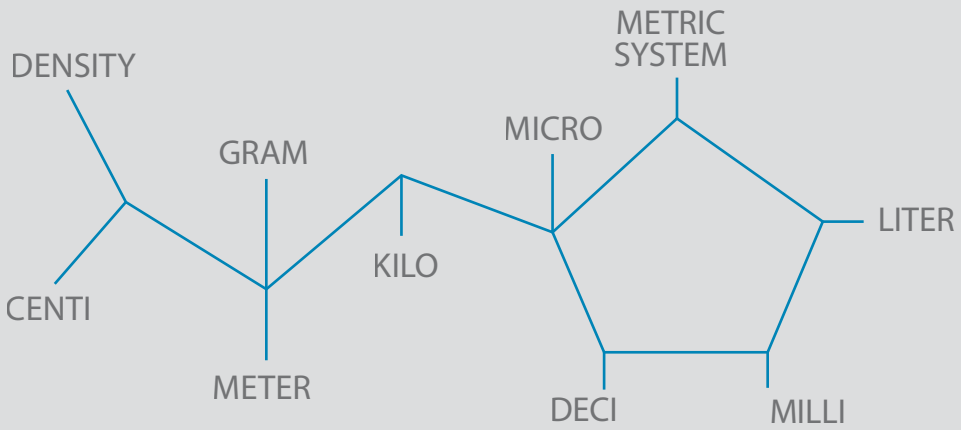
CHAPTER 2

METRIC MEASUREMENTS IN CHEMISTRY

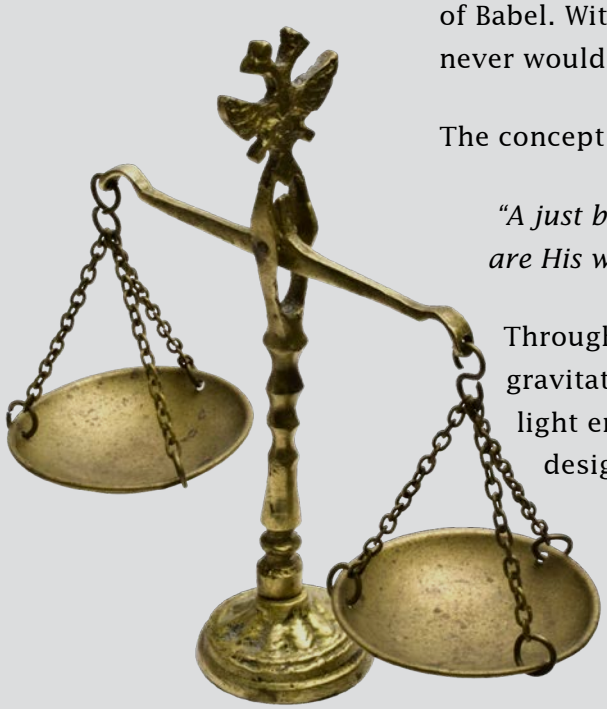
OBJECTIVES AND VOCABULARY

At the conclusion of this lesson the student should have an understanding (as evidenced by successfully completing the quiz at the end of this lesson) of:

1. Common units used in the metric system
2. Units of density and how density is used to explain flotation patterns
3. Application of the prefixes milli-, centi-, deci- and kilo- in the metric system.



Measurements are very important in all of the sciences and everyday life. If you take a medication, it has to be very carefully measured out. That has not always been the case. Can you imagine some of the results of that? The use of measurements probably go back to Adam. They definitely had to be used in building the Tower of Babel. Without accurate means of measuring and planning, the tower never would have stood.



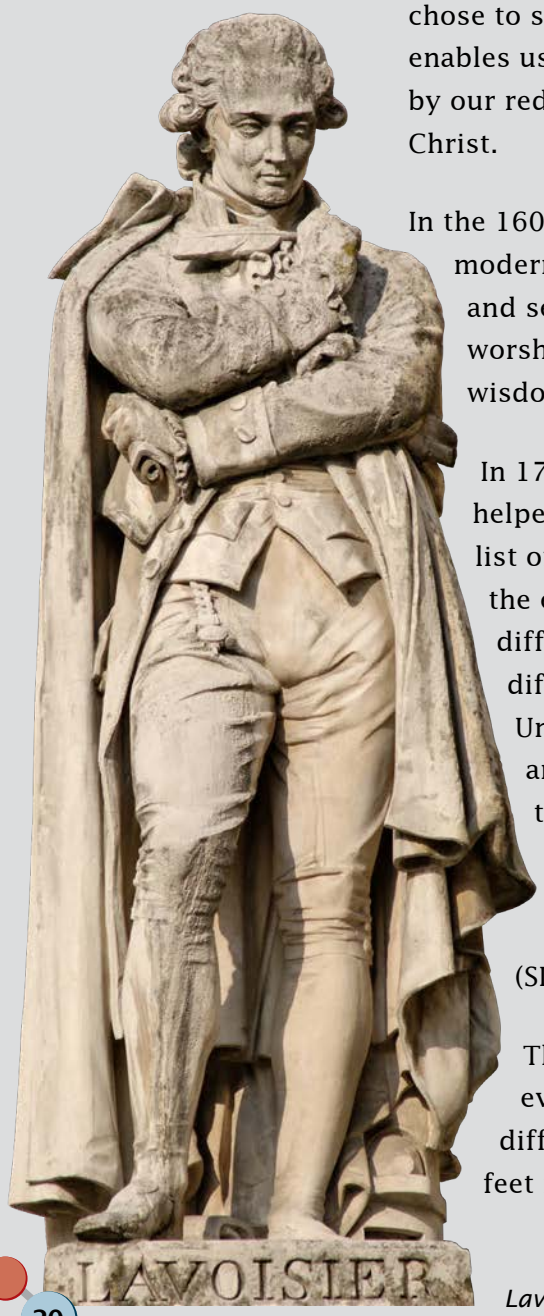
The concept of accurate measurements came from the mind of God.

> *"A just balance and scales are the Lord's; all the weights in the bag are His work." (Proverbs 16:11)*

Throughout the universe, numbers are important, such as the gravitational forces holding galaxies together and the wavelengths of light emitted from the distant edges of the universe. God's wisdom designed the forces and elements at the beginning of creation.

"I, wisdom, dwell with prudence, and I find knowledge and discretion. The Lord possessed me at the beginning of His work, the first of His acts of old. Ages ago I was set up, at the first, before the beginning of the earth… when He made firm the skies above, when He established the fountains of the deep, then I was beside Him, like a master workman, and I was daily His delight, rejoicing before Him always, rejoicing in His inhabited world and delighting in the children of men." (Proverbs 8: 12, 22, 23, 28, 30, 31)

The universe functions like well-designed clock work. All of the forces in the universe are balanced mathematically to keep every galaxy, star, planet, moon, and molecule in perfect positions in relation to each other to give us a beautiful place to live. These forces are seen as well in the diverse elements making up the universe, our world and bodies. God chose to share this wisdom with us who are created in His image. He enables us to see the wisdom of His handiwork when our eyes are opened by our redemption from the blinding effects of sin through faith in Jesus Christ.



Lavoisier by Jacques-Léonard Maillet, ca. 1853.

In the 1600s most of the early scientists that laid the foundations of modern science were born-again Christians. When you can stand back and see the patterns of the nature of the elements, you cannot help worshipping the Creator who spoke it all into being showing us the wisdom of His mind.

In 1791, Antoine Lavoisier (called the Father of Modern Chemistry) helped develop the metric system. He also developed an extensive list of elements and made major contributions to the naming of the elements and compounds. Prior to this different countries had different measuring systems. For example, different countries had different lengths for measuring a foot. This was very confusing. Unfortunately, Lavoisier was a member of the French aristocracy and involved in designing the system of taxation right before the French Revolution. He was one of the first ones to go to the guillotine.

The metric system is called the Systeme International d' Unites (SI system) or International System of Units.

The **metric system** is used in scientific measurements because everything comes in units of tens. In the English system there are different numbers of units used such as 12 inches in a foot and 3 feet in a yard.

The standard unit for length in the metric system is the **meter** (about 39 inches), the standard unit of volume is the **liter** (about 1.06 quarts), and the standard unit of mass is the **gram**.

The universe functions like well-designed clockwork.

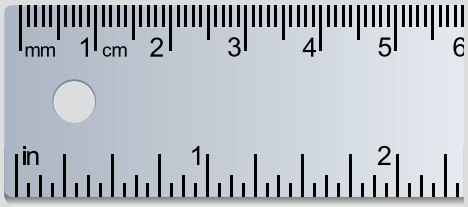
The size of a unit of measurement is known by its prefix. **Deci**- means 1/10 (one tenth). **Centi**- means 1/100 (one hundredth). **Milli**- means 1/1,000 (one thousandth). **Micro**- means 1/1,000,000 (one millionth) and **Kilo**- means 1,000 (one thousand).

Prefix	Numerical Meaning
micro (µ)	0.000001
milli (m)	0.001
centi (c)	0.01
deci (d)	0.1
	1
deca (D)	10
hecto (H)	100
kilo (k)	1,000

A decimeter (dm) is .1 m (m stands for meter and dm stands for decimeter). A centimeter (cm) is .01 m and a millimeter (mm) is .001 m. A kilometer (Km) is 1,000 m.

A deciliter (dl) is .1 L (L and l stand for liter). A centiliter (cl) is .01 l and a milliliter (ml) is .001 l. Kiloliters are not usually used in chemistry. A thousand liters is a lot.

A decigram (dg) is .1 g (g stands for gram). A centigram (cg) is .01 g. A milligram (mg) is .001g and a kilogram (Kg) is 1,000 g.

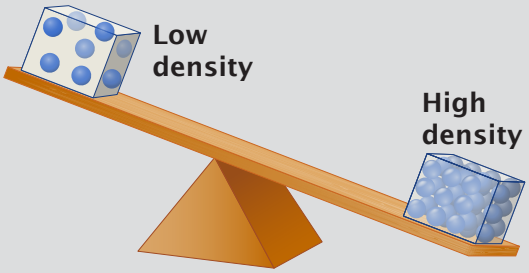


meter (m)
length

liter (l)
volume

gram (g)
mass

In the metric system, the standard unit of measurement for weight (force of gravity) is the Newton — named after Isaac Newton who expressed the Laws of Motion. In chemistry, when you weigh something on a balance the units used are usually milligrams. But milligrams are not weight. The balance is actually measuring the weight but the scale of the balance is adjusted to give mass (milligrams). Milligrams are used in chemistry because of the small quantities of materials used.



Comparing the mass of equal volumes demonstrates the density of the two objects.

The **density** of an object is measured as mass divided by volume, which is g/ml (the number of grams making up each milliliter). In chemistry the units of grams and milliliters are more often used because small quantities are used. A ml of iron is much heavier than a ml of Jell-O® because the density of iron is much greater than that of Jell-O®. Ice floats in liquid water because the density of ice is less than that of liquid water. This is also why a several-hundred-ton aircraft carrier floats in water. Most of the volume of the aircraft carrier is air, which is much lighter than water. The total weight of the aircraft carrier is less than the same volume of water so the aircraft carrier floats. When the king of Sweden had a war ship (*Vasa*) built, he insisted that they put more bronze cannons on the ship. When they launched the ship for the first time, it sank just outside of the harbor in 1628. It was later salvaged in 1961 and placed in the Vasa Museum in Stockholm, Sweden, in 1988.

REACTIONS IN ACTION

Do the following exercise to test your understanding of density. Liquid A has a density of 1.05 g/ml; liquid B has a density of 1.10 g/ml; liquid C has a density of 0.97 g/ml; and liquid D has a density of 1.00 g/ml. When all 4 liquids are poured together into a tall glass, they do not mix; instead they settle out forming 4 layers.

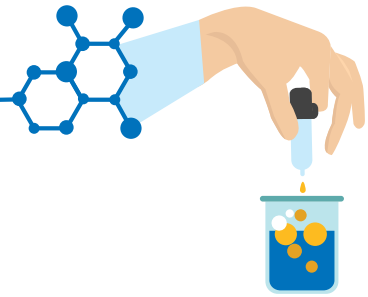
Liquid A	1.05 g/ml
Liquid B	1.10 g/ml
Liquid C	0.97 g/ml
Liquid D	1.00 g/ml

Which liquid will be on the bottom? Which one will be second, floating on the bottom layer? Which liquid will be third up from the bottom and which one will be on top?

Form a hypothesis (a principle or explanation that you make from your observations) explaining how you came up with your answer. Afterwards, and not before, compare your answer to the one below.

Answer: the bottom layer is B because it has the greatest density (1.10 g/ml). On top of B is liquid A (1.05 g/ml). On top of A is liquid D (1.00 g/ml) and liquid C is the top layer with the lowest density (0.97 g/ml). How did you do?

LABORATORY 2



THE METRIC SYSTEM

REQUIRED MATERIALS

- Square or rectangular object
- Ruler with measurements in inches
- Graduated cylinder (10 ml)
- Weighing boat
- Scale

INTRODUCTION

The metric system was developed on the basis of the number 10. The following prefixes are commonly used:

- *milli* meaning 1 thousandth
- *centi* meaning 1 hundredth
- *deci* meaning 1 tenth
- *kilo* meaning 1 thousand

The meter is the metric system's unit of length. It is equivalent to about 39 inches in the English system. By the list above: a decimeter is a _____ of a meter, a centimeter is a _____ of a meter and a millimeter is a _____ of a meter. A kilometer is _____ meters.

See the chart below for the units for length, volume, mass, and force in both the metric and English systems.

Quantity	Metric Unit	English Unit
length	meter	foot (12 inches)
volume	liter	gallon
mass	gram	slug (32.174 lb)
force (weight)	newton	pound

PURPOSE

This exercise is designed to familiarize you with the use of metric units. The sciences exclusively use metric standards of measurement.

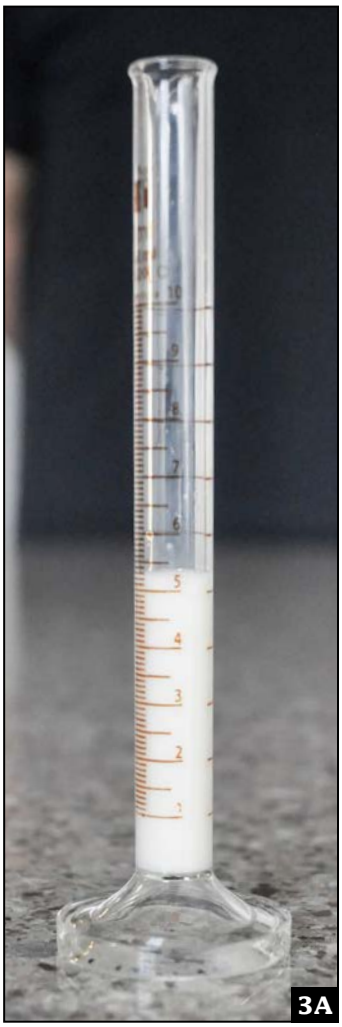
PROCEDURE

You will find the following English–metric conversions helpful for this exercise.

English		Metric
1 inch	=	2.54 cm (centimeters)
1 gallon	=	3.8 liters
1 mile	=	1.61 km (kilometers)
1 pint	=	0.473 liter

1. Solve the following:
   A. If a gas station charges $1.25 for a liter of gasoline, how much is it for a gallon of gasoline?
   B. If you travel 10 miles, how many kilometers have you traveled?
   C. If you have 3 pints of fruit juice, how many liters do you have?
2. Find a square or rectangular object.
   A. Measure its length, width, and height in inches.
   B. What is its volume in cubic inches? (length x height x depth)
   C. Convert each of the measurements into cm.
   D. What is the volume of the object in cubic centimeters (cc)?
   E. A cubic centimeter is exactly the same as a milliliter (ml). What is the object's volume in milliliters and liters?

3. Mass / Density Measurements


3A

A. Measure out 5 ml of a liquid other than water with a 10 ml graduated cylinder. Line up the middle, not the edge, of the surface of the liquid (the meniscus) with the markings on the graduated cylinder.

B. Place a weighing boat on a scale and find its mass in grams.

C. Add the 5 ml of liquid to the weighing boat and find the mass of the 5 ml of liquid including the mass of the weighing boat.

D. Calculate the mass of the liquid by subtracting the mass of the weighing boat from the combined mass.

E. Divide the mass of the liquid in g by the volume in ml. This gives you the density of the liquid in units of g/ml.

3B

3C

LAB INSIGHTS

In chemistry, volumes of liquids are typically measured with graduated cylinders, burets, pipets, and volumetric flasks.

The graduated cylinders measure volumes as small as ml (milliliter); pipets can measure volumes as small as 0.1 ml; and a volumetric flask can only measure a set volume — such as 100 ml.

Left to right: graduated cylinders, pipet, and volumetric flask, and buret (not to scale).

SIGNIFICANT FIGURES

The level of measurement made with a tool in chemistry determines the level of accuracy (how close you are to the true value) of any calculations using the measurement. For example, if three people each measure the volume of the same liquid and get 50. ml, 49. ml, and 50. ml, you cannot express the average as 49.7 ml because the graduated cylinders cannot measure a tenth of a ml. If your measurements were made with pipets instead (which can measure a tenth of a ml), the answer 49.7 ml would be fine because the measurements in a pipet would be expressed as 50.0, 49.0, and 50.0. In the answer 49.7 ml, when based off the 50., 49., and 50. numbers, the numbers 49. would be called the significant figures.

If you used a scale that measures down to a tenth of a gram and you got the measurements of 30.2 g, 30.0 g, 31.0 g, and 30.9 g for the same sample, the average would be 30.525 g., but the scale can only measure down to the level of a tenth of a gram, so the answer needs to be rounded off to 30.5. The trailing 25 is uncertain and the significant figures are 30.5.

Suppose you measured the following volumes of HCl (hydrochloric acid) that reacted with another substance: 20.5 ml, 25.4 ml, 22.7 ml, and 24.2 ml. The average of these results is 23.2 ml. This number is fine because the last number is a tenth of a ml and that is the limit of the measurement of the buret.