PHYS 1405 – Conceptual Physics I
Laboratory # 8
Density and Buoyancy

Investigation: How can we identify a substance by figuring out its density?

What to measure: Volume, mass.

Measuring devices: Calipers, Scale

Calculations: Volume, Density, Buoyant Force

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:

$$\textbf{Density} = M / V$$

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 the volume of water that you have added to the graduated cylinder, remembering to convert from milliliters to cubic meters. Also record the mass of the graduated cylinder and water put together, remembering to convert grams into kilograms.

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

$$\text{Percentage Difference} = \frac{\text{Calculated} - 1000}{1000}\, x\ 100\%$$

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 (m^3)	Mass (kg)	Density (kg / m^3)	% 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. Look carefully at your results – it may not be the reason you think of at first!

Part 2: The Density of a Regular Object

Every substance has its own density, so if we can determine the density of an object, we can predict what it is made of. The densities of some substances are given in the density table in your book. Oddly, it leaves out the density of wood, which is around 300 or 400 kg / m^3.

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 cylinder, use the calipers to determine the diameter of the cylinder and the height. Half of that diameter is the radius of the cylinder, and the volume can be calculated using the formula:

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

The other objects are spherical in shape, and therefore their volumes are equal to

$$V = (4/3)(\pi R^3)$$

Measure the mass of each object, then calculate the density of each object. Remember to convert every distance you measure into meters! The volume numbers that you get will be very small, since a cubic meter is very big, so use as many decimal places as possible.

Based on the information in your book and this lab, 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!

Object	Volume (m^3)	Mass (kg)	Density (kg / m^3)	Material Prediction

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: Archimedes Principle and the Buoyant Force

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** (negative) with a force equal to $m_{obj}g$. The string pulls **up** (positive) with a force T. Finally, the water pushes **up** (positive) on the object, with a buoyant force F_B. If the object is suspended in the water, it is in equilibrium, and the forces are in balance:

$$\Sigma F = T - W_{obj} + F_B = 0$$

Therfore

$$F_B = W_{obj} - T$$

How do we measure the tension in the string? If we tie the string to the bottom of the pan of a balance, it will pull the pan down, just as if we had set an object on the pan. This will register as a "weight," on the scale. We can read off the balance 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:

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

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 objects you measured before

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 mass" is the same as the tension in the string:

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

So when the object is in water, we can say

$$F_B = W_{obj} – T = m_{true}\, g - m_{false}g$$

This formula allows us to measure the size of the Buoyant Force acting on the submerged object, simply by measuring its mass in and out of water. We can do this for the objects we measured the densities of earlier.

Fill a beaker mostly full of water. Suspend one of the objects from Part 2 from 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 or sides of the beaker. Determine and record the "false mass" (mass while submerged in water) of the object. Use these mass figures to find the size of the buoyant force each object feels. We call this the "measured" buoyant force. Record the true mass, the false mass, and the "measured" buoyant force for each object in a data table.

Object	True Mass (kg)	False Mass (kg)	Measured Buoyant Force (N)

Question 4: Were you able to use this method to find the buoyant force on all the objects? Which ones wouldn't work? Why not?

Question 5: Look at the size of the buoyant forces you found. List the objects that feel similar buoyant forces. What do these objects also have in common?

In class, we had another formula for the buoyant force in water:

$$F_B = (\text{Density}_{water})V_{disp}\, g.$$

The volume of water displaced, V_{disp}, is equal to the volume of the object, if the object is totally submerged. You calculated the volume of each object in the Part 2, so now you can get a "calculated" value for the buoyant force for each object. Assume a value of 1000 kg / m^3 for the density of water and a value of 9.8 m / s^2 for g, and calculate a value for the buoyant force felt by each object.

Add a column to the data table you started above for this "calculated" buoyant force. Calculate the percentage difference between the "measured" and "calculated" buoyant force values for each object using the formula

$$\text{Percentage Difference} = \frac{\text{measured} - \text{calculated}}{\text{calculated}} \times 100\%$$

Object	True Mass (kg)	False Mass (kg)	Measured Buoyant Force (N)	Calculated Buoyant Force (N)	% Difference

Come and show me your numbers if you are getting percentage difference values greater than about 15%. Record these percentage differences in the last column of your data table.

Question 6: Based on the percentage differences, do you think that "dunking" is a good way to measure buoyant force?

Part 4: The Density of Irregular Objects

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? Archimedes just measured the water that spilled out of a container when the crown was placed into it, but we can be a little more accurate. We know how to measure the buoyant force felt by an object based on its mass in and out of water:

$$F_B = \text{Weight out of water} - \text{Weight in water} = m_{true}\, g - m_{false} g$$

We also know that the buoyant force felt by an object suspended in water depends on the object's volume:

$$F_B = (\text{Density}_{water})\, V_{disp}\, g.$$

Turning this equation around, we get

$$V_{disp} = F_B / (\text{Density}_{water}\; g)$$

Once we know volume, the density of the object can be found using the formula:

$$\text{Density} = m_{true} / V$$

You will have three rocks and two rings to work with. For each object, determine the true mass, and the “false” mass in water. Calculate the buoyant force each one feels. Use that buoyant force to find the volume of each object. Don’t worry if it’s a small number! Finally, calculate the density of each rock and ring. Create a data table with the following data:

Object	True mass (kg)	False mass (kg)	Buoyant Force (N)	Volume (m^3)	Density (kg / m^3)

Answer the following questions:

Question 7: What is the average density of rock?

Question 8: Which of the two rings contains more gold? Is either one made of pure gold? Defend your answer.

<u>Materials List</u>

Graduated cylinder
Scale
Ring stand with platform to hold scale
Seven objects of various materials, spheres and cylinders
Beaker of water
Lab jack
3 rocks of different types