

## Chemistry 120

### Supplemental Material on Units and Unit Conversion

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## Système International d'Unités

- Science's Standard Units based on Metric System
- Has Seven Base Units which are taken Directly from Invariable, Measurable Natural Quantities
  - Only exception is the base unit for mass
- All Other Units in SI Units are written in Terms of the Base Units

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## SI Units

- The Base Units are
  - Temperature: kelvin (K)
  - Mass: kilogram (kg)
  - Length: meter (m)
  - Time: second (s)
  - Amount of Substance: mole (mol)
  - Electric current: ampere (A)
  - Luminous intensity: candela (cd)
- All Other Units are derived from These

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## Common Derived SI Units

- Some SI Units frequently encountered in Chemistry are
  - Area ( $m^2$ )
  - Volume ( $m^3$ , more often liter, L)
  - Temperature ( $^{\circ}C = K - 273.15$ )
  - Density ( $kg/m^3$ ,  $g/cm^3$ ,  $g/mL$ )
  - Energy (Joule,  $1 J = 1 kg \cdot m^2/s^2$ )
  - Specific heat capacity ( $J/kg \cdot K$ )
  - Frequency (Hertz,  $1 Hz = 1 s^{-1}$ )

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## Metric System Prefixes

- Prefix Denotes Multiplier of Base Unit
- Common Prefixes in Chemistry are
  - Giga- (G) =  $\times 10^9$
  - Mega- (M) =  $\times 10^6$
  - Kilo- = (k) =  $\times 10^3$
  - Centi- = (c) =  $\times 10^{-2}$
  - Milli- = (m)  $\times 10^{-3}$
  - Micro- = ( $\mu$ )  $\times 10^{-6}$
  - Nano- = (n)  $\times 10^{-9}$

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## Metric System Prefixes

- Only One Prefix is used at a Time
  - Something like mks (millikilosecond) is not allowed
- Examples
  - 1 nm (nanometer) =  $10^{-9}$  m
  - 1 MHz (megahertz) =  $10^6$  Hz
  - 1 ms (microsecond) =  $10^{-3}$  s
  - 1 kJ (kilojoule) =  $10^3$  J

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## Sources of More Information

- Textbook
  - Appendices
- Web Page (attached at end of document)  
<http://www.hlalapani.demon.co.uk/Metric/index.html>

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## Dimensional Analysis

- Need to change One Set of Units to Another
- General Form

$$\text{Number} \cdot (\cancel{\text{old unit}}) \times \left[ \frac{\text{new unit}}{\cancel{\text{old unit}}} \right] = \text{New number} \cdot (\text{new unit})$$

↙ Conversion factor

- Note the conversion factor *usually* has as many significant figures as we need

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## Unit Analysis

- Convert 30.0 ms to seconds.
  - Find conversion factor for the metric prefix
  - Place unit to be changed (ms) on left side
  - Place conversion factor to its right with the unit to be changed on bottom, and new unit on the top
  - Multiply everything on top and divide by everything on the bottom

$$30.0 \text{ ms} \left( \frac{10^{-3} \text{ s}}{1 \text{ ms}} \right) = 30.0 \times 10^{-3} \text{ s} = 3.00 \times 10^{-2} \text{ s}$$

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## Unit Analysis

- A substance has a density of 0.750 g/cm<sup>3</sup>. What volume, in mL, will 15.0 g of it occupy?
  - Although it doesn't look like it, it is a unit conversion with density as the conversion factor.
  - Also need to know that 1 cm<sup>3</sup> = 1 mL.
- Try setting It up now, before looking at the Next Page

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## Unit Analysis

- Place grams to left.
- Want to remove grams, so it must be on the bottom of the conversion factor. If we flip the density the grams will be on the bottom and cancels.
- Now we have cm<sup>3</sup>. We want mL, but there is a conversion factor between cm<sup>3</sup> and mL.

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## Unit Analysis

- Putting it all together gives:

$$15.0 \text{ g} \left( \frac{1 \text{ cm}^3}{0.750 \text{ g}} \right) \left( \frac{1 \text{ mL}}{1 \text{ cm}^3} \right) = 20.0 \text{ mL}$$

- Notice how we have "daisy chained" the conversion factors together so that the units we want to change cancel out.

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## Unit Analysis

- Percents work the Same Way
- A 200.0 g sample contains 10.0% lead. How many grams of lead are there in the sample?
  - The definition of percent are some amount per 100
  - This means that the units on the top and the bottom of the conversion factor are the same!

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## Unit Analysis

- So the units on our percentage will be grams of lead in the numerator (top) and grams of sample in denominator (bottom).
- Our complete conversion is

$$200.0 \text{ g of sample} \left( \frac{10.0 \text{ g of lead}}{100 \text{ g of sample}} \right) = 20.0 \text{ g of lead}$$

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# The Metric System (SI)

## A Concise Reference Guide

David Bartlett [Copyright](#) © 1996-2000.

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## 1. Introduction

The *Système International d'Unités* (SI), the modern form of the metric system, is the most widely used system of units and measures around the world. But despite this there is widespread misuse of the system with incorrect names and symbols used as a matter a course - even by well educated and trained people who should know better. For example how often do we see: mHz, Mhz or mhz written when referring to computer clock rates? The correct form is actually MHz. Note that the capitalisation **does** matter.

I have put this brief reference guide together to give accurate but concise information to clarify the mysteries of the SI. Hopefully this will be useful for both the layman and the expert. It is not meant to be an exhaustive guide, for this you are referred to some of the excellent official [publications](#) on the subject.

The SI comprises *units* and *SI prefixes* used to form decimal multiples or submultiples of the units. The units are classified into *Base* units, *Supplementary* units and *Derived* units. The following sections described the different elements.

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## 2. A brief History of the metric system (SI)

As early as 1584 Simon Stevinus had already proposed a decimal system of units and money in his book *De Thiende*. However, it was not until the French Revolution that the climate was conducive to creating a completely new system of units. In 1790 the French Academy of Science was commissioned by the National Assembly to design a new system of units for use throughout the world. They decided that this system should have the following attributes:

1. the system should consist of measuring units based on unvariable quantities in nature,
2. all units other than the base units should be derived from these base units,
3. multiples and submultiples of the units should be decimal.

These principles still underpin the modern metric system (SI).

France created worldwide interest with this development and it resulted in 15 countries subscribing to the Metre convention in 1875. Through this the Bureau International des Poids et Mesures (BIPM) came into being. The BIPM now functions under the guidance of the Conférence Générale des Poids et Mesures (CGPM) which has delegates from all the countries that have subscribed to the convention.

Over the years the metric system evolved, and in 1960 at the 11th CGPM the system was officially named the *Système International d'Unités*, or SI for short. The SI is the logical evolution of the metric system through the years and replaces all previous metric systems. It is a living dynamic system which is continually being improved to keep pace with developments in science and technology.

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## 3. Base and Supplementary units of the SI

The seven base units of the SI

Physical quantity	Base unit	Symbol
length	metre	m
time	second	s

mass	kilogram	kg
electric current	ampere	A
thermodynamic temperature	kelvin	K
luminous intensity	candela	cd
amount of substance	mole	mol

### The two Supplementary units of the SI

Physical quantity	Unit	Symbol
plane angle	radian	rad
solid angle	steradian	sr

## 4. The Derived units of the metric system (SI)

### Derived Units with special names

Physical quantity	Name of unit	Symbol	in base units	in derived units
frequency	hertz	Hz	$1/s$	$1/s$
force, weight	newton	N	$m \cdot kg/s^2$	$m \cdot kg/s^2$
work, energy, quantity of heat	joule	J	$m^2 \cdot kg/s^2$	$N \cdot m$
pressure, stress	pascal	Pa	$kg/(m \cdot s^2)$	$N/m^2$
power	watt	W	$m^2 \cdot kg/s^3$	$J/s$
electric charge	coulomb	C	$s \cdot A$	$A \cdot s$
electric potential difference	volt	V	$m^2 \cdot kg/(s^3 \cdot A)$	$W/A$
electric capacitance	farad	F	$s^4 \cdot A^2/(m^2 \cdot kg)$	$C/V$
electric resistance, reactance	ohm	(Omega)	$m^2 \cdot kg/(s^3 \cdot A^2)$	$V/A$

electric conductance	siemens	S	$\text{s}^3 \cdot \text{A}^2 / (\text{m}^2 \cdot \text{kg})$	A/V
magnetic flux	weber	Wb	$\text{m}^2 \cdot \text{kg} / (\text{s}^2 \cdot \text{A})$	V · s
magnetic induction	tesla	T	$\text{kg} / (\text{s}^2 \cdot \text{A})$	Wb/m <sup>2</sup>
inductance	henry	H	$\text{m}^2 \cdot \text{kg} / (\text{s}^2 \cdot \text{A}^2)$	Wb/A
luminous flux	lumen	lm	cd · sr	cd · sr
illuminance	lux	lx	cd · sr/m <sup>2</sup>	lm/m <sup>2</sup>
absorbed dose	gray	Gy	$\text{m}^2 \cdot \text{kg} / (\text{s}^2 \cdot \text{kg})$	J/kg
activity	becquerel	Bq	1/s	1/s
dose equivalent	sievert	Sv	$\text{m}^2 \cdot \text{kg} / (\text{s}^2 \cdot \text{kg})$	J/kg
Celsius temperature	degree Celsius	°C	K	K

### Some SI units with compound names

Physical quantity	Name of SI unit	Symbol
area	square metre	m <sup>2</sup>
volume	cubic metre	m <sup>3</sup>
speed, velocity	metre per second	m/s
acceleration	metre per second squared	m/s <sup>2</sup>
angular velocity	radian per second	rad/s
angular acceleration	radian per second squared	rad/s <sup>2</sup>
density	kilogram per cubic metre	kg/m <sup>3</sup>
moment of force	newton metre	N · m
electric field strength	volt per metre	V/m
permeability	henry per metre	H/m
permittivity	farad per metre	F/m
specific heat capacity	joule per kilogram kelvin	J / (kg · K)
luminance	candela per square metre	cd/m <sup>2</sup>

## 5. Prefixes in the SI

## Prefix multipliers

Prefix	Symbol	Multiplier	
yotta-	Y	1 000 000 000 000 000 000 000 000 000	$10^{+24}$
zetta-	Z	1 000 000 000 000 000 000 000 000	$10^{+21}$
exa-	E	1 000 000 000 000 000 000 000	$10^{+18}$
peta-	P	1 000 000 000 000 000 000	$10^{+15}$
tera-	T	1 000 000 000 000	$10^{+12}$
giga-	G	1 000 000 000	$10^{+9}$
mega-	M	1 000 000	$10^{+6}$
kilo-	k	1 000	$10^{+3}$
hecto-	h	100	$10^{+2}$
deca-	da	10	$10^{+1}$
deci-	d	0.1	$10^{-1}$
centi-	c	0.01	$10^{-2}$
milli-	m	0.001	$10^{-3}$
micro-	$\mu$	0.000 001	$10^{-6}$
nano-	n	0.000 000 001	$10^{-9}$
pico-	p	0.000 000 000 001	$10^{-12}$
femto-	f	0.000 000 000 000 001	$10^{-15}$
atto-	a	0.000 000 000 000 000 001	$10^{-18}$
zepto-	z	0.000 000 000 000 000 000 001	$10^{-21}$
yocto-	y	0.000 000 000 000 000 000 000 001	$10^{-24}$

## 6. Units that may be used with the SI

### Units that are used with the SI

Quantity	Name	Symbol
time	minute	min
	hour	h

	day	d
plane angle	degree	°
mass	metric tonne	t
volume	litre	l or L
energy	electron volt	eV
speed	kilometre per hour	km/h
area	hectare	ha
rotational frequency	revolution per minute	r/min

The following are some non-SI units which should **not** be used:

- calorie
- grade (angular - 400 grade per revolution)
- kilogram-force
- metric carat
- horsepower
- torr
- atmosphere
- degree fahrenheit

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## 7. Proposals for Binary prefixes

It is generally accepted that a single binary measure of information, the bit, is described symbolically by a small "b", and the byte consisting of 8 bits as capital "B". However, confusion reigns over binary multiplier prefixes.

Considerable confusion exists in the computing industry over the use of kilo meaning either 1000 or 1024 times. Similar confusion exists for Mega being 1000000, 1048576 or even 1024000 in some cases. Some members of the computing industry have proposed using capital K as the prefix for 1024 and small k for 1000. This, however, is still confusing: Frequently we see modems described as 28.8 Kbit/s - which is clearly wrong as they are 28.8 kbit/s (28.8 \* 1000). Nor does it address the problems with Mega.

The IEEE (Institution of Electrical and Electronics Engineers), IEEE Computer Society, ISO (International Standards Organisation) and IEC (International Electrotechnical Commission) have begun work jointly on defining standards and conventions for

prefixes that are multiples of 2 not 10. A current proposal is to use the prefix Ki (kibi) as the kilobinary prefix for the factor  $2^{10}$  (1024), and Mi (mebi) as the prefix for the factor  $2^{20}=(2^{10})^2$ . [NIST](#) presents a little more information about the proposals. Note that they are only **proposals** though.

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## 8. The Physical basis for some of the units

### metre

The metre is the length of the path travelled by light in a vacuum during a time interval of  $1/299\,792\,458$  of a second.

### kilogram

The kilogram is the unit of mass. It is equal to the mass of the international prototype of the kilogram preserved in a vault in Sèvres, France. Since its installation in 1889 it has only been brought out 3 times to be cleaned and weighed. Eighty copies exist, of which 6 are "official". The last time the cylinders were removed and cleaned (between 1988 and 1992) there was found to be a variation of  $23\ \mu\text{g}$ , due to microscopic surface contamination and abrasion. Now the race is on to find a suitable replacement definition based on fundamental or atomic constants.

### second

The second is the duration of  $9\,192\,631\,770$  periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.

### ampere

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed one metre apart in a vacuum, would produce between these conductors a force equal to  $200\ \text{nN}$  per metre of length.

### kelvin

The kelvin is the fraction  $1/273.16$  of the thermodynamic temperature of the triple point of water.

### mole

The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in  $0.012\ \text{kg}$  of carbon-12.

### candela

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency  $540\ \text{THz}$  and that has a radiant intensity in that direction of  $1/683$  watts per steradian.

### radian

The radian is the plane angle between two radii of a circle that cut off on the circumference an arc equal in length to the radius.

### steradian

The steradian is the solid angle that, having its vertex in the centre of a sphere, cuts off an area on the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

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## 9. Notes about and Correct usage of the SI

The following points underline some of the important aspects about using SI units and their symbols, and also mention some of the common errors that are made. The SI

differs from some of the older systems in that it has *definite* rules governing the way the units and symbols are used.

- The *name* of a unit always starts with a small letter, unless it is the first word in a sentence, in which case normal capitalisation applies. This is true even if the symbol uses a capital letter. For example **pascal** and **Pa** are correct.
- The case of the letters in a symbol is important. For example **m** and **M** mean distinctly different things. MHz is megahertz (millions of cycles per second) while mHz is millihertz (thousandths of cycles per second). Computer clocks are typically MHz. A mHz computer is a **very** slow one. :))
- The symbols are printed in upright Roman type always, and the singular and plural are the same. A space should be left between the numerical quantity and the unit symbol. For example 150 MHz.
- The unit of measure is the *metre*, not *meter*. The latter is a device used for measuring things. (Unless you live in the USA - in which case you will just have to live with the ambiguity.)
- The temperature interval of one degree Celsius equals exactly one Kelvin. Celsius temperature is related by the equation:  $t = T - T_0$ , where  $T_0 = 273.15$  K, and T is the kelvin temperature.
- Using a comma to separate groups of three digits is not recommended - a space is preferable, since many countries use the comma as the decimal point marker. Both the USA and UK use the "dot on the line" (fullstop). So the following would be correct: 1 234 555.678 990.
- The term **billion** should be avoided since in most countries outside the USA (including the UK) it means a million-million (prefix tera), whereas in the USA it means a thousand million (prefix giga). Likewise the term **trillion** means million-million-million (prefix exa) in most countries outside the USA.
- The litre (liter in the US) is one of those units which is approved by the CGPM for use with the metric system. The official unit of volume in the SI is the cubic metre. However, since this is not generally convenient for day-to-day use the CGPM has approved the use of the "other unit", the litre. The litre represents a cubic decimetre and you may use either the symbol "L" or "l" (capital OR small "ell") to represent it. They do not approve using any prefixes other than milli or micro with it. It was originally defined as the volume occupied by 1kg of water. Subsequently it was found that this was not precisely 1 cubic decimetre, so the term litre was withdrawn. Later it was re-introduced officially as 1 cubic decimetre exactly. Because of this possible confusion its use in precision scientific measurements is discouraged.

## 10. Further References

1. [Chris Keenan's](#) excellent metrication web site covering UK legislation, EC directives, Trading Standards etc.
2. ANSI/IEEE Std 268-1992. American National Standard for Metric Practice. Published by the [IEEE](#), October 28, 1992.
3. BIPM. Le système international d'unités (SI) 6e édition, textes français et anglais. Sèvres, France. Bureau international des poids et mesures.
4. The [NIST](#) Reference on Constants, Units and Uncertainty.
5. The [US Metric Association](#) also maintains a nice web site.
6. Theodore Wildi. Metric Units and Conversion Charts - A metrication Handbook for Engineers, Technologists and Scientists. IEEE Press, 1995.



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