PHYS 1101: Finding the density of an object of irregular shape

aka Archimedes' Principle

Goal: Problem 1: use Archimedes' Principle to find the density of a cylinder.

Problem 2: use Archimedes' Principle to find the density of a rock.

Introduction

Measuring the volume of an object by immersion

When a solid object is submerged in liquid, it experiences a vertical upward force $\boldsymbol{F_B}$. This force is called the buoyant force. Archimedes' Principle states that F_B equals the weight of the liquid displaced by the solid object:

$$F_B = W_{\text{displaced liquid}} = m_{\text{displaced liquid}} \cdot g = \rho_{\text{liquid}} \cdot V_{object}\ g \qquad \textbf{(1)}$$

$$where\ g = 9.81 \pm 0.01\ m/s^2$$

We can therefore determine the volume of a solid object (V_{object}) from measuring F_B and knowing the density of the liquid (ρ_{liquid}). This is especially useful when the shape of the body is irregular, like a rock.

Measuring the buoyancy force

With a spring scale, we can measure the weight of the object in air W, and its "apparent weight" in the water W_{app}. The object feels less heavy in water because it is supported by the buoyancy force.[1] For example, if an anchor has a mass of 50 kg, when you weigh it in air, you read 490N. When you weigh it in water, you may read 200N. Therefore the buoyancy force is 290N.

$$F_B = W - W_{app} \qquad \textbf{(2)}$$

Instead of using a spring scale to measure the buoyant force directly, we will use the more precise 2-pan balance. Because the balance measures mass rather than force, the above equation can be rewritten in terms of the mass of the object in air m and the *apparent mass* of the object in water m_{app}:

$$F_B = (m - m_{app}) \cdot g \qquad \textbf{(3)}$$

And then we can use **(1)** to get the volume of the object.

1 the buoyant force of the air is neglected.

Attached at the back of this handout is a PRELAB QUESTION for you to work out the volume, and thus density, of a hypothetical rock, with the appropriate uncertainties. Complete the derivations and calculations for this question before coming to the lab.

Problem 1 Find the density of a Cylinder

In this problem, you will review how to perform an experiment and write a lab report. Attached to the back of this handout is a template for this section, to demonstrate good data taking and lab report formatting. When you complete Problem 1, show your report to the instructor(s) to check your procedures and results. You will then be given the rock for Problem 2, and you will produce your own lab report.

Apparatus

- Draw a schematic diagram similar to Fig 1 below. It does not to be THIS detailed, but add labels so that it is clear what you are doing with the apparatus.
- Provide identifying numbers: Two-pan balance # ___, metal cylinder #___ (also give its apparent colour), thread, etc.

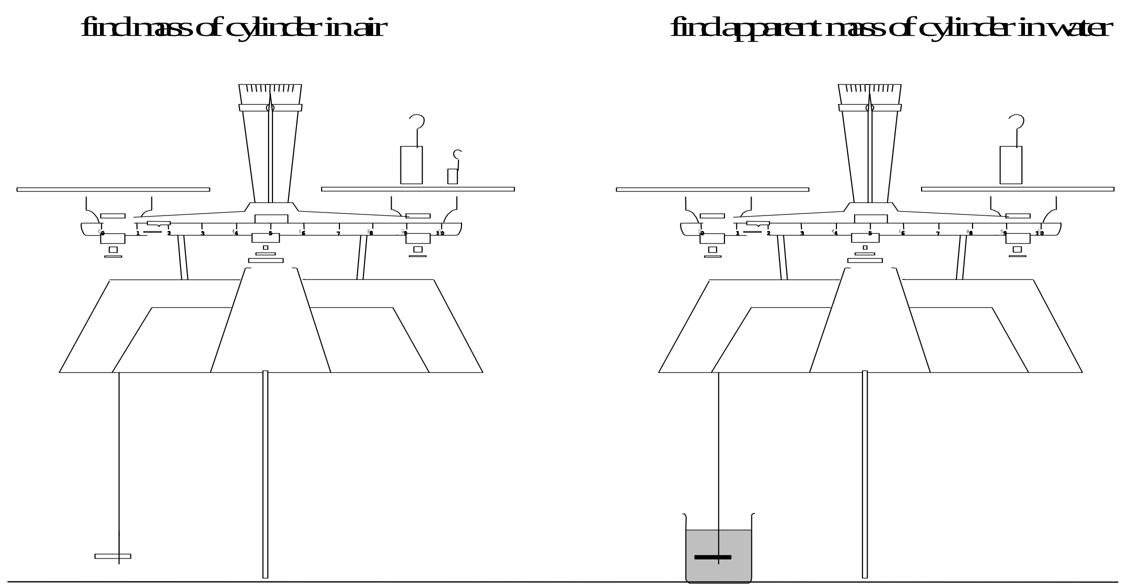

Fig 1

Data

- Hang the cylinder under the 2-pan balance with a thread, looping it on the metal hook right under the *centre* of the left pan. Measure and record the mass of the cylinder in air m.

- Place the beaker of water under the balance so that the cylinder is *completely* submerged in the water. You may have to raise the beaker with a book or the mass box. Record the apparent mass of the cylinder in water m_{app}.

Calculations

- Using your answer to prelab question (4), calculate the density of the cylinder. Keep at least 5 digits (aka DON'T ROUND ANYTHING YET). Take care with any unit conversions.

Uncertainty Analysis

- Calculate the uncertainty in the density of the cylinder. Show your work. You will need both the relative (and percent) uncertainty and the absolute uncertainty.

Conclusions

- State the density of the cylinder in a sentence. Include proper round off, uncertainty (absolute and percent), units and scientific notation.

Discussions

- Compare your result with the reference values in the table below. Which metal do you think you have?

Reference Values for Density of the Cylinder:

Metal	Density ± 0.01 (x 10^3 kg/m^3)
Aluminium	2.70
Brass	8.56
Copper	8.89
Steel	7.85

- Find the percentage discrepancy between your result and the reference value.
- Propose ways of improving the results. Make other observations on why you think you may have a particular type of material.

Problem 2 Density of a Rock

You are now on your own to find the density of your rock. Stay as close as possible to the method of problem 1. Tips: Knock off any air bubbles trapped anywhere on the surface of the rock.

Lab report

Following the format of Problem 1's template, write your own professional quality lab report that states goal, apparatus, data, calculations, uncertainty analysis, conclusion and discussion. Comment, and critique your results.

Name: ______________________
Partner(s): ___________________
Desk: _______________________
Date: _______________________

Archimedes' Principle Prelab

Work out the solutions to this problem, and bring this page to the lab. You will not be given a cylinder and rock until this is completed correctly. Hand this page in with your report.

A rock has a mass of (1000.0±0.5)*g* in air, and an apparent mass of (800±2)*g* when submerged in water. The density of tap water is $(1.00 \pm 0.01) \times 10^3\ kg/m^3$.

1. Calculate the buoyancy force acting on the rock.

2. Calculate the volume of the rock.

3. Calculate the density of the rock.

4. Using symbols only, derive the density of the rock in terms of ρ_{liquid}, m and m_{app}, and derive its uncertainty equation. Use the back of the page if you need more space.

Instructor's initials:

Name: ________________________
Partner(s): _____________________
Desk: _________________________
Date: _________________________

Archimedes' Principle
Problem 1: Density of a Cylinder

Purpose: • Use Archimedes' Principle to measure the density of a metal cylinder

Apparatus:

Data:

Mass of Cylinder # ______ in air and in water

Mass in Air (g)	Uncert (g)
Mass in Water (g)	Uncert (g)

Calculations:

Uncertainty Analysis:

Conclusions:
The density of cylinder # _____ was measured to be (_______ ± ______)$\times 10^3$ *kg/m*^{3} (± ____%), using Archimedes' Principle.

Discussions:
From the reference table given in the lab instructions, we believe that cylinder # ______ is made from ____________________.
The reference value for the density of __________________ is (_______ ± ______)$\times 10^3$ *kg/m*^{3}.

Discrepancy: $= \left| \dfrac{\rho_{ref} - \rho_{meas}}{\rho_{ref}} \right| \times 100\%$

$=$

$=$

Since our experimental result and the reference value (DO / DO NOT) overlap within their uncertainties, we can conclude that the results (DO / DO NOT) agree. We (ARE / ARE NOT) confident with our result.

Other observations: