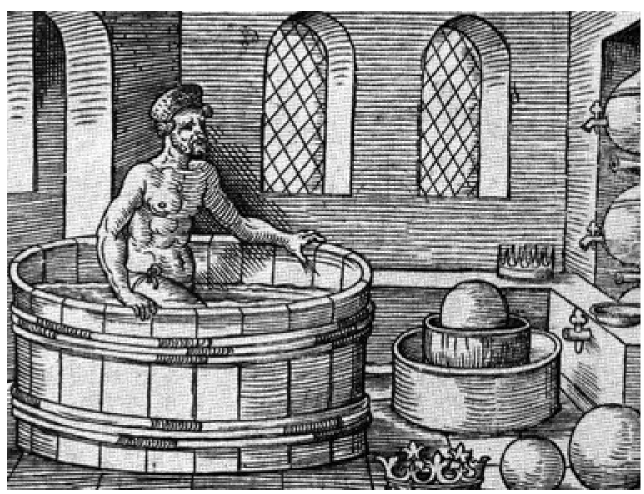
Buoyancy

Goals: Collect and prepare data for an oral presentation. Use error analysis as part of an oral presentation. Compare methods to determine buoyancy and specific gravity.

APPARATUS

The idea that different items vary in density is an ancient one. Specific gravity is a measure of the density of a material compared to water. The earliest use of that comparison goes back to Archimedes of Syracuse in the third century BCE. King Hiero II asked Archimedes to determine if the King's crown was made of pure gold or a cheaper alloy. Archimedes found a solution to the problem when he realized that he could measure the volume of an irregularly shaped object by displacing water. Upon realizing this he jumped out of his bath and ran through town shouting "Eureka", which means "I have found it."



Around 250 BCE Archimedes wrote *On Floating Bodies* which described the principle of buoyancy - "Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object."

We will use both of Archimedes ideas to measure specific gravity. The apparatus consists of a metal overflow cup with a side spigot and a beaker. If the overflow cup is filled to its limit, then an object lowered into the water will cause some of the water to spill out the side spigot. This water can be collected in the beaker and weighed.

Objects in this laboratory will be weighed by a spring scale. The spring scale measures the weight of an object in newtons (N). There are two spring scales available, one with a maximum reading of 2.5 N and one with a maximum reading of 20 N. An object with a weight of more than 2.5 N must be read with the 20 N scale. If the weight is below 2.5 N switch to the 2.5 N scale.

THEORY

Though they are often treated interchangeably, weight and mass are different physical properties. Mass (m) is a fundamental measure of the amount of matter. Weight (w) is a measure of the force exerted by a mass. On the surface of the earth the conversion factor is the acceleration of gravity ($g = 9.8\ \text{m/s}^2$). Thus, an object on earth has a weight related to its mass by EQ 1.

$$w = mg \qquad \textbf{(EQ 1)}$$

Density (ρ the Greek letter "rho") is defined as the mass (m) of an object divided by the volume (V) of the object (EQ 2). The density of a material depends on the phase it is in and the temperature. (The density of liquids and gases is very temperature dependent.) Water in the liquid state has a density (ρ_w) of about 1 g/cm^3 = 1000 kg/m^3.

$$\rho = \frac{m}{V} \qquad \textbf{(EQ 2)}$$

The density of an object can be used to identify the material of the object, and to predict its behavior when placed in a fluid, either liquid or gas. If the density of an object is greater than the fluid it will sink, and if it is less than the density of the fluid it will rise. Water is the most commonly used fluid to compare material for density measurement.

The specific gravity (SG) is the ratio of a material's density compared to water (EQ 3). The official specific gravity is defined using water at 4°C. Because it is the ratio of two densities with the same units (g/cm^3), it has no units itself. Note that since water has a density of 1 g/cm^3, the specific gravity is the same as the density of the material measured in g/cm^3.

$$SG = \frac{\rho}{\rho_w} \qquad \textbf{(EQ 3)}$$

When an object is in a fluid there is a buoyant force acting on the object due to the pressure of the fluid. The buoyant force is equal to $\rho_w gV$ where g is the acceleration of gravity and V is the volume of the object in the liquid. Since $\rho_w V$ is equal to the mass of the water displaced by the object, this quantity is also exactly equal to the weight of the water. This is called the buoyancy (or Archimedes) principle: the buoyant force on a body immersed in a fluid is equal to the weight of the fluid displaced by the object.

If the numerator and denominator of EQ 3 is multiplied gV, and EQ 1 and 2 are used, we get EQ 4.

$$SG = \frac{\rho g V}{\rho_w g V} = \frac{w}{w_{water}} = \frac{w_{out}}{w_{out} - w_{in}} \quad \textbf{(EQ 4)}$$

The last step in the equation used the buoyancy principle for the denominator. Here w_{out} is the weight of the object out of the water, and w_{in} is the weight in water.

DATA COLLECTION

Part A - Heavier than water

1. Weigh the beaker on a a balance beam scale, and record the value of the mass (m_0) in grams including uncertainty.
2. Weigh each of the metal cubes (aluminum, brass, steel, lead) with a spring scale. Record these weights (w_{out}) in newtons including uncertainty.
3. Use the weight of the object in air (w_{out}) and EQ 1 to find the mass (m) of each of the four metal cubes in step 2.
4. Fill the overflow can with water so that water just begins to spill out.
5. Use the spring scale to lower the aluminum cube into the water in the overflow can until it is completely submerged. The water should be collected in the beaker.
6. Record the weight (in newtons) of the cube while it is submerged (w_{in}).
7. Weigh the beaker including the water (m_1) and record the mass difference due to the water $m_w = m_1 - m_0$ in grams.
8. Use the mass of the water (m_w) and density ($\rho_w = 1.0$ g/cm^3) to find the volume (V) of water displaced for the cube measured in step 7 using EQ 2.
9. Use the mass from step 3 the volume from step 8, and EQ 2, to find the density (ρ) of the cube, including the uncertainty based on the calculations at each step. This is equal to the specific gravity (SG) in EQ 3.
10. Use the weight of the cube in air from steps 2 and in water from step 6 with EQ 4 to find the specific gravity (SG) of the four cubes.
11. Repeat steps 4 through 10 for each of the other cubes.
12. Make a data table for the mass, volume and two calculations for SG (EQ 3 and 4) for each cube on a white board. Include the uncertainties and use appropriate significant figures.
13. Make a presentation of the data (person A); Record your results and those of the other groups (person B); Ask questions of other presenters (person C). The person making the presentation should not be the same as the person(s) who presented during the last oral presentation.

Part B - Lighter than water

14. Weigh and record the wood block with attached sinkers (w_b) using the spring scale.
15. Use the spring scale to lower the sinkers, but not the block, into the water. The water should be collected in the beaker.

16. Record the weight (in newtons) of the block and sinkers while just the sinkers are submerged (w_1).

17. Record the weight (in newtons) of the block and sinkers when they are entirely submerged (w_2).

18. Find the specific gravity of the wood in part B using the following equation.

$$SG = \frac{w_b}{w_1 - w_2} \quad \textbf{(EQ 5)}$$

ASSIGNED QUESTION

19. Your TA will assign an additional question to answer in a report.

20. Each student should assemble their own separate report including the assigned question. The report should include the results from parts A and B. The report should include a summary of the data from all the groups in part A and use them to answer the following:

21. How do the results from other groups compare to each other? Describe the results in comparison to the reported uncertainties.