Experiment 11

Buoyant Forces, Density, and Specific Gravity

Preparation

Prepare for this week's quiz by reading the sections of your textbook that cover Archimedes' Principle, buoyant forces, density, and specific gravity.

Principles

Density

The density (ρ, pronounced "rho") of an object is the ratio of its mass to its volume:

$$\rho = \frac{m}{V}$$

Since very few substances have exactly the same density, this property can be used to identify an element or compound.

Buoyant Force

When you are swimming in a pool or in the ocean you seem to weigh less. This is because the water exerts a buoyant force on you. The apparent loss of weight that you feel when submerged in a liquid is exactly equal to the buoyant force the liquid exerts on you. In other words, if you weigh yourself in air and then weigh yourself while submerged in a liquid, your weight in the liquid, called your "apparent weight" will be the smaller of the two. This is because the liquid exerts a larger buoyant force on you than air does. Salt water is denser than fresh water and exerts more force; your apparent weight is less in salt water than in fresh water. In some extremely salty bodies of water like the Salton Sea or the Dead Sea it is almost impossible to sink.

One way to understand buoyant forces is to consider an element of volume ΔV somewhere in a container of liquid. This element is in equilibrium, that is, it is neither rising nor falling in the container. This means that the weight of the liquid, which acts downward, is exactly balanced by an upward force provided by the liquid below it. This upward force is the buoyant force. If the volume of liquid, ΔV, is replaced by an object of the same volume, the object will feel the same force. The buoyant force, therefore, is equal to the weight of the displaced liquid.

$$F_b = mg = \rho \Delta V g$$

where ρ is the density of the liquid, ΔV is the volume of the submerged part of the object, and g is the acceleration due to gravity. This is called Archimedes' principle. He is said to have discovered this principle while he was taking a bath.

If the object's weight is less than the weight of the displaced liquid, it will float. It may also be able to support additional weight. The amount of weight a floating object can support is the difference between the object's weight and the weight of the liquid that the object would displace if it were totally submerged. An object that floats will have negative apparent weight when it is totally submerged.

Specific Gravity

The density of water is 1 gram/ cm^3 which is the same as 1 x 10^3 kg/m^3. The ratio of the density of any solid or liquid or to that of water is called its **specific gravity** *(S)*. Since it is the ratio of two densities, specific gravity has no units and is independent of the system of measurement.

The specific gravity of a liquid can then be measured by finding the ratio of the buoyant force an object feels in the liquid to the buoyant force it feels in water. This is the same as the ratio of the apparent loss of weight in the liquid to the apparent loss of weight in water:

$$S = \frac{w - w_1}{w - w_2}$$

where w, w_1, and w_2 represent the object's weight in air, in the liquid, and in water, respectively. Since g is a common factor in the denominator and the numerator it can be factored out and the specific gravity can be written in terms of the object's apparent mass in air, liquid, and water:

$$S = \frac{m - m_1}{m - m_2}$$

Equipment

1 pan balance
1 graduated cylinder
1 beaker
4 metal cylinders with the same volume and different materials
1 wooden block
1 Vernier caliper
1 rubber band
string

Procedure

Use the CGS system of units. Measure masses to 0.1 gram. Measure lengths to 0.1 mm.

1. Measure the mass of each cylinder and of the wood block. Guess what you think each cylinder is made of.

2. Use the Vernier caliper to measure the height (h) and the diameter (d = 2r) of one of the cylinders and calculate its volume (V_1). Measure the same for the plastic jar and measure the length, width, and height of the wood block. Calculate the volume of each.

3. Fill the graduated cylinder about half full of water. Record the water level at the bottom of the meniscus, the curved surface of the water. Drop the cylinder whose volume you calculated into the water and record the new water level. The difference between the two

readings is the volume of the cylinder (V_2). Note that one milliliter equals one cubic centimeter. Compare this value to the value you calculated by finding the percent error.

4. Calculate the density of the cylinder using your measured value for the volume. Decide what your cylinder is made of. Find the percent error for the density.

5. Set a beaker of water on the platform attached to the balance. Tie a piece of string to the arm of the balance and tie a rubber band to it so that you have a sling with which you can lower objects into the water.

6. Use the rubber band and the string to suspend each of the different cylinders in the beaker of water and find the apparent mass of each one. Calculate the difference between the mass in air and the apparent mass in water for each.

7. Calculate the density of the wood block. Estimate how much of the block will be above the water if you put it into the beaker of water. (Hint: Think about the relative densities of the two substances.)

8. Put the block into your beaker of water. Measure the amount of it that is above the water. Does your measurement agree with your estimate?

9. Estimate how much mass you can put in the plastic jar before it would just start to sink if you put it into the beaker of water.

10. Put your estimated amount of mass in the jar, close the lid and test your estimate. Add or subtract mass until the jar just starts to sink.

11. Take the masses out of the jar. Fill it with water, close it up, and find the mass. How does it compare to the mass the jar would support? Empty the jar and dry it.

.

12. Your instructor will have a balance and a beaker of 'unknown' liquid on the front table. Take one of your cylinders, make sure it is dry, and find its apparent mass in the liquid.

13. Calculate the specific gravity of the liquid. Your instructor will give you the correct value for the specific gravity of your "unknown" liquid. Find the percent error.

14. Put your equipment away neatly.