °C, colored yellow)
- Cold water (about 5 °C, colored blue)
- 2 identical clear baby food jars
- Water-resistant card (from a deck of cards or laminated index card)
- Paper towels

Procedure
Hot water on top



1. Completely fill a baby food jar with hot tap water and add 2 drops of yellow food coloring.
2. Completely fill another baby food jar with very cold water and add 2 drops of blue food coloring. Stir the water in both jars so that the coloring is well-mixed in both. Place the cold water jar on a paper towel.
3. Hold a water-resistant card over the top of the hot water jar.
4. While holding the card against the jar opening, carefully turn the jar upside down.
5. With the card still in place, position the jar of hot water directly over the jar of cold water so that the tops line up exactly.
6. Slowly and carefully remove the card so that the hot water jar sits directly on top of the cold water jar.

Expected results
Although removing the card may result in a little mixing or spilling, the hot yellow water will remain in the top jar and the cold blue water will remain in the bottom jar.

Ask students:

- **Why do you think the hot water stayed on top of the cold water?**
  Students should realize that there is a density difference between hot and cold water. Hot water is less dense so it floats on the denser cold water.

Ask students to make a prediction:

- **What might happen if you placed the cold blue water on top of the hot yellow water and then removed the card?**

Cold water on top

7. Use the same procedure as above, but place the jar of cold water, upside down over the jar of hot water.

Expected results
The cold blue water will immediately fall into the hot yellow water causing mixing. The water will quickly become green throughout.

Ask students:

- **Why do you think the hot and cold water mixed when the cold water was placed on top?**
  When the cold water is placed on top, the colors mix because the cold water is more dense and sinks in the hot water.

Give each student an activity sheet.
Students will record their observations and answer questions about the activity on the activity sheet. The *Explain It with Atoms and Molecules* and *Take It Further* sections of the activity sheet will either be completed as a class, in groups, or individually depending on your instructions. Look at the teacher version of the activity sheet to find the questions and answers.

EXPLORE

2. Have students try adding cold and hot water to room-temperature water.

Question to investigate
Is there a density difference between hot and cold water?

Materials for each group

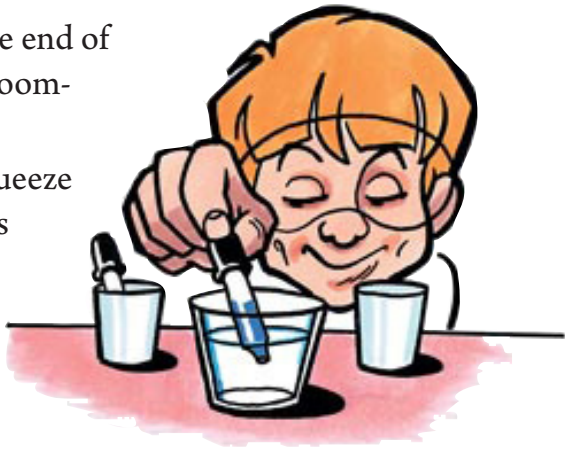
- Cold water (colored blue) in foam cup
- Hot water (colored yellow) in foam cup
- Room-temperature water in clear plastic cup (colorless)
- 2 droppers

Teacher preparation

- Add ice to water to make very cold water. Half-fill one foam cup with cold water (no ice cubes) and another with hot water for each group.
- Add 2 drops of yellow food coloring to the hot water and 2 drops of blue food coloring to the cold water.
- Fill a clear plastic cup about ⅔ of the way with room-temperature water.
- Distribute the set of 3 cups to each group.

Procedure

1. Fill one dropper with blue cold water. Poke the end of the dropper about halfway into the colorless room-temperature water.
2. While observing from the side, very gently squeeze the dropper so that the cold water slowly flows into the room-temperature water.
3. Fill another dropper with yellow hot water. Poke the end of the dropper about halfway into the room-temperature water.
4. While observing from the side, very gently squeeze the dropper so that the hot water slowly flows into the room-temperature water.
5. Record your observations on the activity sheet.



Expected results

The cold blue water will flow down and collect at the bottom of the room-temperature water. The hot yellow water will rise and collect at the surface.

3. Discuss student observations.

Ask students:

About cold water

- **What did you notice when you placed the cold blue water in room-temperature water?**
  The cold water sank in the room-temperature water.

- **Is cold water more, less, or the same density as room-temperature water?**
  Cold water is more dense than room-temperature water.

About hot water

- **What did you notice when you placed the hot yellow water in room-temperature water?**
  The hot water floated to the surface in the room-temperature water.
- **Is hot water more, less, or the same density as room-temperature water?**
  Hot water is less dense than room-temperature water.

EXPLAIN

4. Explain the difference in density between hot and cold water on the molecular level.

Project the animation *Cold and Hot Water*.
www.middleschoolchemistry.com/multimedia/chapter3/lesson6#cold_and_hot_water

Cold water
Point out that the molecules of cold water move slower and are a little closer together than the hot or room-temperature water. Also point out that when the water is cooled, the water level falls slightly in the graduated cylinder.

Ask students:

- **In the animation, you saw that as water is cooled the water level goes down. Cold water has a smaller volume, but the mass stays the same. What does this tell you about the density of cold water?**
  Students should understand that when the molecules come together as the water is cooled, the volume decreases. But the mass of the water does not change. Students should realize that decreasing the volume without increasing the mass is going to increase the density.
- **How does this help explain why cold water sinks in room-temperature water?**
  The more-dense cold water sinks in the room-temperature water.

Hot water
Point out that the molecules in the hot water are moving faster and are a little farther apart than the molecules in room-temperature water. Make sure students notice that when the water is heated, the water level rises slightly in the graduated cylinder.

Ask students:

- **In the animation, you saw that as water is heated the water level rises. Hot water takes up more volume, but the mass stays the same. What does this tell you about the density of hot water?**
  Based on the animation, students should understand that the spreading apart of the molecules increases the volume but does not affect the mass of the water. Students should realize that increasing the volume without increasing the mass is going to decrease the density.
- **How does this help explain why hot water floats on room temperature water?**
  The less-dense hot water floats on the more dense room temperature water.

EXTEND

5. Do a demonstration to show students how dense cold water causes mixing.

Tell students that in winter, ice can form on the tops of ponds and lakes. In the spring when the ice melts, the cold water sinks. This causes mixing from the bottom which brings nutrients up to the surface. Tell students that you will model this process.

Materials

- Room-temperature water
- Ice cubes
- 2 identical tall clear plastic cups
- Small cup
- Food coloring, any color other than yellow
- Dropper
- Sheet of plain white paper

Procedure

1. Fill two tall clear plastic cups about ⅔ of the way with room-temperature water.
2. Place about 15 drops of food coloring into a small empty cup.
3. Use a dropper to pick up the food coloring. Then carefully push the dropper into the water until the tip of the dropper is near the bottom of the cup.
4. Very gently squeeze the dropper so that all of the food coloring slowly flows to the bottom of the cup. Then carefully remove the dropper to prevent food coloring from mixing into the water. (It is ok if a little coloring gets mixed in the water.)
5. Repeat steps 2–4 for the other cup of water.
6. Gently place two ice cubes in the water in one of the cups. (Avoid agitating the water.)
7. Place a piece of white paper behind each cup and observe.

Expected results

The coloring in the cup with the ice will move up from the bottom and begin to mix throughout the water. The coloring in this cup will mix faster than the coloring in the cup without ice.

Ask students:

- **The food coloring mixed more quickly in the cup that had the ice. Use what you know about the density of water at different temperatures to explain why this happened.**
  Ice is about 0 °C and the water in the cup is about 20 °C. As the ice melts, the water from the melted ice is colder than the water around it. This colder water is also more dense, so it sinks to the bottom. This sinking water pushes the food coloring out of the way, causing mixing.

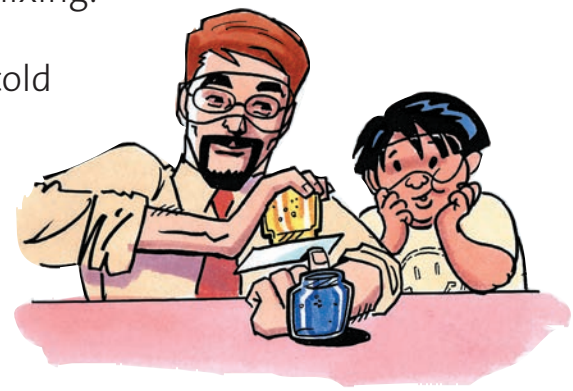
Activity Sheet
Chapter 3, Lesson 6
Temperature and Density

Name _____

Date _____

DEMONSTRATION

You saw a jar of hot water placed upside down over a jar of cold water. The hot water stayed on top of the cold water without mixing.



1. Why did the hot water stay on top of the cold water?

2. Why do you think the hot and cold water mixed when the cold water was placed on top?

ACTIVITY

Question to investigate
Is there a density difference between hot and cold water?

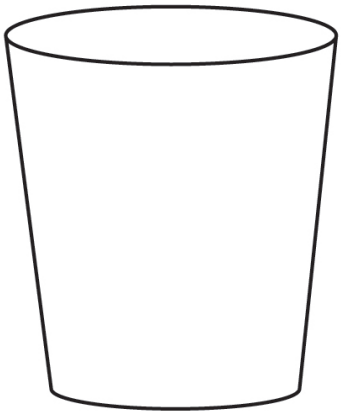
Materials for each group

- Cold water (colored blue) in foam cup
- Hot water (colored yellow) in foam cup
- Room-temperature water in clear plastic cup (colorless)
- 2 droppers

Procedure

1. Fill one dropper with blue cold water. Poke the end of the dropper about halfway into the colorless room-temperature water.
2. While observing from the side, very gently squeeze the dropper so that the cold water slowly flows into the room-temperature water.
3. Fill another dropper with yellow hot water. Poke the end of the dropper about halfway into the room-temperature water.
4. While observing from the side, very gently squeeze the dropper so that the hot water slowly flows into the room-temperature water.
5. Record your observations on the activity sheet.

3. Draw what you observed in the cup of room-temperature water after adding blue cold water and yellow hot water.



Be sure to label the areas of cold and hot water.

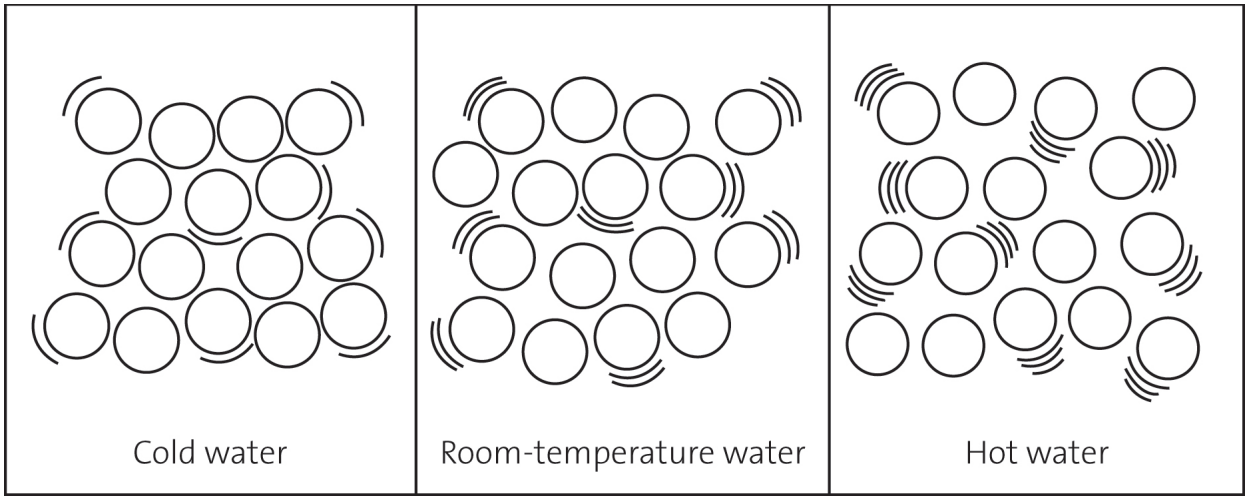
Is *cold* water more, less, or the same density as room-temperature water?

Is *hot* water more, less, or the same density as room-temperature water?

EXPLAIN IT WITH ATOMS & MOLECULES

In the animation, you saw water molecules being heated and cooled.

4. Look at the model of water molecules in the diagram below to help you compare the volume, mass, and density of cold and hot water.



Write *more*, *less*, or *same* in the chart to describe the volume, mass, and density of cold and hot water compared to room temperature water.

Comparing cold and hot water to room-temperature water		
	Cold water	**Hot water**
Volume		
Mass		
Density		

5. Use what you know about density to answer the following questions.

   Why does cold water sink in room-temperature water?

   Why does hot water float on room-temperature water?

TAKE IT FURTHER

3. Your teacher did a demonstration with two cups of water that both had food coloring on the bottom. Ice was placed in one cup of water, but not the other. The food coloring mixed more quickly in the cup that had the ice. Use what you know about the density of water at different temperatures to explain why this happened.

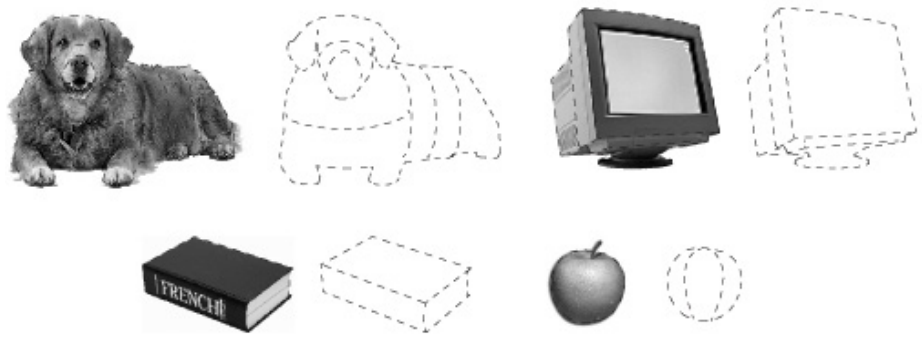
***Note**: Students may wonder why boats made out of dense material like steel can be made to float. This is a good question but not trivial to explain. To adequately answer this question, you will need to consider another aspect of sinking and floating. For an object to float, the mass of the water displaced by the object must equal the mass of the object. For example, a cube of steel will displace a certain volume of water equal to the volume of the cube. But the mass of the water displaced is less than the mass of the cube, so the cube sinks. But if you flatten out the steel cube and shape it into a large enough bowl and place the steel bowl in the water, the bowl will float. Its mass hasn't changed, but the volume of water it can displace has increased. The mass of the water displaced now equals the mass of the bowl and the bowl floats. You could stop your explanation here but there is another good question that can arise.*

Why should the *mass* of water displaced matter? This question requires a more physics-like perspective to answer. The mass of the bowl is pushing down onto the water by a force equal to the mass of the bowl × the acceleration of gravity (Force = m × a). There is a law in physics that says that for every force on a stationary object, there is an equal and opposite force. In this case, the downward force of the bowl on the water is met with an equal force of the water pushing up on the bowl resulting in the bowl floating. If students have any question about an opposing upward force, ask them if they have ever tried to push an inflated ball like a beach ball under water.

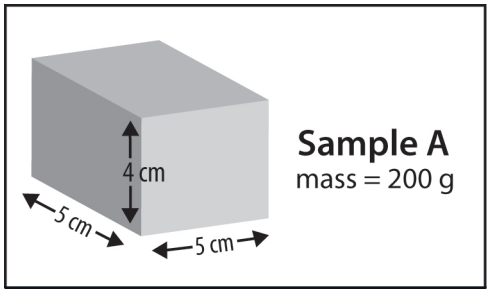
Chapter 3—Student Reading

If you hold a solid piece of lead or iron in your hand, it feels heavy for its size. If you hold the same size piece of balsa wood or plastic, it feels light for its size. The property of an object that causes this effect is called *density*. The density of an object depends on its mass and its volume. The mass is the amount of matter in the object. The volume is the amount of space that the object takes up in three dimensions.

All the objects around you take up a certain amount of space, no matter what shape they are. They all have length, width, and depth so they take up space in three dimensions.



These pictures show that every object has a volume that takes up 3-dimensional space.
The volume of a wooden block, for instance is its length × width × height. For the block shown, the volume equals 5cm × 5cm × 4 cm = 100 cubic centimeters (cm^3).



A mathematical equation for density is: Density = mass/volume or D = m/v. If something has a large mass compared to its volume, it has a high density. This is like a set of weights which can be small but heavy.

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But if an object has a small mass compared to its volume it has a lower density. This is like an apple or a piece of wood which can seem light for its size.

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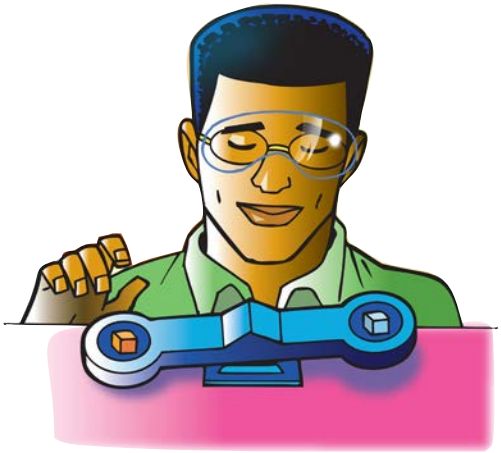
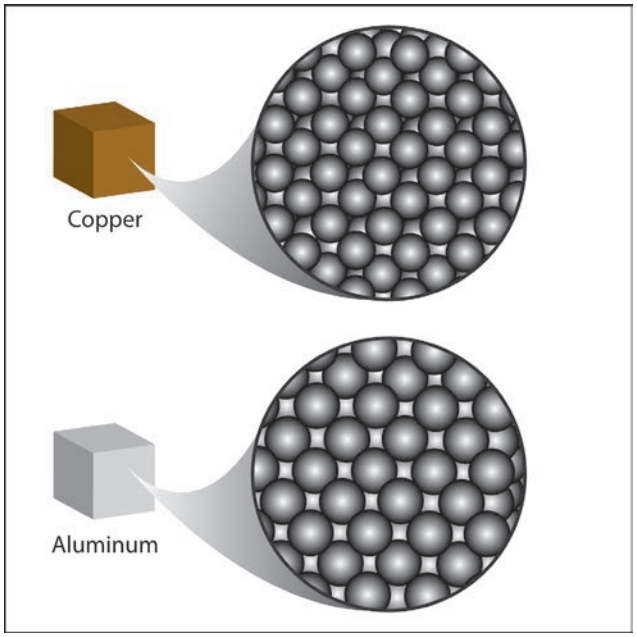
Different types of plastic, metal, wood, and other materials have different densities. The density of a material is based on the atoms or molecules the substance is made from. For example, a copper and an aluminum cube of the same volume feel very different when you hold them. The copper cube feels much heavier than the aluminum cube. If you put them on a balance, you see that the copper cube has more mass than the aluminum cube.



Since the cubes have the same volume and the copper has a greater mass, the copper cube is more dense than the aluminum cube. This is true since D = m/v. If the cubes have the same volume, the one with the greater mass must be more dense.

If you think about the atoms of the two metals, there can only be a couple of reasons why the copper is more dense than the aluminum:

- Copper atoms might have more mass than aluminum atoms.
- Copper atoms might be smaller than aluminum atoms so more can fit in the same volume.
- Copper atoms might be arranged differently than aluminum atoms so more can fit in the same volume.



Either one or any combination of these explanations could be the reason why the copper cube has more mass. It turns out that copper and aluminum atoms are arranged about the same way but copper atoms are smaller and have more mass than aluminum atoms.

Therefore more can fit into the same volume and each one has more mass. This makes copper more dense than aluminum.

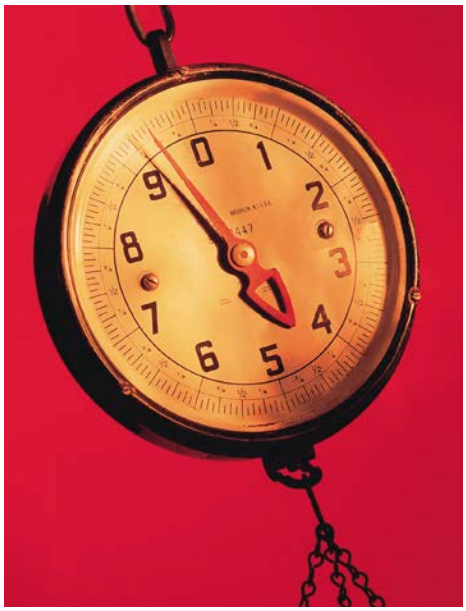
A sample of a substance with a higher density will always have a greater mass than the same size sample of a substance with a lower density. For example, a sample of lead weighs more than the same size sample of wax.

A small sample of a substance with a high density may weigh as much or more than a larger sample of a substance with a lower density. For example, a small piece of iron may weigh as much or more than a larger piece of plastic.

A closer look at mass and volume

In order to find the density of a substance, you need to measure the mass and the volume of a sample of the substance.

Mass is the amount of matter in an object.



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People are often confused between the meaning of "mass" and "weight". The meaning of mass and weight are different but they are related to each other. Let's say you have an object like a bowling ball. The bowling ball, like everything else, is made of a certain amount of matter. Let's call the amount of matter that makes up the bowling ball the *mass* of the bowling ball. You hook the bowling ball to a scale that shows that the amount of mass that makes up the bowling ball weighs 9 pounds.

Then you do something unusual: You fly the bowling ball and the scale to the moon and hook the bowling ball to the same scale again. The moon has less gravity than Earth so the bowling ball is not pulled down as hard as it was on Earth.

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Let's say that on the moon, the scale shows that the mass that makes up the bowling ball weighs only 1.5 pounds. You know that the bowling ball itself didn't change. It is still made of the same amount of matter so it still has the same mass. The only thing that changed was the force of gravity pulling down on the bowling ball.

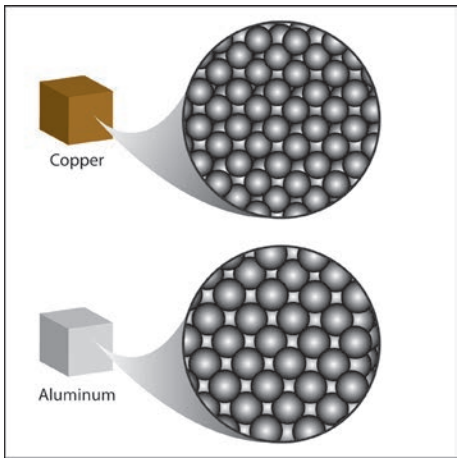
So mass is a measure of the amount of matter that makes up an object. Weight is a measure of the force of gravity on a certain mass.

So how can you measure the mass of an object by putting it on a scale? Since gravity is pulling down on the object, why doesn't a scale always measure weight? That is a great question and the answer has to do with how the scale is made.

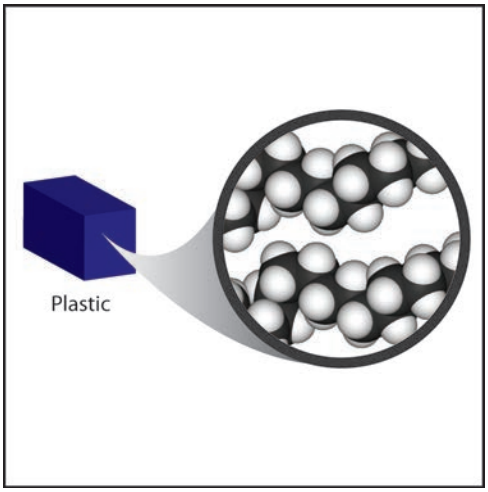
When you put an object on a scale, of course the scale "feels" the effect of gravity but the scale is programmed or calibrated to do an internal calculation to factor out the effect of gravity and to display only the mass.

The density of copper is greater than the density of plastic or wood

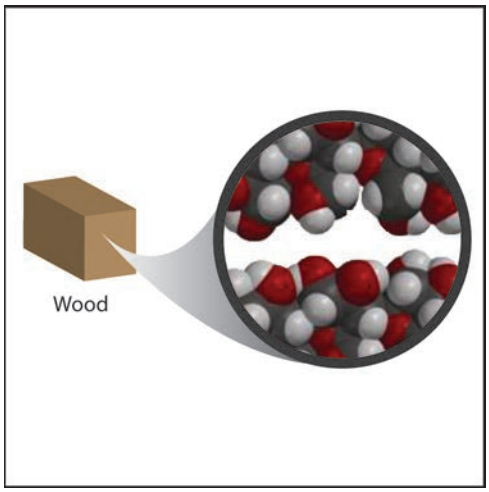
If you compared the density of a copper cube and a plastic cube of the same volume, the copper is more dense. This is because copper is made from small massive atoms that are packed closely together. This gives copper a fairly high density.



Plastics are made mostly of carbon and hydrogen which are not as massive for their size. They are connected together in long chains and not packed as tightly as the atoms in copper. This makes plastic less dense than copper.



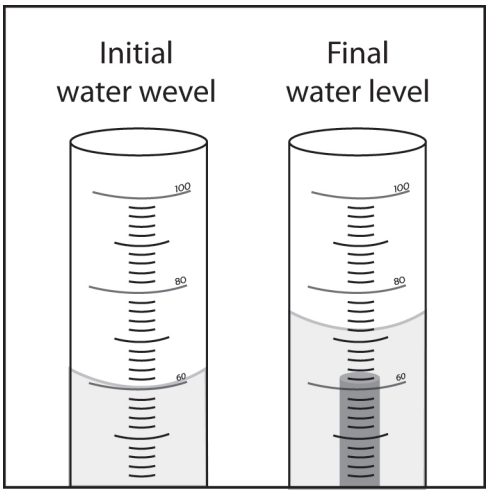
Wood is made of carbon, hydrogen, and oxygen atoms. These are pretty similar in size and mass to the atoms in plastics. Wood is also made mostly of long molecules that are arranged and packed together to make the structure of the wood.



Because of the size, mass, and arrangement of its molecules, the density of wood is more similar to plastic than to copper.

Finding volume using the water displacement method

Sometimes finding the volume of an object is not as easy as simply using a metric ruler to measure its length, width, and height. Another method is the water displacement method. There are two basic ways of doing the water displacement method to find volume.



Fill a graduated cylinder with water to a level that is high enough so that the object placed in the water will be submerged. Record the initial level of the water.

Carefully place an object in the water and let it sink to the bottom. If it doesn't sink, push it down gently with something thin like a pencil point so that it is just under the surface. The water level will rise. Record the final water level. Subtract the initial water level from the final water level to calculate the volume of water that was displaced by the object. The volume of water displaced by an object equals the volume of the object. In this case the final water level (72 mL) - initial water level (60 mL) = 12 mL. Since a milliliter is the same as a cubic centimeter (cm^3), the volume of the object is 12 cm^3.

Another water displacement method:

Place a cup or beaker in a larger container. Fill the cup as full as possible until it is ready to overflow. Gently place an object in the water and let it sink to the bottom. If it doesn't sink, push it down gently with something thin like a pencil point so that the object is just under the surface.

Some water will flow out of the cup and into the outer container. This water was displaced by the object. Carefully pour this water into a graduated cylinder to measure its volume. The volume of the displaced water equals the volume of the object.

The density of a substance is the same no matter what the size of the sample.

This means that a big piece of wax, for example, has the same density as a small piece of the same wax. Take water for instance. 100 mL of water has a mass of 100 grams. Since density = mass/volume, this sample of water has a density of 100 grams/100 mL = 1 gram/mL = 1 g/cm^3. 50 mL of water has a mass of 50 grams. The density of this sample of water is 50 grams/50 mL = 1 gram/ cm^3.

Water or any substance always has the same density no matter what the size of the sample.

Density in sinking and floating

The density of an object and the density of the liquid it is placed in determine whether an object will sink or float.

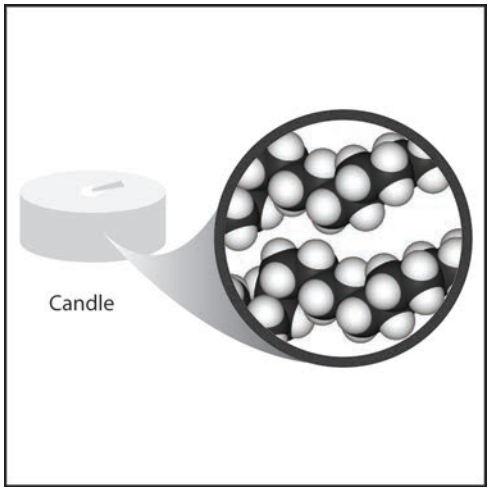
Even though one object might be heavier than another, the heavy one might float and the lighter one might sink. An example is a piece of clay and a heavier wax candle placed in water. Even though the wax is heavier than the clay, the wax floats and the clay sinks.

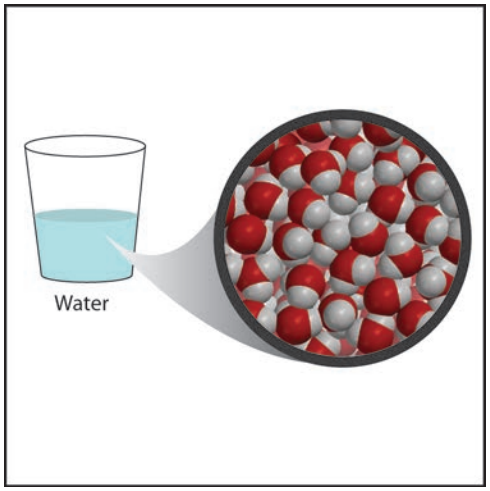
This is possible because its not the mass of the object that matters in sinking and floating but its density compared to the density of water.

An object that is less dense than water will float. An object that is more dense than water will sink. This is why the clay sinks in water and the wax floats. The clay is more dense than water and the wax is less dense than water.

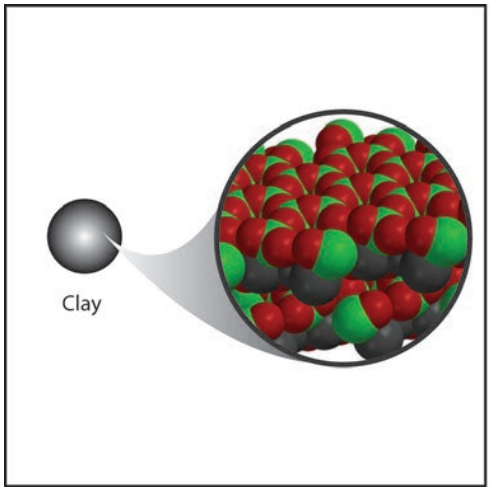
Since water is more dense than wax, a volume of water has more mass than an equal volume of wax. You can prove this by putting a volume of wax and an equal volume of water on opposite ends of a balance. The balance will show that the water has a greater mass than the wax. This means that the water is more dense than the wax. This is why the wax floats.

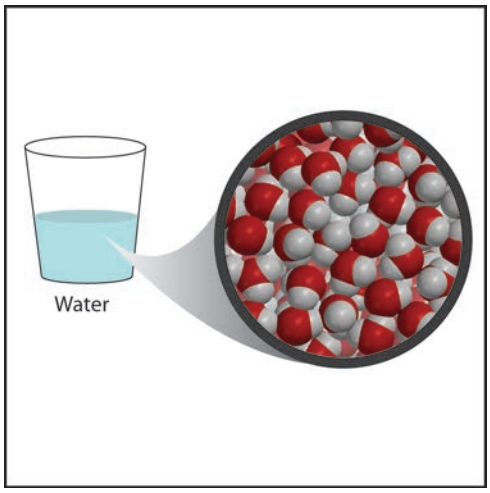
Wax is made of carbon and hydrogen atoms linked together into long molecules.
These atoms are pretty light and the arrangement of the molecules makes wax less dense than water.





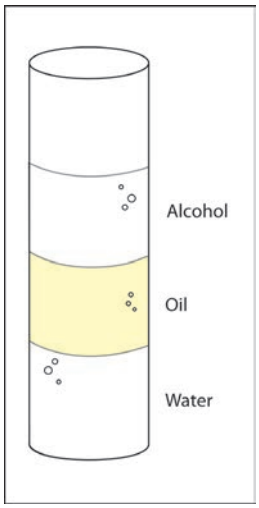
If you put a volume of clay and an equal volume of water on opposite ends of a balance, the balance will show that the clay has more mass. This means that the clay is more dense than the water. This is why the clay sinks. Clay is made from oxygen and heavier atoms like aluminum and silicon. The mass of these atoms and their arrangement make clay more dense than water.





Liquids can sink and float in other liquids

Sinking and floating applies to liquids too. You can test this by carefully placing different liquids together in a graduated cylinder. For example, if you add vegetable oil to water, the oil floats on the water. If you add isopropyl alcohol, the alcohol floats on the oil.



This means that oil is less dense than water and alcohol is less dense than oil.

The density of an object or the water it is placed in can be changed so that an object that normally sinks will float.

If an object sinks in water, this means that the object is more dense than the water. There are two possible ways to make the object float. You can increase the density of the water so that the water becomes more dense than the object. Or you could increase the volume of the object so that the object becomes less dense than the water.

If you put a slice of carrot in water, the carrot sinks. This is because the carrot is more dense than water. But if you dissolve something like salt in the water, the density of the water increases.

This is because the mass of the water increases a lot and the volume does not increase as much. Since D=m/v, increasing mass a lot and volume just a little will result in an increase in density. If enough salt dissolves, the density of the water can be increased enough that the salt water will become more dense than the carrot and the carrot will float.