PHYS 1401 – General Physics I
Laboratory # 6
Density and Buoyancy

INTRODUCTION

In this experiment we shall investigate density. Density is a measure of how tightly packed material is in an object. The density of an object depends on two things: the mass of the object (how much material there is in an object) and its volume (how much space it takes up). If we increase the mass of an object without increasing its volume, the density rises. If we increase the volume of an object without changing its mass, density goes down. We can express this relationship with an equation:

$$Density = \rho = \frac{M}{V}$$

Note that the units of density will be kg / m^3 (mass/volume). We often measure volume in liters or milliliters (ml). One milliliter is the volume of a cube 1 cm (0.01 m) on a side, so 1 ml = 1 cm^3 = 0.000001 m^3. Another way to put that is

$$1\ m^3 = 1{,}000{,}000\ ml$$

The standard for density is pure water, which is defined to have a density of 1000 kg / m^3. We shall check the accuracy of this definition in the first part of this experiment.

Part 1: The Density of Water

In this part of the experiment, you will determine the density of water in a graduated cylinder. First determine the mass of an empty graduated cylinder and record this number. Fill the graduated cylinder with water up to one of the lower marks on the side. Record both the amount of water that you have added to the graduated cylinder, and the mass of the graduated cylinder and water put together.

Question 1: How can you determine the mass of the water you have just put in the graduated cylinder?

Calculate the density of the water that you have just added to the graduated cylinder, in kg / m^3. Calculate the percentage difference between the density that you have calculated and the defined density of water using the formula

$$Percentage\_Difference = 100\% \times \frac{(Calculated - 1000)}{1000}$$

Repeat these measurements four more times, filling the graduated cylinder a little more each time. Record your findings in a table with the following columns: volume, mass, density, % difference.

Question 2: The density of water is defined to be 1000 kg / m^3 for pure, distilled water. Give reasons why your figures might not agree.

<u>Part 2: The Density of a Regular Object</u>

Every substance has its own density, so if we can determine the density of an object, we can predict what it is made of. If an object has a regular shape, we can easily compute its volume. Then we can measure the mass, and figure out the density. For this part of the experiment, you will use the objects set out before you, labeled A through G. For each sphere, use the calipers to determine the diameter of the sphere. Half of that diameter is the radius of the sphere, and the volume can be calculated using the formula:

$$V = \frac{4}{3}\pi R^3$$

The other objects are cylindrical in shape, and you can measure their diameters and heights, and find their volumes with

$$V = \pi R^2 h$$

Measure the mass of each object, then calculate the volume and density of each object. The volume numbers that you get will be very small, so use scientific notation to express those numbers.

Based on the information in your book, predict what the object is made of. Create a data table with the following columns: volume, mass, density, material prediction. Take care to make sure you use the right units for all calculations! WARNING: If you don't get a density figure between about 50 kg / m^3 and about 25,000 kg / m^3, you have mis-measured or miscalculated!

Part 3: Testing Archimedes Principle

So, how do you find the density of something without a regular shape? This question was answered by the ancient Greek philosopher Archimedes, who discovered that when an object is submerged in a container of water, the water level will rise by an amount equal to the object's volume. We say that the submerged object will displace an amount of water equal to its volume.

If you immerse an object in water suspended by a string, three forces are acting on the object. As always, gravity pulls the object down with a force equal to $m_{obj}g$. The string pulls up with a force T. Finally, the water pushes up on the object, with a buoyant force $F_B = \rho_{water}V_{disp}g$. The volume of water displaced, V_{disp}, is equal to the volume of the object, if the object is totally submerged. If the object is suspended in the water, it is in equilibrium, and the forces are in balance:

$$\sum F = T - W_{OBJ} + F_B = 0$$

Therefore,

$$T = W_{OBJ} - F_B = m_{OBJ}\,g - \rho_{Water}V_S\,g$$

How do we measure the tension in the string? If we tie the string to the bottom of the scale, it will measure the mass, just as if we had set an object on the scale. This will register as a "weight," on the scale. We can read off the scale the mass that would cause this "weight." If the weight is out of water, the tension in the string is equal to the true weight of the object:

$$\text{If } F_B = 0, \text{ then } T = W_{obj} - 0 = m_{obj}g$$

Question 3: If you submerge an object in water while it is suspended from a scale, will the mass reading on the scale be less than, greater than, or equal to, the reading out of water? Justify your answer in terms of forces, and test your prediction with one of the regularly-shaped objects.

When an object is suspended in water from a scale, the reading on the scale will be different from the reading out of water. We can call this a "false weight," corresponding to a "false mass" reading on the scale. Remember that this "false weight" is the same as the tension in the string:

$$T = W_{false} = m_{false}g$$

And so we can calculate the Buoyant Force felt by each object by finding the difference between the true weight out of water, and the "false weight" in water:

$$F_B = m_{obj}g - m_{fa;se}g$$

When the object is in water, we can say

$$T = m_{false}g = m_{OBJ}g - \rho_{Water}V_D g$$

The factor of g drops out, and we are left with

$$m_{false} = m_{OBJ} - \rho_{Water}V_{Disp}$$

Now solve this for the volume displaced, which, recall, is the volume of the suspended object:

$$V_{Disp} = \frac{m_{OBJ} - m_{false}}{\rho_{Water}}$$

So we now have a way to determine the volume of an object without measuring its dimensions! We can then divide the "true mass" by that volume to get a measure of the density.

First, let's test this principle. Fill a beaker mostly full of water. Suspend one of the regular-shaped objects by the bottom of the scale. Record the "true mass" of the object. Then carefully submerge the object in the water. Make sure it is totally immersed, and not touching the bottom of the beaker. Determine and record the "false mass" (mass while submerged in water) of the object. Repeat for all of the objects.

Question 4: Calculate the Buoyant Force felt by each of the objects using these mass figures. Are there any objects that feel similar Buoyant Forces? What else do those objects have in common?

Use the true and false mass figures for each object to calculate the volume of each object. Use a density for water of 1000 kg / m^3. Remember to use scientific notation as before, since the numbers will be small. Also calculate a value for the density of each object, and calculate the percentage difference between the density you get in Part 3 and the density you got in Part 2.

$$Percentage\_Difference = 100\% \times \frac{(Part3 - Part2)}{Part2}$$

Do this for all the regularly-shaped objects. Create a data table with the following data: True mass, False mass, Buoyant Force, Part 3 volume, Part 3 density, Part 2 density, Percentage difference. Come and show me your numbers if you are getting percentage difference values greater than about 15%.

Question 5: Were there any objects you could not determine the volume of with this submerging method? Why not? Looking at your numbers from Part 2, is there something that sets these objects apart?

Archimedes was given the task of determining if a crown was made of gold or not, without harming the crown. Archimedes knew that if he could determine the mass and volume of the crown, he could calculate the density of the crown, and tell if it was made of gold or not. But how to determine the volume of the irregularly-shaped crown? This is how he came up with the method we used in Part 3. We shall now apply this method to a variety of objects.

Use the submersion method to find the volumes and densities of the three rocks and the two rings. Create a data table with the following data: True mass, False mass, Volume, Density. Answer the following questions:

Question 6: What is the average density of rock?

Question 7: Which of the two rings contains more gold? Is either one made of pure gold? Defend your answer.

Part 4: Density and Buoyancy

Diet drinks float, but their sugary counterparts do not! Why do things float? As an object sinks or floats in water, gravity pulls it down. Therefore, the object is pushing down on the water, just like you are pushing down on your chair right now. And just as the chair in turn pushes up on you, the water pushes up on the object with a buoyant force. The buoyant force always opposes the gravitational force. If the gravitational force is greater than the buoyant force, the object will sink. If the buoyant force is greater than the gravitational force, the object will float.

Another word for the gravitational force in this case is the weight, which as always is given by

$$W = m_{obj}\, g$$

The buoyancy force is the weight of the water displaced by the object, which works out to be

$$F_B = m_{water} g$$

We can turn the density formula around to get the mass in terms of the density:

$$M = \rho V$$

So $M_{OBJ} = \rho_{OBJ} V$ and $M_{Water} = \rho_{Water} V$

And $W = \rho_{OBJ} V g$ and $F_B = \rho_{Water} V g$

The acceleration due to gravity is the same for both objects, as is the volume, if the object is submerged. The only difference is in density. So we can say, in general

- **If an object has a density greater than water, the weight of the object is more than the buoyant force, and it will sink in water.**
- **If it has a density less than that of water, the weight of the object is less than the buoyant force, and it will rise in water.**
- **If the two densities are equal, then the weight force and the buoyant force are balanced, and the object will neither rise nor sink.**

Use the calipers to determine the diameter and height of each coke can. Compute the volumes of the cylindrical cans using the formula

$$V = \pi R^2 h$$

Measure the masses and compute the volumes and densities of both soda cans. Present your findings in a data table.

Question 8: Explain, using the concept of density, why diet soda floats in water and regular soda does not. Then explain in terms of the ingredients.

Question 9: Explain why a balloon filled with helium floats in air, while a balloon filled with carbon dioxide from your lungs does not.

Question 10: A battleship's outer "skin" is made of steel. How then can a battleship float?

<u>Materials List</u>

Graduated cylinder
Scale
Stand with platform to hold scale
Seven objects of various materials, spheres and cylinders
Beaker of water

Lab jack
3 rocks of different types