PHYS 1P92 Experiment 02

Fluid statics : buoyancy

Notes

- Words in blue are links to additional reading or videos.
- Text in gray boxes are hints and things to take note of.
- Text in red boxes are important instructions or prompts that guide you to DISCUSS some of the key RESULTS and CONCEPTS learned in the lab. These prompts may not be the only items that need to be included in your report.

1 Objectives

- Determine the density of metal using estimation and the iOLab.
- Understand by measurement the buoyant force of water with the iOLab.

For each equation that error propagation must be used please write both the equation and the propagation rules/derivation on a separate piece of paper. Scan and submit it as a second file with your lab on Sakai. There are lots of free document scanner apps which can be used to scan and create files with your phone. Follow the instructions found here.

2 Introduction

Archimedes' principle of buoyancy is how boats float. In one sentence it states: an object immersed in a fluid will experience a net force due to the fluid which acts upward, with a magnitude equal to the weight of the fluid displaced by the object.

It is this change in materials that often confuses students; the **volume of water** displaced is the same as the **volume of the object**. But buoyant force is determined by the **weight of that amount of water**. This is not the same as the **weight of the object**, because the water and the object have different **densities.**

3 Procedure

In this lab, you will need the calibration mass and tape measure from the 1P91 accessory kit, some string, two ziplock sandwich bags, and some paper towels. You'll also need the tallest clear drinking glass or see-though water bottle you have. It needs to be see-through to mark the level of water.

If you choose a water bottle, make sure the mouth is wide to easily fit the 100 g calibration mass. One idea is to take a typical bottled water container and carefully cut the screw top off.

3.1 Determining the density of a metal

Archimedes's shout of "Eureka" supposedly came in the bath when he realised the volume of bath water displaced as he entered was the same as the volume of his body. To test the purity of gold, he needed to measure its density; of course he could weigh the gold, but to determine the volume of an irregular shaped object he needed a more precise method.

Let's identify the metal the 100 g mass is likely made of by measuring its density, but without taking a bath. The mass seems to be comprised of three simple shapes; the body is a right cylinder, and a sphere sits atop a nearly cylindrical neck.

Figure 1: Guide to the geometric shapes of the calibration mass. Note the three distinct outlined shapes; A sphere, and two cylinders of differing sizes.

Use the tape measure and record the diameter and height of the calibration mass body, the diameter of the sphere, the diameter and height of the neck in units of cm (see Figure 1).

Calculate the volume of the three components with their uncertainty, in units of cm^3. **The equations for volumes of various shapes can be easily found online**.

Calculate the total volume of the calibration mass V_m with its uncertainty, in units of cm^3.

Calculate the density of the calibration mass, ρ_m, in units of g/cm^3. You can assume its mass is exactly 100 g.

From the table of densities of various materials in the OpenStax textbook, what is the most likely material the calibration mass is made from? (Sorry, it's not gold.)

Is the suspected material density within your calculated uncertainty?

> Your measurements by eye may seem crude, but you should be able to measure to the nearest mm, and the results of density calculated this way should be within 5% of the actual material!

3.2 Fluid displacement

If you were to lower the calibration mass into a glass of water, the water level would rise. The *volume* amount of water displaced V_w is the same as V_m.

Start by attaching the calibration mass to a piece of string. Either lightly tie the string to the calibration mass (so that it is tight enough to not slip, but loose enough you will be able to untie) OR use the paperclip setup from calibration and the tie string to the other end of the paperclip.

Take the tallest glass or water bottle you have, and fill it with water, leaving room at the top for the water to rise without spilling.

> **IMPORTANT:** If your water container is not cylindrical, you must make the necessary adjustments to the volume calculations. A container with a small diameter is also preferred to make the water dis-

placement more dramatic.

Mark the bottle with a pen/marker or piece of tape the level of the water. Lower in the calibration mass, and note the water level increase. The volume of water that rises above the mark is the volume of displaced water.

Use the tape measure to record the height of the displaced water, and the diameter of the container.

Calculate the total volume of the displaced water V_w and its uncertainty, assuming a cylindrical container.

How does your new volume V_w compare to the volume of the calibration mass you calculated previously? Compare the values and their uncertainties.

Which volume calculation should be more accurate in practice - explain why?

The density of water is 997 kg/m^3. Calculate the mass of water m_w that was displaced, with its uncertainty.

Carefully poor off the **displaced** water into a ziplock bag and seal it. Set the bag aside for the next part. This can be done by leaving the weight in the water, and slowly pouring off the water until it is level with your mark.

3.3 Buoyancy force

Because the mass of the **displaced** water is less than the mass of the calibration mass, the mass of course, *sinks.*

Based on the mass of displaced water you just calculated, find the buoyancy force and its uncertainty (in units of N), acting on the calibration mass immersed in the water. Use the volume V_m acquired for your submerged weight from the previous section.

(See Equation 11.30 in the Openstax text. If you are still confused see Example 11.8 for guidance.)

The next step is to use the iOLab force sensor to experimentally measure that buoyancy force you've just calculated.

IMPORTANT: If you do not remember how to do the Force sensor calibration review the Preplab document section 4.2. You will be following this procedure with the following adjustment. Connect your calibration mass holder (paperclip) by a string to the eye bolt. Make the string long enough you can submerge the mass underwater. Calibrate the iOLab with the string and paperclip holder.

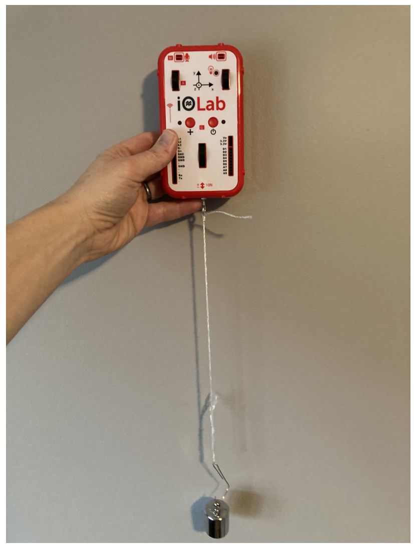

Figure 2: Adding a string to the force sensor calibration. This can be submerged in water and the weight recorded.

Calibrate the iOLab with the string and paperclip holder if you have not already done so.

Fully submerge the 100 g calibration mass in water at three different depths. Ensure that it does not touch the bottom or sides of the container. At each depth record the weight of the 100 g mass and its uncertainty.

Although fluid pressure varies with depth, the buoyant force doesn't. The buoyant force is always present whether the object floats, sinks, or is suspended in a fluid think of it as an 'added' force. For example:

$$\text{In air} \quad F_{air} = m * g$$

$$\text{In water} \quad F_{water} = m * g - F_b$$

This can be rearranged such that

$$F_b = F_{air} - F_{water}$$

Was the weight of the calibration mass the same at all three depths? (*i.e.* were the weights within uncertainty of each other) Why or why not?

Calculate the **average** weight of the calibration mass in water using all three depths - make sure to update your uncertainty.

Calculate the buoyant force F_b and its uncertainty from the difference between the weight of the mass in air and the **average** weight of the mass in water.

Calculate the buoyant force using the weight of the displaced water. Use the iOLab to weigh the saved ziplock bag of water. Don't forget to subtract off the weight of the empty bag, leaving only the weight of the displaced water, $m_w g$. Weighing a second bag is a perfectly fine approximation.

Compare the three values for the buoyant force use uncertainties and or percent differences to make your argument for if the values agree.

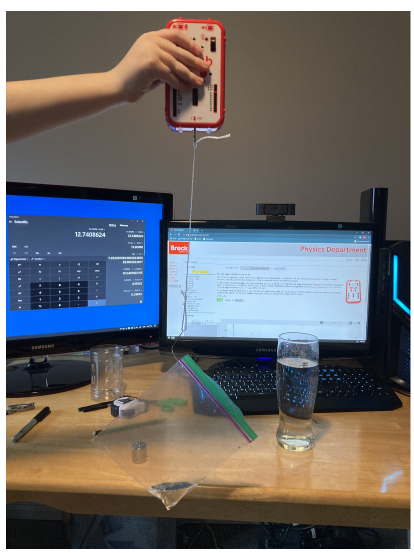

Figure 3: An example of weighing the displaced water in the ziplock bag by piercing the bag with a paperclip.

For discussion: Imagine you had an object *the exact same shape and size* as the calibration mass, but made of different material. Referring back to the table of materials in the Openstax text, which materials could you use to make this object float? Is there a metal you could use? What would be the object's mass for each of those materials?

Finishing Up

Now that you have completed the lab, be sure you filled out all portions of the data tables (templates found in the Resources Tool on Sakai), include figures, and develop a robust discussion using prompts found throughout the manual.

Ensure to give yourself enough time to complete the report and to hand it in by the due date as late lab reports will not be accepted! If you have any questions please attend a live lab session to get help from one of the course lab demonstrators, or email Phys1P92@brocku.ca.