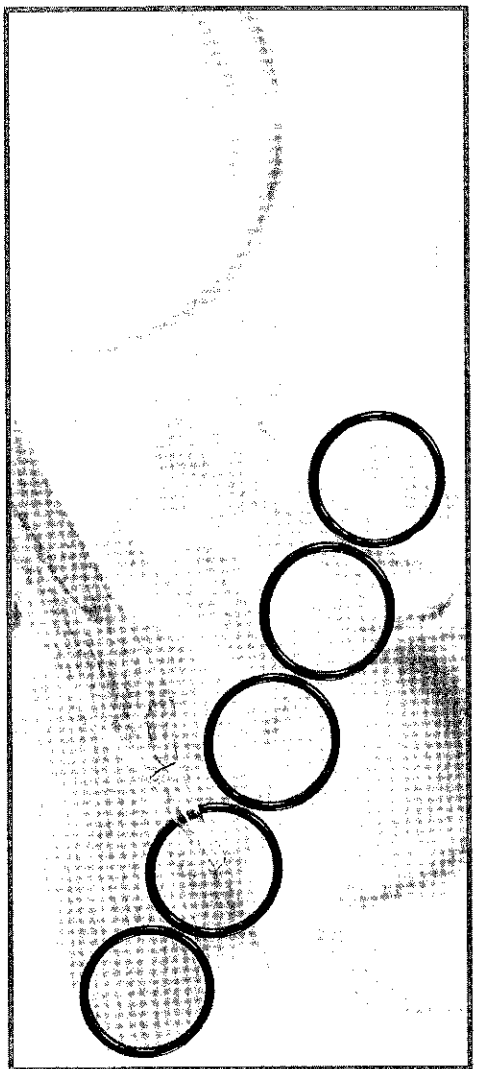
## I. INTRODUCTION

It is important for a scientist to be able to measure objects accurately. An object can be measured by its length, mass and volume. Different units can be used to express size or value of a measurement. For example, volume can be measured in cups, gallons, liters or milliliters and the same measurement may have a very large or very small number depending upon the units that are used.

Scientists have developed a standard method for expressing these units. Based upon in the **metric system,** all the different units are related by tens. For instance, there are 10 milligrams in a centigram, 10 centigrams in a decigram, 10 decigrams in a gram, etc.

In the metric system the base units for the different forms of measurement are: for length is the meter (m), for mass is the gram (g), and volume is expressed in liters (L). Each of these measurements may have metric prefixes applied to indicate size of the value; **kilo**grams and **milli**liters is an example. Sometimes cubic units such as cubic centimeters ($cm^3$) are also used to indicate volume.

In the laboratory, volumes are measured in a graduated cylinder. The volume of a regularly shaped solid object (must be insoluble in water!) may be determined by measuring the dimensions with a ruler and applying a mathematical formula to find the volume. It is not so easy to find the volume of an irregularly shaped object such as a piece of broken glass. Instead, the object may be placed in a graduated cylinder that contains a measured volume of water. Next, place the object in the water; by immersing it completely, the level of the water will rise by exactly the volume of the object. The volume of the object is measured by the difference between the initial and final volume of water in the cylinder. This is called "**displacement**."



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# Mass and Density

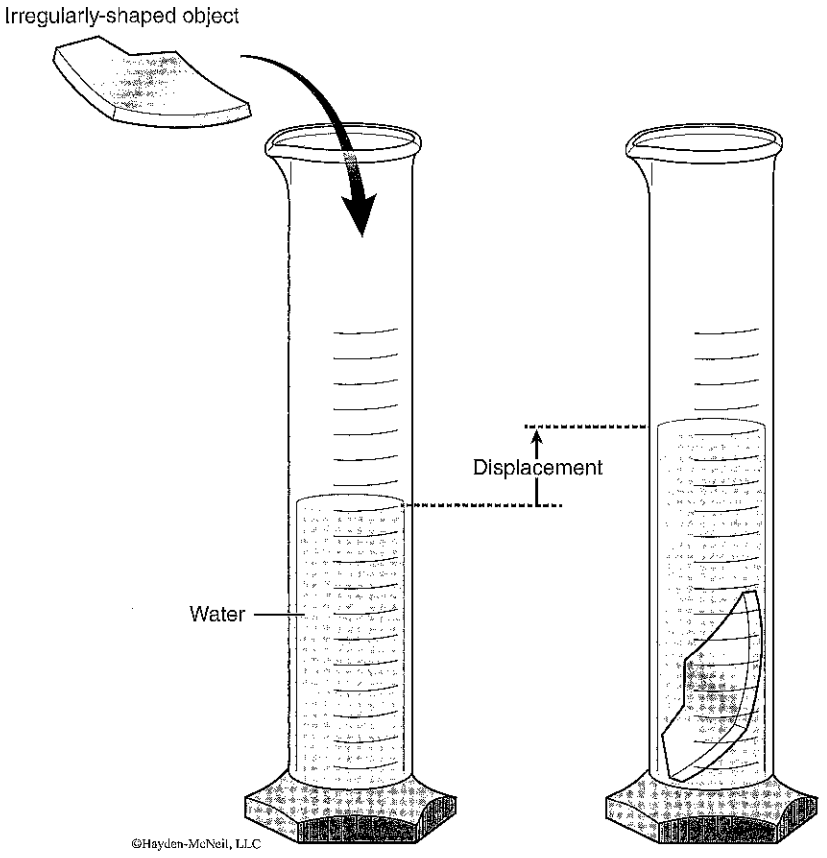



**Figure 2-1.** Water displacement after an object is introduced.

Measured *volume* and *mass* are combined to determine the *density* of an object. Density is the mass divided by the volume. A cube of aluminum and a cube of lead may have the same volume, but the lead will be much heavier because the lead has a higher density.

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

Where:

$d$ = density

$m$ = mass

$V$ = volume

If a solid block had a mass of 1721 g and a volume of 151.8 mL, the density is:

$$\frac{1721\,\text{g}}{151.8\,\text{mL}} = 11.34\ \text{g/mL}$$

A quick check of Table 2-1 shows that is the density for lead.

## II. SAFETY

- For this experiment you will need to wear your safety glasses, closed toe shoes, and a laboratory apron whenever anyone in the room is doing lab work (even if they are only using water). Everybody needs to use them as long as anybody is still working on the experiment.
- There is absolutely no food or drinks allowed in the lab at *any time*. This includes bottled water. All food or drink must be left outside the lab.
- Any broken glass should be disposed of in the *"Broken Glass Container."*
- Clean your work area with soapy water and wipe it with paper. Wash your hands.

## III. EQUIPMENT AND REAGENTS

| Equipment | | Chemicals | |
|---|---|---|---|
| 1 | Ruler, 12 inch | | Water |
| 1 | Reading card | 1 | Unknown liquid |
| | Balance | 1 | Unknown metal |

Also, you will need (from your locker) a 10 mL and 100 mL graduated cylinder and a test tube.

## IV. PROCEDURE

### PART A. MEASURING LENGTH

1. Measure the length of a test tube in your drawer in millimeters and in inches. Record in Table 2-2.
2. Convert the measured millimeters to centimeters and to inches.
3. Check if the conversion to inches gives you the same number as the initial measurement of inches.

### PART B. MEASURING THE MASS OF AN OBJECT

1. Select 4 items to measure on the laboratory balance; these can be coins, keys, or equipment from your lab drawer. Record the identity and mass of each object in Table 2-3.

### PART C. DETERMINING THE DENSITY OF WATER

1. Weigh a clean **dry** 10 mL graduated cylinder and record the mass ($m_0$) in Table 2-4 to the nearest 0.01 g.
2. Remove the cylinder from the balance and fill the cylinder with water to between the 9 and 10 mL marks.

3. Read the volume of water to the nearest 0.01 mL. Your instructor will discuss the proper way to read the graduated cylinder as illustrated in the figure below. Also how to use the reading card to obtain the right volumes.

4. Record the initial volume ($V_0$) in Table 2-4.

5. Weigh the cylinder plus the water and record the mass ($m_1$) in the same table.

   a. Calculate the mass of the water ($m_2$) by subtracting the mass of the empty cylinder ($m_0$) from the mass of the filled cylinder ($m_1$).

   b. Calculate the density of water by dividing the mass of the water by its volume. Record the density in Table 2-4.

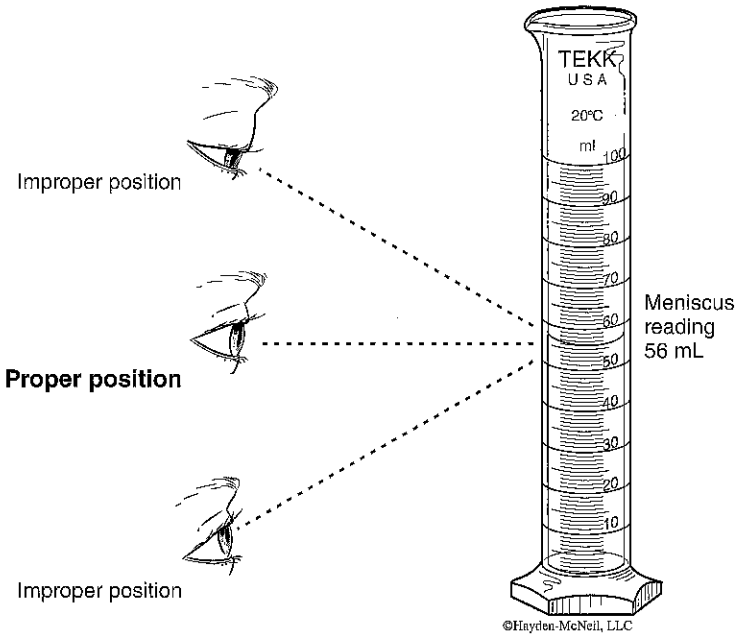



**Figure 2-2.** Reading a graduated cylinder. Always read the bottom of the meniscus and look at it at eye level!

## PART D. DETERMINING THE DENSITY OF A METALLIC ELEMENT BY DISPLACEMENT

1. Obtain a sample of unknown metal from your instructor. Record the number of your unknown.

2. Add approximately 50 mL of water to a clean, dry 100 mL graduated cylinder. Record the initial volume ($V_0$) in Table 2-5 to the nearest 0.1 mL.

3. Weigh the graduated cylinder with the water to the nearest 0.01 g and record the mass ($m_0$) in the table.

4. Record the mass of the unknown metal (make sure it is completely dry) to the nearest 0.01 g in Table 2-6.

5. Carefully place the unknown dry metal into the graduated cylinder. Avoid splashing water on the sides of the cylinder by holding the cylinder at an angle and sliding the metal down the side of the cylinder and into the water.
6. Record the new volume ($V_1$) of the water and metal in the table.
7. Measure the mass ($m_1$) of the cylinder, water, and metal and record this in the table.
8. Determine the density of the object by using the values from Table 2-1, predict the identity of your metal sample.

## PART E. DETERMINING THE IDENTITY OF A METALLIC ELEMENT BY MEASUREMENT

1. Using the SAME unknown metal object measure the radius (half of the diameter) and length in centimeters (cm) if the object is a cylinder, if it is cuboid, measure the length, width, and height.
2. Calculate the volume of the object:
   - For cylinder: $V = \pi r^2 l$

     $\pi = 3.14$

     $r$ = radius

     $l$ = length
   - For cuboid: $V = lwh$

     $l$ = length

     $w$ = width

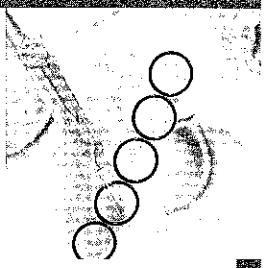
     $h$ = height
3. Calculate the density. How close is your number to the calculation using displacement?

**Table 2-1.** Densities of Some Common Metals

| Element | Density g/cm$^3$ |
|---|---|
| Aluminum | 2.710 |
| Calcium | 1.540 |
| Copper | 8.960 |
| Germanium | 5.350 |
| Iron | 7.874 |
| Lead | 11.340 |
| Magnesium | 1.740 |
| Nickel | 8.910 |
| Silicon | 2.350 |
| Tin | 5.750 |
| Tungsten | 19.350 |
| Zinc | 7.133 |

## PART F. DETERMINING THE DENSITY OF AN UNKNOWN LIQUID

1. Using the same procedure as in Part C, determine the density of the unknown liquid provided by your TA. Remember to rinse the graduated cylinder with 1–2 mL of your unknown to remove all the water.
2. Show your measurements and calculations in Table 2-7.
3. You should only use 5–10 mL of liquid from the unknown bottle, so proceed carefully.



Name: Date:

TA's Name: Section Number:

# V. RESULTS AND CALCULATIONS

## PART A. MEASURING LENGTH

**Table 2-2.**

| | | | | | |
|---|---|---|---|---|---|
| Measured | | mm | | | |
| Convert to | | cm | | | |
| Convert to | | in | Compare to the measured | | in |

Show work here:

2.54 cm = 1.00 in

## PART B. MEASURING THE MASS OF AN OBJECT

**Table 2-3.**

| Object | Mass | Units |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

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## PART C. DETERMINING THE DENSITY OF WATER

**Table 2-4.**

| | | | |
|---|---|---|---|
| Mass of graduated cylinder | ($m_0$) | | g |
| Mass of cylinder and water | ($m_1$) | | g |
| Mass of water | ($m_1$) | | g |
| Volume of water | ($V_0$) | | mL |
| Density of water | | | g/mL |

Show calculations:

## PART D. DETERMINING DENSITY BY DISPLACEMENT OF AN UNKNOWN METAL

Unknown # _____

**Table 2-5.** Mass and volume data and calculations

| | | | |
|---|---|---|---|
| Volume of water | ($V_0$) | | mL |
| Mass of cylinder and water | ($m_0$) | | g |
| Volume of water and metal | ($V_1$) | | mL |
| Mass of cylinder, water, and metal | ($m_1$) | | g |
| Volume | ($V_1$–$V_0$) | | mL |
| Mass in grams | ($m_1$–$m_0$) | | g |
| Density of object | | | g/mL |
| Identity of metal | | | |

Show calculations:

## PART E. DETERMINING DENSITY OF A METAL UNKNOWN BY CALCULATION

**Table 2-6.**

| | | |
|---|---|---|
| Mass of object | | g |
| Length | | cm |
| Width | | cm |
| Height | | cm |
| Diameter | | cm |
| Radius | | cm |
| Volume of object | | mL |
| Density of object | | g/mL |

Show calculations:

$1\ cm^3 = 1\ mL$

Which method do you prefer—calculation or displacement, and why?

## PART F. DETERMINING THE DENSITY OF AN UNKNOWN LIQUID

Unknown liquid # _____

**Table 2-7.**

| | | | |
|---|---|---|---|
| Mass of graduated cylinder | ($m_0$) | | g |
| Mass of cylinder and unknown | ($m_1$) | | g |
| Mass of unknown | ($m_2$) | | g |
| Volume of unknown | ($V_1$) | | mL |
| Density of the unknown liquid | | | g/mL |

Show calculations:

## VI. QUESTIONS

1. Read the graduated cylinder and record the volume to the correct number of possible significant digits.


_____ mL

2. In Part D you measured the density of an unknown metal in order to identify it. Using your measured density and the actual density from Table 2-1, calculate your percent error. Percent error is calculated by taking the difference between the experimental value and the theoretical value and dividing by the theoretical value as shown below. Percent error is expressed as an absolute value.

$$\%\text{Error} = \frac{\text{Theoretical value} - \text{Experimental value}}{\text{Theoretical value}} \times 100$$

3. A friend of yours went panning for gold last weekend and found a nugget that appears to be gold. With your new skills, you set out to determine if it is really gold. Your tests show the nugget has a mass of 7.6 g and a volume of 0.84 mL. The density of gold is 19.32 g/mL, what will you tell your friend?

4. You are asked to measure the volume of an irregularly shaped piece of candy that is soluble in water. What will you do?

5. What is the volume of a tank that can hold 754 kg of methanol whose density is 0.788 g/mL?

6. The density of phenol is 1.07 g/mL. If you had 5.368 L of phenol, what is the mass in micrograms (μg)?

7. The density of paper is 1.20 g/cm$^3$. What is the mass of the paper in a notebook that is 76 mm thick, 215.9 mm wide, and 279.4 mm long?