Buoyancy and the Density of Liquids (approx. 2 h) (11/24/15)

Introduction

Which weighs more, a pound of lead or a pound of feathers? If your answer to this question is "a pound of lead", then you are confusing "weight" with "density." If you have a pound of anything, it weighs a pound (i.e. it is attracted by Earth's gravity with a force of one pound). The density of a substance is its mass divided by its volume. Since a pound of lead does not take up as much space (i.e. volume) as a pound of feathers, it has a greater density. Density is one of the most important properties by which we characterize a substance. In this lab you will measure the density of various objects and of a liquid by measuring buoyant force, displaced volume, and mass and volume directly.

Equipment

- assorted metal cylinders (1 ea.)
- irregular solid
- "unknown" liquid
- pitcher
- overflow can
- specific gravity bottle
- caliper
- ruler
- string with loops on ends (~36”)
- balance
- small beaker (50 ml)
- beaker (250 ml)
- graduated cylinder (10 ml)
- funnel

For class as a whole: liquid soap or detergent (used as a surfactant); eye droppers

***Theory*:** Density depends on how closely spaced the atoms of a substance are as well as on the mass of each atom, and therefore is a physical property of the substance. Its numerical value depends on the units used for mass and volume. For example, the proper SI unit for density is kilograms per cubic meter (kg/m^3). A unit that is often more convenient for use in the laboratory is grams per cubic centimeter (g/cm^3 or g/cc), or equivalently, grams per milliliter (g/ml). (1 milliliter = 1 cubic centimeter of volume.) This unit is particularly handy, since the density of water, the must commonly encountered liquid, is 1.0 g/cm^3 (not just by coincidence!). If we measure density in one of these units we immediately know if a substance is more dense or less dense than water, and hence whether a solid "chunk" of it will float or sink when placed in water. In fact, these units are so commonly used that they are often omitted, in which case we speak of the "specific gravity" of a substance, which is numerically equal to the ratio of the density of the substance to the density of water. In other words, the specific gravity of a substance is numerically equal to its density expressed in g/cm^3, but without the units.

Specific Gravities of Some Common Metals

Aluminum (Al), 2.70	Tin (Sn), 7.31	Lead (Pb), 11.34	Brass, 8.6
Steel, 7.83	Zinc (Zn), 7.14	Copper (Cu), 8.96	

Archimedes' principle states that the buoyant (i.e. upward) force on an object due to the fluid in which it is immersed is equal to the weight of the fluid displaced by the object. This is why a solid immersed in a liquid, for example, appears to weigh less, and why some things float. This principle will be used to find the specific gravity of an object immersed in water.

Procedure

1. Hold a cylinder of a relatively high density metal, such as steel, brass, or copper in one hand, and a cylinder of a lower density metal, such as aluminum in the other hand, and get a qualitative feel for their relative weights. Using a common ruler, make approximate measurements of the lengths and diameters of the cylinders. Using a caliper, make more precise measurements of these dimensions (if you are using a Vernier caliper, see Appendix 4.: "Reading a Vernier" in the online lab manual). Compute the volumes of the cylinders using these measurements.

2. Use a laboratory balance to determine the masses of the two cylinders, then compute the density of each by dividing its mass, in grams, by its volume, in cm^3. Record your measured and calculated values in the table on p. 6. How do they compare to your qualitative feel for the masses and densities?

3. Using a string with loops, bring the loop on one end thru the loop on the other and pull the resulting large loop tight around the middle of one of the cylinders, then lower the cylinder into a pitcher of water. As the cylinder becomes immersed in the water, notice the change in its apparent weight (i.e. the pull of the string) and the change in the water level in the can. Remove and dry the cylinder.

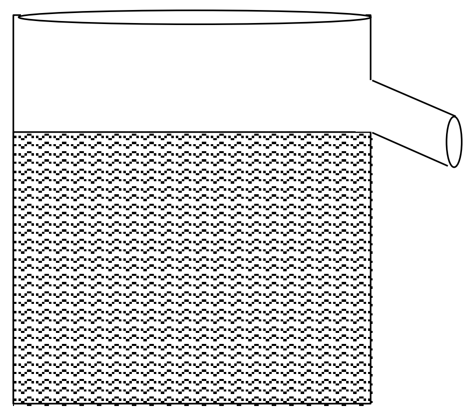

Figure A: Overflow Can

4. Pour water into an overflow can (Figure A) until it slowly flows out of the spout (into a beaker). Stop pouring and wait until the spout stops dripping. Carefully place a drop of soap or detergent on the surface of the water in the overflow can to reduce the effect of surface tension. Measure the mass of the graduated cylinder then place it under the spout and slowly lower the cylindrical mass into the water, catching the overflow in the graduated cylinder. Determine the mass of the overflow water and thereby determine its volume, based on the known density of water.

5. Determine the density of the cylinder using its previously measured mass and the volume of the displaced water. Compare this value with that determined in step 2. What is the specific gravity of the cylinder?

6. With the weighing end of the balance projecting beyond the edge of the table (see Fig. B), suspend the cylindrical mass from the underside of the balance by attaching the loop

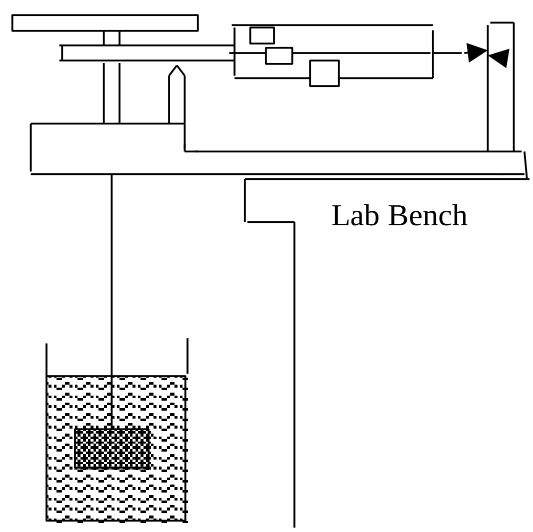

Figure B: Buoyant Force Arrangement

on the string to the upturned end of the metal pin on the bottom of the balance arm. Measure its mass while suspended in air. If the mass of the cylinder is not the same as was determined in step 2, use the zero adjustment on the balance to make it read the same.

7. Now measure the mass of the suspended cylinder while it is totally submerged in water (but not touching the bottom of the pitcher) as shown in Figure B. The difference between this reading and the mass measured in air is due to the buoyant force of the water. Does this mass difference correspond closely to any of your previous measurements? If so, which one? Is this to be expected based on Archimedes' principle?

8. Compute the ratio of the mass reading of the cylinder (in air) to the difference between the mass readings obtained in air and submerged in water. To what does this correspond? Explain.

9. Do your observations in steps 3 thru 5 suggest a possible method for finding the volume of an irregularly shaped solid? Determine the volume of an irregularly shaped object and use the methods of steps 2 & 4 to determine its specific gravity. Next, use the method of steps 6 thru 8 to determine its specific gravity and compare results by calculating the per cent difference. Which method do you think gives the most accurate result? Why? Record your data and the kind of material of the irregular body.

10. **Specific Gravity of a Liquid by Specific Gravity Bottle (Pycnometer).** The specific gravity bottle is provided with a perforated glass stopper that permits the excess liquid to flow out of the bottle when the stopper is inserted. This results in a well defined volume of any liquid placed in the stoppered bottle. First, determine and record the mass of a clean, dry bottle and stopper. Then fill it with the "unknown" liquid by pouring very carefully from a small beaker. Make sure the outside of the bottle and the surface of the balance platform are dry and measure and record the mass of the stoppered bottle + liquid x. Pour liquid x back into the beaker and rinse the bottle with water. Then fill the bottle with water and measure and record the mass of the stoppered bottle + water as before. From the measured masses, calculate the mass of each equal volume of liquid and calculate the specific gravity of liquid x and record. (Note: The handbook value for the specific gravity of isopropyl alcohol is 0.78.)

11. Use the graduated cylinder and balance to determine the density of a liquid directly by mass and volume measurements (see p. 7). (Note: The mass of the empty graduated cylinder is commonly referred to as a "tare". If your beam balance has a black “tare” mass on the back slider, you can use it to make the balance read zero when the empty graduated cylinder is on the balance and then read the mass of the liquid directly after you pour it into the cylinder. Digital balances may have a “tare” button to reset the zero reading.) When reading the volume of the liquid in the cylinder, notice the "meniscus" shape of the liquid surface due to the attraction (or repulsion) between the liquid and the walls of the cylinder. Be sure to use the height of the center of the liquid column for your measurement, not the edge.

Questions

1. You determined the volume of a cylinder by two different methods. Which do you think is more accurate and why? Can you suggest yet another method for finding the volume?

2. Describe a method of determining the specific gravity of a solid object that does not involve determining the objects volume (i.e. no overflow can or size measurements).

3. From the observations made in this lab, write a statement of the relation between the apparent loss of weight of a body immersed in water and another weight you have determined. Why does an immersed body appear to lose weight? Would this same relation exist for liquids other than water? Explain.

4. What relation did you find between the density and the specific gravity of the cylinder? Why does this relation exist? If the density were measured in slugs per cubic foot (English system of units), would the relation be any different? Explain.

5. Assume the overflow can is filled and preparations are ready for catching the overflow water. A block that will float is now carefully placed in the can, and the overflow water is caught and measured. The experiment is then repeated with gasoline in the can. Discuss the relative volumes and masses of the two overflow liquids. (Note: Gasoline is less dense than water.)

6. One kilogram of iron and one kilogram of aluminum are submerged in water and their apparent weights are recorded. How do the apparent weights compare (qualitatively)? Explain.

7. One cubic centimeter of aluminum and one cubic centimeter of lead are each weighed in air and then in water. How do their apparent weight losses compare? Explain.

8. Suppose a vessel of water is balanced on a laboratory balance. Will the balance be disturbed if you put your finger into the water? Why? If in doubt, try it.

9. In general, do you think the density of a body depends on its temperature? Why?

10. If a body floats in a liquid, how does the loss of weight (buoyant force) compare with the weight of the body? Explain.

11. What is the density of the irregular solid used in the experiment in grams per cubic centimeter? In the SI system?

12. How much does a cubic foot of water weigh in pounds?

13. Can you suggest a way to use Archimedes' principle to find the length of a tangled bundle of wire without undoing the tangle?

RECORD OF DATA AND RESULTS

Density of a Solid Cylinder
(steps 1 & 2)

	Cylinder no. 1	Cylinder no. 2
Material		
Mass (grams)		
Length (cm)		
Diameter (cm)		
Volume (cm)		
Density (g/ cm^3)		
Specific gravity		

Displacement Data

	Cylinder (From steps 2 & 4 – 8)	Irregular Solid (From steps 2 & 4 – 8)
Material		
Mass		
Mass of empty catch vessel		
Mass of vessel + overflow water		
Mass of overflow water		
Balance reading of solid in water		
Difference when suspended in air and water		
Ratio of mass in air to difference when suspended in air and water		

Density of cylinder	From Step 2 =	From Step 5 =	% difference =
Sp. Gr. Of cylinder	From Table (p. 1) =	Result From Step 8 =	% difference =
Sp. Gr. of irregular object (from step 9)	Method of Steps 2, 4 & 5 =	Method of Steps 6 – 8 =	% difference =

Specific Gravity of a Liquid by Specific Gravity Bottle (Step 10)

Mass of empty, dry pycnometer (bottle) ________________________g

Mass of pycnometer full of liquid x ________________________g

Mass of liquid x in pycnometer ________________________g

Mass of pycnometer full of water ________________________g

Mass of water in pycnometer ________________________g

Specific gravity of liquid x ________________________

Density of a Liquid by Direct Measurements of Mass and Volume (Step 11)

Balance reading with dry, empty graduated cylinder ________________________g

Balance reading with graduated cylinder plus alcohol ________________________g

Net mass of alcohol ________________________g

Volume of alcohol ______________________ml

Density of alcohol (g/ml) ____________________(g/ml)