Buoyant Force

Goals and Introduction

When an object is placed in a fluid, it either floats or sinks. While the downward gravitational force, F_g, still acts on the object, an object in a fluid is also subject to an upward buoyant force, F_B, that depends on the volume of the object within the fluid. This means the maximum value of the buoyant force on an object is achieved when the object is completely submerged. Ignoring other forces, if the magnitude of the gravitational force on the object is greater than this buoyant force, the object will sink. In this scenario where the object sinks, the net force on the object is called an *apparent weight*, W. This is what the objet would appear to weigh while submerged in the fluid. It is as if the weight of the object is lessened as the gravitational force is in competition with the upward-pointing buoyant force (Figure 14.1). In this lab, you will measure the apparent weight of several objects immersed in water and thereby measure the buoyant force. This can then be used to determine the density of each object. You will also use your results to determine the density of an unknown fluid.

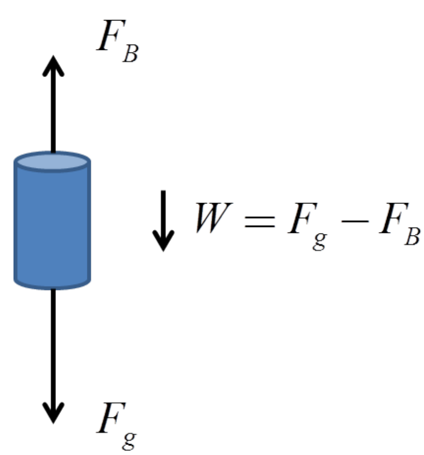

Figure 14.1

The gravitational force on an object is typically written as $F_g = mg$, where m is the mass of the object in kg. Using the definition of density $(\rho = m/V)$, we can express the gravitational force in terms of the density of the object, ρ_o, and the volume of the object, V_o, as in Equation 1.

$$F_g = mg = \rho_o V_o g \qquad \text{(Eq. 1)}$$

A buoyant force acts on any object within a fluid and points in the direction of decreasing pressure (upward for a static fluid in a downward-pointing gravitational field). In essence, the object is taking up space that would normally be occupied by fluid when it is submerged. Thus, it could be said that there is fluid displaced by the object. The weight of the displaced fluid would depend on the density of the fluid, ρ_f, the volume of the submerged object, V_o, and the gravitational acceleration on Earth, g. It turns out that the buoyant force that acts on the submerged object is equal in magnitude to the weight of the fluid displaced by that object, as in Equation 2.

$$F_B = \rho_f V_o g \qquad \text{(Eq. 2)}$$

The apparent weight, W, of a submerged object then would be given by the difference between these two forces acting on the object. Because this will only be downward when the gravitational force is bigger, and the object sinks, this is written as shown in Equation 3.

$$W = F_g - F_B \qquad \text{(Eq. 3)}$$

We could also think of the apparent weight as being related to an *apparent mass* of the object. This apparent mass, m_a, is the mass whose weight would be equal to W, or

$$W = m_a g \qquad \text{(Eq. 4)}$$

When you examine the buoyant and gravitational forces for a submerged object (Equations 1 and 2), you can see that the only difference between the forces is the density. The determining factor as to whether the object sinks or floats is whether the density of the object is greater or less than the density of the fluid. If the density of the object were less than the density of the fluid, the buoyant force would be greater than the gravitational force, and the object would rise. For the case when the object sinks, it must be true that the density of the object is greater than the density of the fluid.

By measuring the apparent weight of an object in an unknown fluid, the buoyant force may be determined in the same way, using Equation 3, assuming the mass is known. This buoyant force can then be used to calculate the density of the unknown fluid, using Equation 2. Thus, a method for measuring the density of a fluid is to measure the apparent weight of an object of known density when it is submerged in the fluid.

In this lab, you will measure the apparent weight of objects in water in order to determine the buoyant force on each object, and compare to the predicted buoyant force from Equation 2. You will then use these objects to determine the density of an unknown fluid. Also, you will predict the buoyant force on an irregularly-shaped object in water and test your prediction.

Goals: (1) Become familiar with the concept of the buoyant force and its relationship to the volume of an object submerged in a fluid

(2) Be able to determine the density of an object using its mass and volume.

(3) Develop a method for finding the volume of an irregularly-shaped object, and determine its density.

Procedure

Equipment – triple beam balance, several cylinders, a rock, calipers, water, an unknown fluid, beaker, graduated cylinder

1) **Measure and record** the length and diameter of each cylinder. Create a table to organize your results and be sure to keep track of which cylinder is which!

2) **Measure and record** the mass of each cylinder. You can hang the cylinder, in the air, from the underside of the scale. Add this information to your table.

HINT: Be aware of the units you use in measuring each of these quantities. Record these units on your table to be sure you remember to convert to SI units for the purposes of calculations.

3) One at a time, hang each cylinder from the cord on the underside of the balance and place it into the beaker with enough water so that it is completely submerged. **Measure and record** the apparent mass of each cylinder while it is submerged.

We will now attempt to determine the density of the rock.

4) **Measure and record** the mass of the rock.

5) Think and develop a method for measuring the volume of the rock. Consider all of the equipment you have at your disposal at your lab station. **Record** the volume of the rock. Be sure to describe your method of measurement in the Procedure section of your lab report. Label your result as V_{rock1}.

6) Hang the rock from the cord on the underside of the balance and place it into the beaker with enough water so that it is completely submerged. **Measure and record** the apparent mass of the rock while it is submerged.

We will now attempt to find the density of the unknown fluid. As described in the Goals and Introduction section, we must measure the apparent weight of an object in the fluid, in order to determine the density of the fluid.

NOTE: DO NOT pour this liquid down the sink. Return it to the container after you have finished using it. Ask your TA if you are uncertain.

7) Choose one of the cylinders to use for this part of the experiment and make note of your selection so that you know its mass, length, and diameter.

8) Hang the cylinder from the cord on the underside of the balance and place it into the beaker with enough of the unknown fluid so that it is completely submerged. **Measure and record** the apparent mass of the cylinder while it is submerged.

Data Analysis

First, we will analyze the data from the cylinders in the water. Because you are about to calculate several quantities for each cylinder, organize the results of your calculations in a table when you are finished.

Use the length and diameter to calculate the volume of each cylinder.

Calculate the density of each cylinder.

Use the mass of each cylinder to calculate the gravitational force on each cylinder.

Use the measured apparent mass of each cylinder to calculate the apparent weight of each cylinder.

Now, using Equation 3, calculate the measured value of the buoyant force on each cylinder. Label your results as F_{Bm}.

The density of water is 1000 kg/m^3 (note the SI units of density are kg/m^3). Use Equation 2 to calculate the predicted value of the buoyant force on each cylinder. Label your results as F_{Bp}.

Question 1: Suppose that you had two cylinders that had identical volumes but very different masses. How would the buoyant forces on the two cylinders compare? How would their apparent weights in water compare to each other? Explain your answers.

Now, we will look at the rock and find its density using its apparent weight. To begin, first calculate the gravitational force on the rock.

Use the apparent mass of the rock to calculate the apparent weight of the rock.

Using Equation 3, find the buoyant force on the rock.

Now, use Equation 2 and the buoyant force you found to calculate the volume of the rock. Label this result as V_{rock2}.

Calculate the density of the rock using its mass and your calculated value, V_{rock2}.

Question 2: Is the density of the rock similar to what would be expected? Explain. What materials have similar densities?

We will now examine the results for the unknown fluid. Recall the volume and gravitational force, you calculated previously, for the cylinder chosen in the experiment.

Calculate the apparent weight of the cylinder in the unknown fluid.

Use Equation 3 to find the buoyant force on the cylinder in the unknown fluid.

Lastly, use Equation 2 to determine the density of the unknown fluid.

Question 3: If thin-walled plastic sphere with negligible mass were filled with this fluid, would the sphere float in water? Explain your answer.

Error Analysis

Calculate the percent error between the predicted value of the buoyant force, F_{Bp}, and the measured value, F_{Bm}, for each cylinder.

Assuming the volume of the rock found in the Data Analysis, V_{rock2}, is the predicted, or expected value, calculate the percent error between that and your measured value, V_{rock1}.

Question 4: How does the experimentally derived value of the volume compare with your measured volume in step 5 of the Procedure? Which method do you feel would be more reliable for measuring the volume of an irregularly-shaped object, like the rock? Explain.

Questions and Conclusions

Be sure to address Questions 1-4 and describe what has been verified and tested by this experiment. What are the likely sources of error? Where might the physics principles investigated in this lab manifest in everyday life, or in a job setting?

Pre-Lab Questions

Please read through all the instructions for this experiment to acquaint yourself with the experimental setup and procedures, and develop any questions you may want to discuss with your lab partner or TA before you begin. Then answer the following questions and type your answers into the Canvas quiz tool for "Buoyant Force," and submit it before the start of your lab section on the day this experiment is to be run.

PL-1) A small cup of water has marks on the side so that the volume of water it contains can be measured in milliliters (mL). A small toy is placed into the cup and the height of the water rises so that the volume reading changes from 20 mL to 28 mL. What is the volume of the toy in mL?

PL-2) The toy (density of 1200 kg/m^3 and volume of 8.0×10^{-6} m^3) is submerged in water. What is the buoyant force on the toy in N? (The density of water is 1000 kg/m^3)

PL-3) Suppose the toy (density of 1200 kg/m^3 and volume of 8.0×10^{-6} m^3) is now submerged in a fluid with an unknown density. If the apparent weight of the toy is measured to be 0.010 N, what is the buoyant force on the toy in N?

PL-4) Given the information from the previous problem, what is the density of the unknown fluid in kg/m^3? *[PL-3 stated "Suppose the toy (density of 1200 kg/m^3 and volume of 8.0×10^{-6} m^3) is now submerged in a fluid with an unknown density. If the apparent weight of the toy is measured to be 0.010 N, what is the buoyant force on the toy?"]*

PL-5) If the toy (density of 1200 kg/m^3 and volume of 8.0×10^{-6} m^3) is going to float in a fluid, the density of the fluid must be at least what value in kg/m^3?