

## **Buoyancy and the Density of Liquids** (9/20/04)

### **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
- irregular solid
- "unknown" liquid
- displacement can
- overflow can
- specific gravity bottle funnel
- vernier caliper
- ruler
- string & scissors
- triple beam balance
- small beaker (50 ml)
- beaker (200 ml)
- graduated cylinder (10 ml)

### **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 ( $\text{kg/m}^3$ ). A unit that is often more convenient for use in the laboratory is grams per cubic centimeter ( $\text{g/cm}^3$  or  $\text{g/cc}$ ), or equivalently, grams per milliliter ( $\text{g/ml}$ ), since 1 milliliter = 1 cubic centimeter of volume. This unit is particularly handy, since the density of water, the most commonly encountered liquid, is  $1.0 \text{ g/cm}^3$  (not just by coincidence!). If we measure density in one of these units we immediately know if a substance is denser 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  $\text{g/cm}^3$ , but without the units.

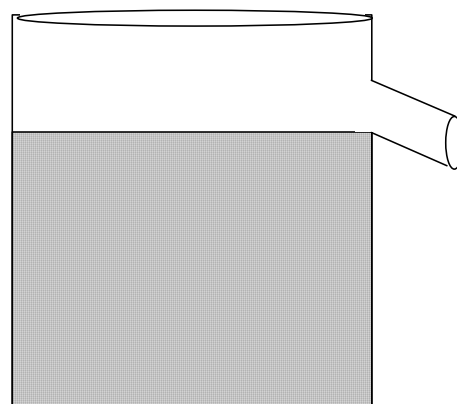
#### **Specific Gravities of Some Common Metals**

Aluminum (Al), 2.70	Tin (Sn), 7.31	Lead (Pb), 11.34	Brass, 8.6
Iron (Fe), 7.87	Zinc (Zn), 7.14	Copper (Cu), 9.0	

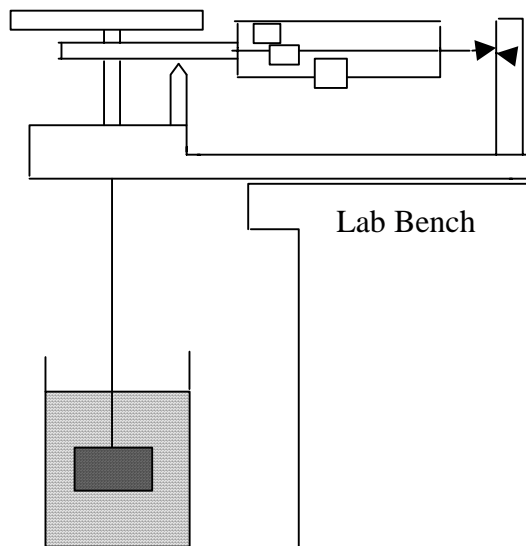
Archimedes' principle states that the buoyant (i.e. upward) force on an object due to the fluid in which it is immersed is equal to the weight of the fluid displaced by the object. This is why a solid immersed in a liquid, for example, appears to weigh less, and why some things float. This principle 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 lead 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 vernier caliper, make more precise measurements of these dimensions (see Appendix: Reading a Vernier). 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  $\text{cm}^3$ . Record your measured and calculated values. (How do they compare to your qualitative feel for the masses and densities?)
3. Tie a string around one of the cylinders and lower it into a can 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.
4. Pour water into an overflow can (Figure A) until it slowly flows out of the spout. Stop pouring and wait until the spout stops dripping. 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 a graduated cylinder then place it under the spout and slowly lower the cylinder 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 the volume of the displaced water and its previously measure mass. Compare this value with that determined in step 2. What is the specific gravity of the cylinder?
6. Arrange a laboratory balance and a vessel of water as shown in Figure B. Suspend the cylindrical mass from the underside of the balance by attaching the string to the balance arm and measure its mass. 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. Now measure



**Figure A:** Overflow Can



**Figure B:** Buoyant Force Arrangement

the mass of the suspended cylinder while it is totally submerged in water (but not touching the bottom of the can). 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?

7. 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.
8. Do your observations in step 3 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 step 7 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.
9. **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 the mass of a clean, dry bottle and record. 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 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 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.)
10. Use the graduated cylinder and balance to determine the density of a liquid directly by mass and volume measurements. (The mass of the empty graduated cylinder, which must be subtracted from the mass of the graduated cylinder with the liquid in it, is commonly referred to as a "tare".) 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. Can you suggest a method of measuring the specific gravity of a solid that's simpler than using the displacement can? If so describe it.
3. From the observations made in *this* experiment, write a statement of the relation of the apparent loss of weight of a body immersed in water to other weights of the body 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, 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. 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

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

### Displacement Data

	Cylinder Steps 4, 5 & 6	Irregular Solid Step 7	
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			
Density of cylinder	Step 2 =	Step 5 =	% difference =
Sp. Gr. Of cylinder	Step 5 =	Step 7 =	% difference =
Sp. Gr. of irreg. obj.	Step 2 & 4 Method	Step 7 Method	% difference =

**Specific Gravity of a Liquid by Specific Gravity Bottle (Step 9)**

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 10)**

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)