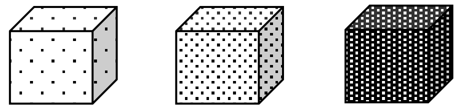
Density
Student Handout

Background

Density is a property of all matter, including solids, liquids, and gases. The density of a substance is a measure of how "tightly packed" it is, or how much matter is present in a certain volume of the substance.



The density of an object is equal to its mass divided by its volume.

Density = ρ = m/v = mass / volume

From this formula, you can see that when their volume is the same, objects with a greater density contain more matter and have a greater mass. Therefore, for objects of equal size, the denser object will weigh more. If two liquids have different densities, the liquid with the lower density will float on top of the other. A solid that is less dense than a liquid will float in the liquid (for example, most kinds of wood in water), while a solid that is more dense than the liquid will sink (for example, metal in water).

Each element or compound has its own density, which is always the same for a given temperature and pressure.

Element or Compound	Density (g / cm^3, at room temperature and pressure)
Helium	0.000176
Oxygen	0.001331
Wood (Balsa)	0.16
Wood (Oak)	0.75
Sodium	0.968
Plastic (Polyethylene)	0.93
Water	0.997
Sea Water (average)	1.025
Copper (II) Sulfate (for blood testing)	1.05
Blood	1.06
Plastic (Nylon)	1.15
Wood (Ebony)	1.2
Plastic (PVC)	1.5
Aluminum	2.70
Carbon (graphite)	2.267
Carbon (diamond)	3.513
Zinc	7.14
Iron	7.86
Copper	8.96
Silver	10.49
Lead	11.34
Gold	19.3
Platinum	21.45

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Experiment #1: Measuring the density of a regular object

Background
The density of an object can be calculated by dividing its mass by its volume.

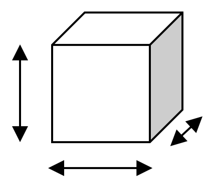
density = ρ = mass / volume

For a **regular object**, the volume is easily calculated from the geometric formula for volume for that shape.

Materials
1 Die
1 Penny
Scale (ruler)
Balance

Protocol / Data and Analysis
Part 1a. Measuring the density of a cube
1. Measure the sides of the die in centimeters, cm. Calculate the volume using the formula for the volume of a cube.

Length x width x height = volume



The volume of the die is: _______________ (in cm^3)

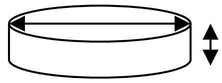
2. Weigh the die to find its mass (in grams, g). The mass of the die is: _____________ (in g)

3. Calculate the density of the die by dividing the mass by the volume. The density is: ____________ (in g/cm^3)

Part 1b. Measuring the density of a cylinder
1. Measure the diameter and the height of the penny in centimeters, cm. Calculate the volume using the formula for the volume of a cylinder.

Area x height = volume

π x $radius^2$ x height = 3.14 x $(diameter / 2)^2$ x height = volume



The volume of the penny is: ______________ (in cm^3)

2. Weigh the penny to find its mass (in grams, g). The mass of the penny is: _______________ (in g)3.

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3. Calculate the density of the penny by dividing the mass by the volume. The density is: ______________(in g/cm^3)

Discussion Questions

1. Which weighs more: the die or the penny?

2. Which is denser: the die or the penny? What does this say about the materials used to make each of these objects?

3. As a class, compare the densities you calculated for your penny. Do you notice any differences? What might explain the difference?

<u>Experiment #2: Measuring the density of an irregular object</u>

Background
An irregular object is one whose volume cannot be calculated easily with a geometric formula. For an irregular object, you can still calculate density by dividing the mass by the volume, but the volume can be much more difficult to calculate. For this activity, you will use an ancient trick to measure the volume of an irregular object, immersing it in water. The object takes up some of the space formerly occupied by the water, so the height of the water will increase. The change in volume will be equal to the volume of the object.

> The Greek mathematician Archimedes (c. 287 BC – c. 212 BC) is frequently credited with inventing the method of measuring the density of an irregular object. King Hiero II suspected that his gold crown had been mixed with less expensive metals and wanted Archimedes to find the density of the crown, but he would not let him melt it down into an easily measurable shape. While taking a bath, Archimedes realized that he displaced an amount of water equal to his volume, and he was so excited at his discovery that he ran through the streets naked yelling, “Eureka!” (“I have found it!”). He used this method to measure the volume of the crown and determined that it was indeed not solid gold and that the king had been cheated.

Materials
1 Graduated cylinder
40mL Water
1 Irregular object (note: groups with the glass beads should measure them together)
Balance

Protocol / Data and Analysis
1. Weigh the object to determine its mass. The mass of the object is: _______ (in g)

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2. Add 40mL of water to the graduated cylinder.

3. Without splashing the water, place the object in the graduated cylinder. Measure the height of the water (in milliliters, mL).

The height of the water after addition of the object is: ______ (in mL)

4. To find the volume of the irregular object, subtract 40mL from the final volume of the water plus the object.

The volume of the object is: _______ (in mL)

5. Now, calculate the density by dividing the mass by the volume. The density is: ________ (in g/mL = g/cm^3)
The unit mL is equivalent to the unit cm^3, so you can easily compare the densities of the regular and irregular objects.

Discussion Questions

1. How does measuring the density of a regular and irregular shape differ?

2. Compare the densities of your regular and irregular objects. Which was the densest? What does this say about the materials that make up your objects?

<u>Experiment #3: Layered Column</u>

Background
This experiment involves layering common household liquids in a column. The liquids have different densities, and they will form layers in order by density. Food coloring is added to some of the liquids to make the layers easier to see.

Materials
10-20mL of: (see hints)
- Water (dyed blue)
- Vegetable oil
- Isopropanol (rubbing alcohol), 91% (dyed yellow)
- Dish soap
- Syrup
- Baby oil

6 Dixie cups (one for each liquid)
1 clear cup

Safety
Although the liquids used in this experiment are common household liquids, students should not ingest any of them. Isopropanol may cause irritation if it comes into contact with the eyes.

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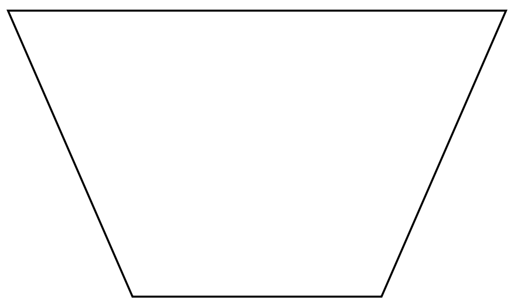
Protocol / Data and Analysis

Part 3a. Making a layered column

1. Pour 10-20mL of water, isopropanol, vegetable oil, syrup, and dish soap into separate Dixie cups (one-third to two-thirds full).
2. The densities of the liquids are listed in the table below. Based on their densities, what order do you think the liquids will take? Record your prediction in the table (under "Expected order").

Liquid	Density (g/cm^3, at room temperature and pressure)	Expected order in column (1 = bottom, 5 = top)	Actual order in column (1 = bottom, 5 = top)
Water	0.998		
Isopropanol	0.786		
Vegetable Oil	0.922		
Dish Soap	1.060		
Syrup	1.325		

3. Slowly add the liquids one at time by pouring them down the side of the clear cup in the order they are listed in the table.
4. Draw your layered column, labeling each of the liquids:



5. Record the order of the liquids in the table (under "Actual order"). How does the order correspond to the density of the liquids? Does this match your prediction?

Part 3b. Estimating the density of a liquid

Now, you will estimate the density of another liquid and use this information to predict where it will go in your column.

6. Weigh an empty Dixie cup. The weight of the empty cup is: ___________ (in g)

7. Measure exactly 15mL of baby oil in a graduated cylinder. Pour it into the cup and weigh it again.

   The weight of the cup plus the baby oil is: ____________ (in g)

8. To find the weight of the baby oil, subtract the weight of the empty cup from the weight of the cup with the baby oil.

   (Weight of cup + weight of baby oil) – (weight of cup) = weight of baby oil

   The weight of the baby oil is: ___________ (in g)

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9. To calculate the density of the baby oil, divide the mass (in g) by the volume (15 mL).

   The density of baby oil is: ______________ (in g/mL)

10. Now that you know the density of the liquid, where do you expect this liquid will layer in your column?

    Between ________________________ and __________________________.

11. Slowly pour the baby oil into the cup. Was your prediction correct?

Discussion Questions

1. Summarize the results of the experiment. How does density affect the position of a liquid relative to other liquids?

2. How does estimating the density of a liquid differ from estimating the density of a regular or irregular solid?

3. Can you think of an example from daily life where you have observed liquids with different densities interact? What does this say about their relative densities?

Optional online extension: http://www.youtube.com/watch?v=KzUEr7uMnXU (An underwater lake. The "lake" water is of a much higher salinity than the surrounding water, increasing its density.)

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Experiment #4: Density changes with temperature and pressure (online demonstrations)
Changing the **temperature** of a substance or the **pressure** surrounding it affects its density, because it alters the volume of the substance without adding or taking away any of its mass.

For example, gases **expand** (take up more volume) when heated and **contract** (take up less volume) when cooled, so they are less dense when hot. This is very important for weather: when a warm front and a cold front collide, the warm front rises above the cold front because it is less dense. Then, it cools down at the higher elevation, releasing precipitation. Similarly, hot air balloons rise because they heat the air inside the balloon to make it less dense than the surrounding air.

Substances placed under greater pressure **compress**, resulting in a greater density. Deep-sea divers need to be careful because they are under greater pressure in deep water than on land. While underwater, they breathe in gases that are denser than they are on the surface. As they come back up to surface pressure, the gases in their blood vessels expand and can form bubbles. Unless they come up to the surface slowly to allow the gases to gradually exit the body, they can get a painful and sometimes fatal condition called decompression sickness (the bends).

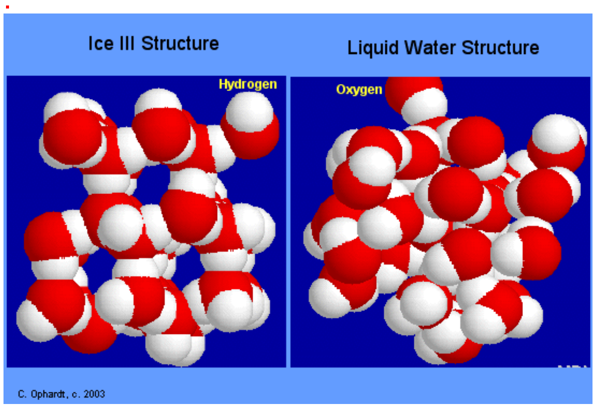
The following examples demonstrate how density changes when temperature and pressure are changed:

http://www.youtube.com/watch?v=Ak9CBB1bTcc, (hot water rises above cold water when they are mixed)
http://www.youtube.com/watch?v=n-3cu_Q119s (a steel drum imploding as the air inside rapidly cools)
http://www.youtube.com/watch?v=qEIBfMGstp0 (Styrofoam cup shrinking in a pressure cooker)
http://www.youtube.com/watch?v=NLRpbJ9bHKE (Styrofoam cup shrinking after exposure to deep ocean pressure)

Discussion Questions

1. When the temperature of a substance increases, its molecules have greater energy and move farther apart. What effect did temperature have on the density of water in the water mixing demonstration?

2. An exception to this rule is ice. In general, most compounds become denser as they transition from liquids to solids, because their molecules are more closely packed. The solid compound will sink in the liquid compound, because it is denser. Ice, however, floats on water. Why do you think this is?



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3. When an object is placed under higher pressure, its molecules are forced closer together. A Styrofoam cup will shrink deep in the ocean because the surrounding water exerts stronger pressure on the cup than air does. What effect does this have on the density of the cup?

Extension Questions

1. Oil is typically less dense than water. During an oil spill, specialized boats called oil skimmers are deployed to help clean-up efforts. Based on your knowledge of the behavior of liquids of different densities, what do you think an oil skimmer does?

2. Have you or anyone in your family ever donated blood? To qualify for blood donation, a person must have a sufficient amount of hemoglobin (the protein that carries iron) in his/her blood. Based on your knowledge of density, what do you think would be a quick test for this?

3. Body mass index (BMI) is a measurement that compares a person's height (as an estimate of volume) and weight to determine whether they are within a healthy weight range. However, athletes tend to have higher BMIs than nonathletes of the same size. Why do you think this is?