**Lesson 5 – Density is a Relationship Between Mass and Volume**

**Storyline Summary:**

Now that students have experience measuring mass and volume, set the stage to introduce the concept of ***density***. You could continue the discussion from the previous lesson about why density might be important in how the Lava Lamp works. With careful questioning, and using examples, you can lead students to understand that the amount of mass in a certain volume can be shown with a mathematical formula or ratio, *density equals* *mass divided by volume* or D=m/v.

Through two teacher demonstrations, students observe objects of the same volume with different masses, and then objects of the same mass but different volumes. Students develop the understanding that density is a measure of the amount of mass in a unit of volume.

Students also conclude that density is a characteristic property of a substance based on its atoms and molecules and can be used to identify a substance. If you know the mass and the volume of a pure substance, you can calculate the density to determine what the substance is.

Students also extend their learning with an activity where they graph the mass and volume of a specific type of matter to see that the slope is a straight line – the relationship between mass and volume is constant.

**Note:** This lesson covers two demonstrations and one activity and is presented in three parts. Depending on the amount of questioning and class discussion, this lesson should take at least two class periods.

**What Students Do**

**Part 1:** Students observe a teacher demonstration measuring the mass of a copper and an aluminum cube of the same volume. Students see that different materials have different densities and relate the density of each material to the atoms it is composed of.

**Part 2:** Teacher demonstrates three rods of different materials all with the same mass but different volumes. Students determine they have different densities and again use the size and mass of atoms in the materials to explain these differences.

**Part 3:** Students use the mass and volume of the rods they measured in Lessons 3 and 4 to calculate their densities. Since they are the same material, they should have the *same* density. Students then analyze the results for the three different types of materials and confirm that their densities are different.

The density of water will be explored in the next lesson.

**What Students Learn**

* Density = mass/volume.
* The density of a substance is determined by the atoms and molecules it is composed of.
* Density is a characteristic property of a substance and can be used to identify it.
* The density of a substance is the same regardless of the size of the sample.

**Materials & Preparation:**

**Part 1**

* DQB
* Density Cube Set (Only need one copper and one aluminum cube.) <https://www.amazon.com/Chemistry-Paperweight-Experiment-Investigation-Experiments/dp/B0B48QPYVV>
* Large plastic balance

**Part 2**

* Equal Mass Rods (5 rods of different volumes but same mass. Only need the small, medium, and large rods.) <https://www.flinnsci.com/equal-mass-set---individual-kit/ap4636/>

**Part 3**

* Mass and volume data for rods measured in Lessons 3 and 4

**Part 1 - Density**

**Same Volume but Different Mass**

(From Middle School Chemistry - Chapter 3, Lesson 1)

**Materials**

* Density Cube Set (Only need one copper and one aluminum cube.) <https://www.amazon.com/Chemistry-Paperweight-Experiment-Investigation-Experiments/dp/B0B48QPYVV>
* Large plastic balance

**ENGAGE**

 **1. Return to the DQB to review what students have learned so far and to introduce a new concept - density.**

Remind students of the driving question, “How does a Lava Lamp work?” and review what they have learned so far about mass and volume. Remind students from the last lesson that understanding mass and volume alone are not enough, but the ***relationship*** between mass and volume (density) is invaluable!

Remind students that they have measured the mass and volume of samples of the *same* material but different volumes. As a class, they have seen that objects with the same volume made from different materials have different masses. Let students know that this lesson will go deeper into these observations and introduce the concept of **density**.

**Question to investigate:**

Why do cubes of the same size and shape, but different materials, have different masses?

**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 has a greater mass than the aluminum cube.

 **EXPLORE**

**2. Demonstrate two objects of the same volume but different masses and have a class 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 spaces inside. Explain that the aluminum cube is made of only aluminum atoms and the copper cube is made of only copper atoms.

Ask students:

* **Thinking about atoms, why do you think the copper cube is heavier than the aluminum 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 for Part 1.**

Students will record their observations and answer questions about the activity on the activity sheet. Look at the teacher version of the activity sheet to find the questions and answers.

**EXPLAIN**

**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 Student Activity Sheet.

Show students the image Aluminum and Copper Atoms:

[www.acs.org/middleschoolchemistry/simulations/chapter3/lesson1.html](http://www.acs.org/middleschoolchemistry/simulations/chapter3/lesson1.html)

Explain to students that the copper and aluminum atoms are *arranged* in the same way in their cubes. Also explain that measuring the *size* of atoms in a metal is difficult. Copper atoms are a little larger than aluminum atoms. This means there may be fewer copper atoms in the copper cube than aluminum atoms in the aluminum cube. But copper atoms have much more mass than aluminum atoms. So even though there might not be as many copper atoms, their extra mass makes up for it and makes the copper cube heavier than the aluminum cube of the same size and shape (volume).

**Note:** *There are different ways of measuring the size of atoms, and in close cases the results are not always in agreement. This is true with copper and aluminum. Some sources report copper as larger by some measures and some report aluminum as larger. For the purposes of this lesson, we will treat copper as the larger atom.*

**EXTEND**

**4. Using the copper and aluminum cube demonstration, have a class discussion to tease out the definition of *density* as the relationship or ratio of the amount of mass in a certain volume.**

After seeing that the two cubes with equal volume have different masses you are likely to get at least one student able to explain the relationship between mass and volume: how much mass is in a certain amount of space.

Offering hints such as: “the relationship is mathematical” or “think ratios” may also be helpful if students get stuck.

Most students will not know that the relationship between mass and volume is called "density" but with careful questioning, you can lead them to the mathematical expression, or ratio: mass$/$volume. You could give an example of a ratio using a substance they are familiar with: A bag or stones might be 50 pounds per bag, while a bag of wooden blocks might be 8 pounds per bag for the same size bag. This can be an early step to helping students eventually understand the ratio most commonly used for density: grams per cubic centimeter (g/cm3).

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.

**Ask students**:

* **Which is more dense, stone or wood and how do you know?**

Stone is more dense because if you weigh the same volume of each, stone is heavier.

**Ask students:**

* **How do the size, mass, and arrangement of atoms** **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 do the size, mass, and arrangement of atoms** **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.

Let students know that an understanding of density might be more helpful than mass and volume alone in discovering how the Lava Lamp works.

**Part 2 - Density**

**Different Volumes but Same Mass**

(From Middle School Chemistry Chapter 3, Lesson 2)

**Materials**

* Equal Mass Kit (5 rods of different volumes but same mass. Only need the small, medium, and large rods.) <https://www.flinnsci.com/equal-mass-set---individual-kit/ap4636/>

***Notes about the materials:***

This demonstration uses the ***Equal Mass Kit*** from Flinn Scientific but can be adapted to any set of equal mass rods. Each rod is made of a different material, all rods have the same mass, but each has a different volume. There are several versions of these rods available from different suppliers.

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.

**Note:** For this demonstration, you will only need to use three of the five rods. You will use the shortest (Brass), the longest (Polyethylene), and the one in-between (PVC).

|  |  |  |  |
| --- | --- | --- | --- |
| **Sample** | **Material** | **Approximate density (g/cm3)** | **Relative length** |
| Smallest metal | Brass | 7.5 | shortestlongest |
| Shiny gray metal | Aluminum | 3.0 |
| Dark gray | PVC | 1.4 |
| Tall off-white | Nylon | 1.1 |
| Tallest white | Polyethylene | 0.94 |

**ENGAGE**

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

Show students the longest, middle-sized, and shortest rods and explain that they all 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.

**EXPLORE**

1. **Give each student an Activity Sheet for Part 2, and ask students to predict the densities of the three rods: shortest (most dense), longest (least dense), and in-between length (in-between density).**

Ask students:

* **What do you think about the atoms and molecules that make up the three different rods?**

Students should reason that the atoms or molecules that make up the smallest rod are heavy or close together or both, and that the atoms or molecules that make up the longest rod are light or farther apart or both.

Students should understand that the difference in density between the small, medium, and large rods can be explained based on the atoms and molecules they are made from and how they are arranged.

**EXPLAIN**

1. **Explain how the atoms and molecules in the three rods give their different densities.**

Show students the chart of Atomic Size and Mass.



Explain that this chart is based on the periodic table of the elements but that it only includes the first 20 elements out of 118. 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 Chapter 4 of middleschoolchemistry.com, but for now 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 difference in size is a little harder to explain. Atoms have positively charged protons in the nucleus, neutrons which are neutral, 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.*

**Project the image *Polyethylene* (longest rod).**

[www.acs.org/middleschoolchemistry/simulations/chapter3/lesson2.html](http://www.acs.org/middleschoolchemistry/simulations/chapter3/lesson2.html)

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.acs.org/middleschoolchemistry/simulations/chapter3/lesson2.html](http://www.acs.org/middleschoolchemistry/simulations/chapter3/lesson2.html)

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.acs.org/middleschoolchemistry/simulations/chapter3/lesson2.html](http://www.acs.org/middleschoolchemistry/simulations/chapter3/lesson2.html)

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.

**Part 3 - For any one material, density stays the same regardless of the size of the sample.**

**Note:** The above statement is true if the samples are at the same temperature. In fact, students will eventually discover that the key to the Lava Lamp phenomena is that the density of a sample ***does*** change with the size of the sample when the sample expands when heated or contracts when cooled.

**Materials**

* Mass and volume data for rods measured in Lessons 3 and 4

**ENGAGE**

**1. Review what students have seen so far and what they will do.**

Remind students that they have looked at two cubes of different material that were the *same volume* but *different mass*. They also saw three rods of different material that were the *same mass* but *different volumes*. All these *different* materials had *different* densities.

Remind students they have already explored the other situation: They have measured objects of the *same material* that were *different volume* and *different mass*. They will now calculate the density of the rods they measured.

**EXPLORE**

**2. Give each student an Activity Sheet for Part 3, and have students find the density of three samples (different volumes) of the *same* material.**

1. Have students look at their data of the mass and volume of three samples of the same material from lessons 3 and 4 and record these measurements in the chart.

2. Have students use the formula D=m/v to calculate the density of both rods.

3. Have students graph their results on the Student Activity Sheet and on a class data sheet.

Students should see that the data for a specific type of matter is a straight line that has a certain slope. (If students have not yet covered “Slope” in algebra, you do not need to focus on the technical meaning of slope. It is enough to show that both lines are straight but different because of the different relationship between mass and volume.)

**EVALUATE**

**3. Have students explain the mass and volume graph of the same type of matter.**

If students complete a graph of mass and volume for different size samples of the same material, or you provide a completed graph for them, students should be able to:

* Explain why the line showing the relationship between mass and volume for a particular type of matter is constant (straight). The slope of the line is the change in mass /change in volume. Since the material is the same throughout, any change in mass will be accompanied by the same change in volume and the slope will be constant.
* Explain why one line for one type of matter is different from the line for another type of matter. Since density is different for different materials, the amount of mass per unit of volume will be different.
* Compare each type of matter presented in the graph in terms of their density - which is more dense and which is less dense?
* Calculate the density using values for mass and volume for any point on the line.

**4. Have students predict and then calculate the density of samples A, B, and C which are all made from the same material.**

Discuss student conclusions about why the samples have the same density.

**EXPLAIN**

**5.** **Discuss how models of particles can be used to show that different samples of the same material have the same density.**

Start with an example model of small circles as particles to show the concept of density. It is important to emphasize that no matter the size of the object, if you cut it in half the arrangement, size, and mass of the particles remains the same.

You may need to return to the illustration of the different size blocks of the same material and draw dots on the illustration of the blocks to indicate that since it’s the same material, the dots are the same size, distance apart, and arranged the same way no matter how big or small the size of the sample and therefore density remains the same.

**EXTEND**

**6.** **Discuss how density applies to the blob material before and after the Lava Lamp is turned on.**

Once you are satisfied with students’ understanding of density, you could have them return to their Lava Lamp model to add something about the concept of density.

Since students do not yet know that the blobs float because they are less dense when heated and sink because they become more dense when cooled, it won’t be easy at this time for students to accurately *model* density for the floating and sinking blobs.

You could ask students to make predictions about whether the blob is more dense or less dense before the Lava Lamp is turned on and ask them to explain their reasoning.

Discuss with students whether understanding more about the density of liquids and why they float or sink could be useful in understanding more about how the Lava Lamp works.

The density of different liquids and why they sink and float will be explored in the next lesson.