Measurements

When you measure something, you must write the number with appropriate unit. Unit is a standard quantity used to specify the measurement. Without the proper unit, the number you write is meaningless. Say for example, you measured the length of an object and wrote the number 2.54 without the unit. Since it has no unit, this number is meaningless or means so many different things; it may mean that it may be a length or a mass or a pressure or a volume, etc.

The study of any science to a greater extent depends on the measurement. As you will see in the laboratory, you will do lots of measurements. Hence, it is essential that any number you write down must always be associated with its proper unit. And also, the unit clearly tells you what kind of a measurement the number represents. If you record the measurement like 8.25 cm, it means that it is a length of some object because cm is the unit of length.

Therefore, you need to understand various units in usage. There are only seven basic standard units in science (SI base units) and the rest of the units are derived from the basic units.

SI Units

The system of units used by the scientists throughout the world is based on the metric system (decimal system , represented as powers of 10) is known as **International System of Units** or simply **SI units** (actually SI is the abbreviation for French **S**ystem **I**nternational d'Unites). The following table lists the seven base units along with their names and symbols in order of their importance in general chemistry.

Quantity	**Name**	**Symbol**
Length	Meter	m
Mass	Kilogram	kg
Amount of substance	Mole	mol
Temperature	Kelvin	K
Time	Second	s
Electric Current	Ampere	A
Luminous intensity	Candela	cd

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Scientific notations allow us to express very large and very small numbers in a compact way. However, the prefixes used with SI units are still compact notations to indicate such numbers. Like metric units, SI units are modified by a series of prefixes shown in the following table.

SI Prefixes

Prefix	**Symbol**	**Meaning**	**Example**
Exa	E	1,000,000,000,000,000,000 = 1×10^{18}	2.5 Em = 2.5 exameter = 2.5×10^{18} m
Peta	P	1,000,000,000,000,000 = 1×10^{15}	7.5 Pm = 7.5 petameter= 7.5×10^{15} m
Tera	T	1,000,000,000,000 = 1×10^{12}	5.6 Tm = 5.6 terameter = 5.6×10^{12} m
Giga	G	1,000,000,000 = 1×10^{9}	8.2 GW = 8,2 gigawatts = 8.2×10^{9} W
Mega	M	1,000,000 = 1×10^{6}	2 M$ = 2 megadollars = 2×10^{6} $
Kilo	k	1,000 = 1×10^{3}	3.5 kg = 3.5 kilograms = 3.5×10^{3} g
Deci	d	1/10 = 0.1 = 1×10^{-1}	1.5 dm = 1.5 decimeter = 1.5×10^{-1}m
Centi	c	1/100 = 0.01 = 1×10^{-2}	5.1 cm = 5.1 centimeters = 5.1×10^{-2} m
Milli	m	1/1,000 = 0.001 = 1×10^{-3}	4.5 mg = 4.5 miligrams = 4.5×10^{-3} g
Micro	µ (mu)	1/1,000,000 = 1×10^{-6}	9.5 µg = 9.5 micrograms = 9.5×10^{-6} g
Nano	n	1/1,000,000,000 = 1×10^{-9}	6.5 ng = 6.5 nanograms = 6.5×10^{-9}g
Pico	p	1/1,000,000,000,000 = 1×10^{-12}	4.4 pm = 4.4 picometers = 4.4×10^{-12} m
Femto	f	1/1,000,000,000,000,000 =1×10^{-15}	2.8 fg = 2.8 femtogramas = 2.8×10^{-15} g
Atto	a	1/1,000,000,000,000,000,000 = 1×10^{-18}	9.9 ag = 9.9 attograms = 9.9×10^{-18} g

- Note that the symbols are the first letter of the name except in micro that has the Greek symbol µ (pronounced as mu) to eliminate the confusion with milli.

- The symbols are in capital letters for prefixes greater than kilo and in lower cases for prefixes less than or equal to kilo.

- Remember, the prefixes are substituted for power of 10 part only:

$$225 \text{ mg} = 225 \times 10^{-3} \text{ g}$$

As you can see the use of SI prefixes greatly condenses the space for writing the number and besides, it is very compact.

We often make few measurements in the laboratory, namely, **we measure the length of an object, weigh an object, and measure the volume of a particular liquid or solution. In addition, we also take the temperature**. Let us discuss some of the convenient units for these measurements.

Length

The base SI unit of length is meter. But, two other convenient and smaller units are centimeter (one hundredth of a meter) and millimeter (one thousandth of a meter):

$1 \text{ m} = 100 \text{ cm} = 1 \times 10^{2} \text{ cm}$ or $1 \text{ cm} = 1 \times 10^{-2} \text{ m}$

$1 \text{ m} = 1000 \text{ mm} = 1 \times 10^3 \text{ mm}$ or $1 \text{ mm} = 1 \times 10^{-3} \text{ m}$

Therefore, 1 cm = 10 mm

Click on

Hands on Practice on Length Conversion

Mass and Weight

Mass is the amount of matter in an object whereas the **weight** is a measure of the gravitational pull (gravitational force) on the object. Every planet has force of gravity and it is uniform throughout the planet. But different planets have different gravitational forces. That means the same person (constant amount of matter) weighs differently on different planets due to different gravitational pulls. You have watched astronauts on the television jumping and hopping on the moon without any difficult because their weight is much lighter than the weight on earth due to different gravitational fields.

[Gravity on earth = 9.80665 m / s^2 and on moon = 1.63444 m / s^2. The moon's gravity is just $1/6^{th}$ of earth's gravity. For example, if your weight is 140 lb on earth, your weight will be 23.2 lb on moon, which just $1/6^{th}$ of your earth's weight.

If you are interested you can calculate your weight on the moon by going to the following link http://www.moonconnection.com/moon_gravity.phtml**]**

As long as we are confined to the same gravitational field, say for example earth, the terms " mass" and "weight" are often interchangeable because the same amount of matter weighs the same throughout the planet. If we say, this object weighs 120 lb is the same thing as saying its mass is 120 lb.

The base unit of mass is kilogram (kg), which is a larger unit that may not be convenient in chemistry. The most convenient units are gram and milligram:

$1 \text{ kg} = 1000 \text{ g} = 1 \times 10^3 \text{ g}$ or $1 \text{ g} = 1 \times 10^{-3} \text{ kg}$

$1 \text{ g} = 1000 \text{ mg} = 1 \times 10^3 \text{ mg}$ or $1 \text{ mg} = 1 \times 10^{-3} \text{ g}$

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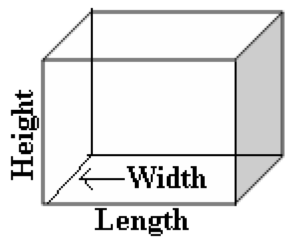
Hands on Practice on Mass Conversion

Volume

Volume is a three-dimensional quantity that is expressed as

Volume = Length x Width x Height



The base unit of length is meter, the volume is then meter cubed (m^3). Thus the unit of volume is derived unit. However, in chemistry much smaller units are used like liter [cubic decimeter (dm^3)] and milliliter [cubic centimeter (cm^3)]:

$1\ dm^3 = (1 \times 10^{-1}\ m)^3 = 1 \times 10^{-3}\ m^3 = 1$ liter = 1 L

$1\ cm^3 = (1 \times 10^{-2}\ m)^3 = 1 \times 10^{-6}\ m^3 = 1$ milliliter = 1 ml

Therefore,

$1\ L = 1000\ ml = 1000\ cm^3$ or $1\ ml = 1/1000\ L = 1 \times 10^{-3}\ L$

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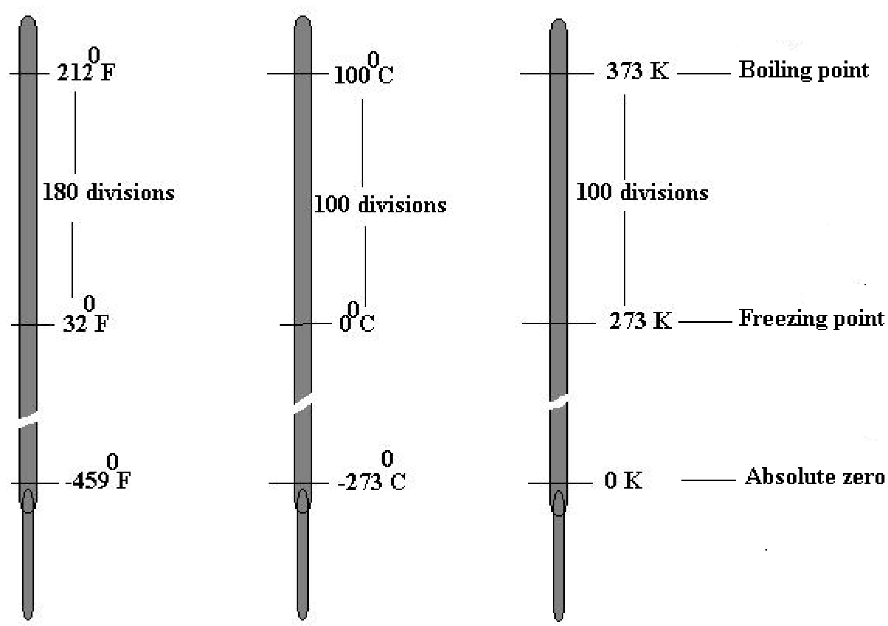
Hands on Practice on Volume Conversion

Temperature

In a simple term, the temperature is a measure of intensity of heat. There are three temperature scales in which temperature is measured. Their units are ^{0}F (degrees Fahrenheit), ^{0}C (degrees Celsius), and K (Kelvin). These are respectively invented by Fahrenheit, Celsius, and Kelvin, and hence the names. In science, the Celsius and Kelvin scales are in usage but not the Fahrenheit scale. The latter scale is commonly used in the United States outside the science. All the countries in the world, except United States, have adopted the Celsius scale for inside as well as outside the science to create uniformity and to facilitate the easy communications between them. Now the United States is in the midst of transition from Fahrenheit to Celsius scale and in a few years, the Fahrenheit scale will disappear.

All three scales mentioned above are based on the same reference material, water, as it is the most common liquid on this planet. Water (to that matter any liquid) has two extreme points, boiling point and freezing point. The scales differ in how they label these points. The boiling point of pure water is labeled as 212^0 F in Fahrenheit scale, 100 ^{0}C in Celsius scale, and 373 K in Kelvin scale. The freezing point of pure water is labeled as 32^0 F in Fahrenheit scale, 0^0 C Celsius, and 273 K in Kelvin scale. Fahrenheit scale is divided into 180 (= 212 – 32) equal divisions and one division is called 1^0 F. Likewise, the Celsius scale is divided into 100 (= 100 - 0) equal divisions and one division is called 1^0 C. Similarly, Kelvin scale is divided into 100(= 327 – 273) equal divisions and one division is called 1 K (note that degree, ^{0} , is not used for Kelvin). The comparison of these scales is shown below:

Comparison of Temperature scales



The Kevin scale offers and advantage over other two scales. First of all, Kelvin scale is much wider range (373) compared to Fahrenheit scale (180) or Celsius scale (100). If the temperature goes below freezing point, the Fahrenheit and Celsius scales produce negative numbers that are not always easy to work with. However, Kelvin scale still maintains the positive numbers that much nicer to work with. The zero temperature in Kelvin is known as **absolute zero,** which has great significance in science. The crystal for example, diamond, is not so perfect (contrary to common belief) at room temperature because the atoms in the crystal vibrate around their equilibrium position due to existing energy at room temperature. Scientists think that the crystal becomes a perfect crystal at this temperature due to the fact all vibrations cease to exists as there is no energy of any kind at this temperature.

We can convert one scale into another scale using the following relations:

- Celsius to Kelvin: $K = {}^0C + 273$
- Celsius to Fahrenheit: ${}^0F = ({}^0C \times 1.8) + 32$
- Fahrenheit to Celsius : ${}^0C = ({}^0F - 32)/1.8$

Among these conversions, the far easiest one is the conversion from Celsius to Kelvin; simply you need to add 273 to Celsius. The Celsius to Fahrenheit and vice versa is based on the ratio of ${}^0F / {}^0C$ = 180 divisions / 100 divisions = 9/5 = 1.8. The number 32 is added to take care of the difference in freezing points of Celsius and Fahrenheit.

Example

The body temperature is 98.6 ^{0}F. Convert this temperature to Celsius and Kelvin.

Answer

The following equation is used to convert ^{0}F to ^{0}C.

$${}^0C = ({}^0F - 32)/1.8 = (98.6 - 32)/1.8 = 37.0\ {}^0C$$

The get the Kelvin temperature, add 273 to the Celsius temperature:

$$K = {}^0C + 273 = 37 + 273 = 310\ K$$

Example

The freezing point of ethylene glycol, an organic liquid compound used in car radiators, is -11.5 ^{0}C. What is this temperature in ^{0}F and K?

The conversion is carried out by solving

$${}^0F = ({}^0C \times 1.8) + 32 = (-11.5 \times 1.8) + 32 = 11.3\ {}^0F$$

$K = {}^{0}C + 273 = -11.5 + 273 = 261.5$ K

Example

Convert -40^{0}F to ^{0}C and K.

$^{0}C = ({}^{0}F - 32)/1.8 = (-40 - 32)/1.8 = -40^{0}$ C

$K = {}^{0}C + 273 = -40 + 273 = 233$ K

This calculation illustrates that both Celsius and Fahrenheit temperatures become equal to one another at -40^{0}.

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Hands on Practice on Temperature Conversion

Density

Density is the ratio of mass of an object and its volume. Mathematically, written as,

$$density = \frac{mass}{volume} \qquad or \qquad d = \frac{m}{v}$$

The mass is usually expressed in grams and volume in ml or cm^3. Therefore, the unit of density is either g/ml or g/cm^3.

Density is an intensive property that does not depend upon the amount matter. The density is a simply physical property and yet it yields lots information about substnace. For example, how the atoms or molecules are bonded to one another and what kind of force (stronger or weaker) exist.

Another important aspect of the density equation is that it converts mass into volume or volume into mass through the following equations:

mass = density x volume

volume = mass / density

You will be using this equation throughout the semester to convert mass into volume and volume into mass. So, remember this equation!

Densities of Some Substances

Substance	**Density (g /cm^3)**	**Substance**	**Density (g/cm^3)**
Air	0.001	Titanium	4.51
Ethanol	0.79	Iron	7.86
Ice	0.917 (at 0^0C)	Copper	8.96
Water	1.0 (at 4^0 C)	Lead	11.4
Sugar(Sucrose)	1.58	Mercury	13.55
Table salt	2.16	Gold	19.3
Glass	2.6	Platinum	21.4
Aluminum	2.70	Osmium	22.6

Example

An object weighs 4.56 g and has the volume of 1.50 cm^3. What is the density of an object?

$$d = \frac{m}{v} = \frac{4.56g}{1.50cm^3} = 3.04g/cm^3$$

Example

A piece of gold with density of 19.3 g /cm^3 has the mass of 250 g. What is the volume of this gold?

$$v = \frac{m}{d} = \frac{250g}{19.3g/cm^3} = 12.95cm^3$$

Example

A glass of water has the volume of 450 ml. What is the mass of the water?

$$m = v \, x \, d = 450ml \, x 1.0g / ml = 450g$$

Things to remember: Since the density of water is close to 1.0, the mass of the water is the same as the volume. The only difference is the unit; you have g instead of ml.

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Hands on Practice to Calculate Density, Mass, and Volume

Specific Gravity

Specific gravity is a relative density derived from the density, and is defined as *the ratio of the density of a substance to that of a standard substance.* The standard substance is taken as water that has the density of 1 g/cm^3 at 4^{0}C. Therefore,

Specific gravity = density of a substance (g/cm^3) / density of water (g/cm^3)

= density of a substance (g/cm^3)/ 1 g/cm^3

The unit g/cm^3 in the numerator get cancels with that in the denominator. Hence, the specific gravity has no unit. Also, the density of water is 1 g/cm^3, and hence the specific gravity is the same as the density without any unit:

Specific gravity = density of a substance

The term gravity is misleading; it is nothing to do the gravity of the planet.

Example

The density of gold is 19.3 g/cm^3. What is the specific gravity of the gold?

Answer

Specific gravity = 19.3 g/cm^3 = 1 g/cm^3 = 19.3

Example

What is the density of silver if the specific gravity of silver is 10.46?

Answer

Density of silver = specific gravity of silver x density of water
= 10.46 x 1 g/cm^3 = 10.46 g/cm^3