Module 4 – Density

INTRODUCTION

What do ballpoint pens, armor-piercing bullets, fingerprints, DNA, and the boat below have in common? All of these topics are related to density. Osmium[1] is the most dense of all elements, and it is often combined with other metals to form extremely hard alloys used to make ballpoint pens and armor-piercing bullets. Osmium tetroxide is used by forensic scientists to detect DNA and fingerprints. Mass density is a physical property that determines whether boats will sink or float.

Figure 1

In this experiment, you'll learn how mass density is defined, how to measure an object's mass density, and how to use mass density to predict if an object will float.

You will learn why it doesn't make sense to say that lead is heavier than air.

DENSITY

Why doesn't it make sense to say that lead is heavier than water? The answer, of course, is that it depends on how much water and lead you have. For example, the weight of 1 cubic foot of lead is 708 lb, but the weight of 12 cubic feet of fresh water is about 750 lb. When someone says that lead is heavier than water, they are really trying to say that lead is more dense than water. They mean that when they have the same volume of lead and water, then lead will be heavier. Mass density is the physical quantity that relates the mass (or the weight) of a substance to its volume. Mass density is defined as follows.

$$\text{Mass Density} = \frac{\text{Mass}}{\text{Volume}} \tag{1}$$

Weight density is defined as follows.

$$\text{Weight Density} = \frac{\text{Weight}}{\text{Volume}} \tag{2}$$

[1] osmium.pdf

COMMON SUBSTANCE DENSITIES				
Substance	**Type**	**Mass Density** D (kg/m^3)	**Weight Density** D_W (lb/ft^3)	**Specific Gravity**
Solids				
Juniper Wood	m	560	35	0.56
Ice	c	917	57.2	0.917
Liquids				
Gasoline	m	680	42	0.68
Ethyl alcohol	c	791	49	0.791
Gases (at 0°C and 1 atm)				
Hydrogen	e	0.09	0.0056	0.00009
Helium	e	0.18	0.011	0.00018

DENSITY AND CRYSTAL STRUCTURE

The Sl units of mass density are kg/m^3, but there are several other common units. One of the most commonly used units of mass density is gram per cubic centimeter, or g/cc. This is because pure water has a mass density of 1 g/cc. It turns out that 1 mL of liquid is equal to 1 cc of volume. So it is also possible to express the mass density of water as 1 g/mL. This makes water a useful tool since it is possible to use graduated cylinders to measure volumes.

Take a look at the following elements and their densities.

Element	**Atomic Number**	**Mass Density**
Osmium	76	22.7 g/cc
Gold	79	19.3 g/cc
Lead	82	11.4 g/cc

Notice that osmium has the smallest atomic number, which means that it has the fewest protons in its nucleus, but notice that osmium's mass density is the largest. So, apparently, the mass of an element does not determine its density. If it did, then lead should have the greatest mass density of these three elements.

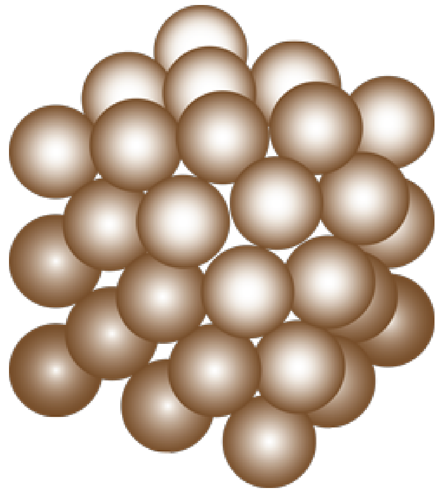

Figure 2

Elements in the solid state have crystalline structures. The more closely packed the atoms in these structures, the more mass a given volume of the element will contain. In other words, osmium has nearly twice as much mass packed into 1 cubic centimeter of space as does lead. Since lead is a more massive element, this can only occur if the atoms of osmium are closer together in their crystal structure than lead. In fact, osmium atoms pack together more closely than any other element.

MEASURING MASS DENSITY

Suppose you need to measure the mass density of an irregular object. Say that you are Archimedes, and the King of Syracuse has asked you to determine whether a craftsman has made a crown of silver rather than gold. What would you do? If you were Archimedes, you'd invent a procedure! The first step is to measure the volume of the crown by immersing it into water. The amount of water displaced is equal to the volume of the crown. Then all you'd need to do is weigh the crown and apply the definition for mass density. Let's try it!

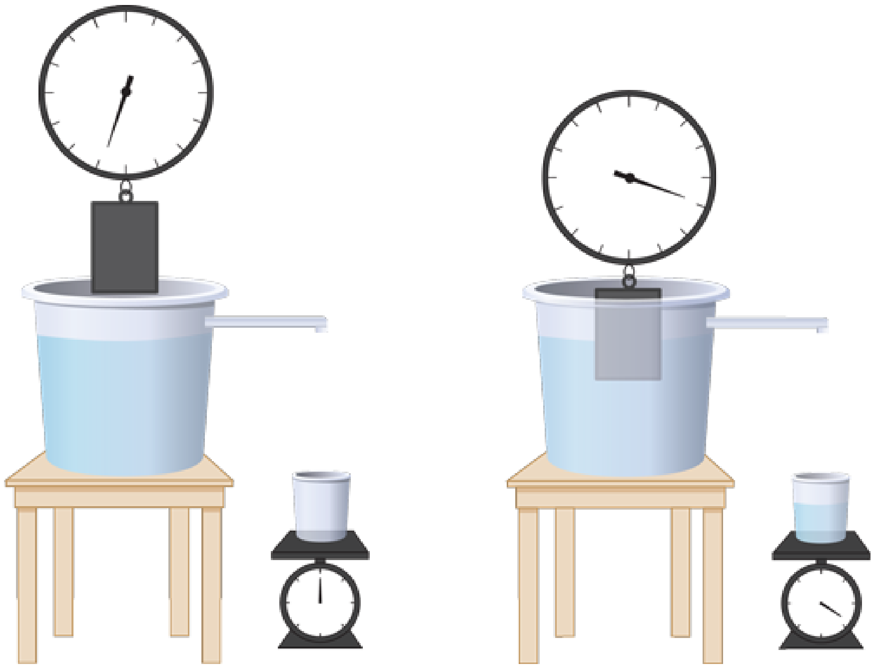

Figure 3

Archimedes immerses the crown into a tub of water and measures the volume of displaced water to be about 100 mL. Then he weighs the crown and finds the mass to be about 1050 g, or about 2 pounds. Using the formula for mass density, he calculates the following.

$$\begin{aligned} \text{Mass Density} &= \frac{\text{Mass}}{\text{Volume}} \\ &= \frac{1050\text{ g}}{100\text{ mL}} \qquad \text{Equivalently, you could say} = \frac{1.050\text{kg}}{0.100\text{L}} \\ &= 10.5\text{ g/mL} = 10.5\text{ g/cc} \qquad \text{(which is equivalent to 10.5 kg/L)} \end{aligned}$$

Next you compare this to the mass density of gold, which is 19.3 g/cc.

Oh, boy! The craftsman is in real trouble now! (Actually, Archimedes did it a much simpler way. Select the Archimedes[2] link to find out how.)

WILL IT FLOAT OR SINK? ASK ARCHIMEDES!

From your reading, you should recall Archimedes' Principle, as described below (Ostdiek and Bord 2018, 148).

[2]http://www.visionlearning.com/library/module_viewer.php?mid=37http://

Archimedes' Principle:

The buoyant force acting on a substance immersed in a fluid at rest is equal to the weight of the fluid displaced by the substance.

$$F_\text{b} = \text{weight of displaced fluid}$$

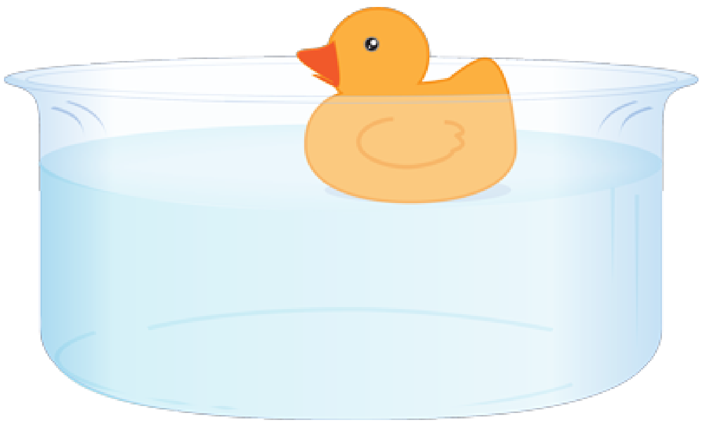

Figure 4

How can you use the mass density of an object to determine if it will sink or float? Simply compare the mass density of the object to that of the liquid. The object will sink if it has a greater mass density. Let's explore why.

The condition for floating is that the buoyant force is greater than the weight of the object. In equation form, this is:

$$To\ Float\colon \text{weight of object} < \text{weight of displaced fluid.}$$

Since the volume of the displaced fluid is the same as the volume of the object, this can be written as the following.

$$\text{mass density of object} \times \text{object volume} < \text{mass density of fluid} \times \text{object volume}$$

$$\text{mass density of object} < \text{mass density of fluid}$$

PROCEDURE

This experiment consists of three parts.

1 Open the experiment instructions and worksheet.

- Density Experiment Instructions (HTML[3] or PDF[4])
- Density Experiment Worksheet[5]

2 After you have thoroughly read the instructions and worksheet, open the experiment simulation[6] in which you will conduct the experiment and collect your data.

3 Record your data in the worksheet. (You will need it for the lab report assignment in WebAssign.)

[3] ../lab_4_1_procedure/manual.html
[4] ../lab_4_1_procedure/manual.pdf
[5] ../lab_4_1_procedure/worksheet.pdf
[6] https://phet.colorado.edu/sims/density-and-buoyancy/density_en.html

