Lecture Notes

(Measurements)

Intro:

- physics is a way of thinking based on experiments with numerical results that can be reproduced by others

- mathematics is the language of science

Measures of Science:

- a measurement is a comparison between an unknown quantity and a standard

- to be considered valid, the measuring device must be compared against a widely held standard

- the standard must be readily available, reproducible and constant over time

- the French developed our current system of measurement in 1795; it is called the metric system

- until this time, communication among scientists was difficult because the units of measurement were not standardized

- the metric system uses standards of measurement that are divisible by powers of ten

- the Systeme Internationale d'Unites (SI) keeps the standards of length, time, and mass to which instruments are calibrated

SI & The United States:

- although the US still uses the English system of measurement, Congress officially committed the country to the metric system many years ago

- in 1875 Congress signed the Treaty of the Meter which bound the US as well as sixteen other countries to the metric system

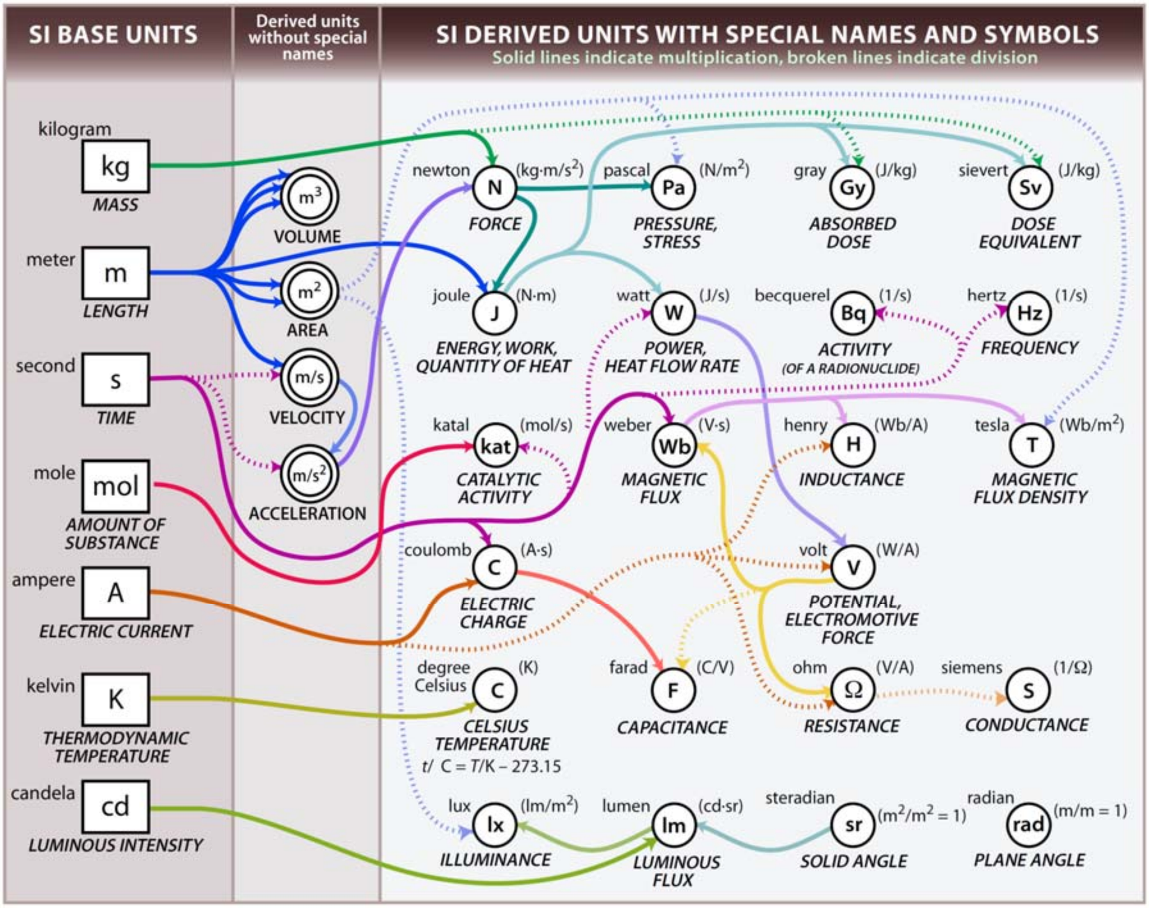
- today, the US is one of only three countries to not use the metric system (Liberia and Myanmar are the other two)

- the inherent ease of use and the economic benefits of switching to the metric system should eventually help sway the US population to move to the metric system

Units:

- there are seven base units which serve as the foundation of the SI

- there are many derived units which are combinations of the seven base units



- the seven base units are the meter (length), kilogram (mass), second (time), kelvin (temperature), mole (amt. of substance), ampere (electric current), and candela (luminous intensity)

- the base units have been measured in different ways over the years; some of those changes are listed below

A) <u>Length:</u>

- the meter was first defined as $\frac{1}{10,000,000}$ of the distance from the north pole to the equator
- the meter was then defined as the distance between two lines engraved on a platinum/iridium bar

- today, the meter is defined as the distance traveled by light in a vacuum during a time interval of $\frac{1}{299,792,458}$ s

B) <u>Time</u>:

- the second is defined today as the frequency of one type of radiation emitted by a cesium-133 atom

- a leap second is added every few years as the Earth's rotation slows

C) <u>Mass</u>:

- the standard is a small platinum/iridium metal cylinder kept at a very controlled temperature and humidity

- the last base unit measured by a physical standard; scientists are trying to find new ways to measure this base unit

Table 9 Definitions of the Base Units

BASE UNIT	HISTORIC DEFINITION Now approximate or unofficial	EXACT CURRRENT DEFINITION Simpler or more reproducible definitions are being developed for kg, K, A, mol
meter (m)	1/40 000 000 Earth's circumference	The distance light travels in vacuum in exactly 1/299 792 458 of a second.
kilogram (kg)	The mass of a liter of water	The mass of the International Prototype Kilogram (preserved in Sèvres, France).
second (s)	1/86 400 of a mean solar day in the year 1900	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.
kelvin (K)	Celsius degrees above absolute zero	The fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
ampere (A)	Coulombs per second (C/s), where $C \approx 6.24 \times 10^{18}$ *e* and *e* is the charge on an electron or proton.	That constant current which, if maintained in two straight parallel conductors of infinite length and negligible circular cross section, and placed one meter apart in vacuum, would produce between those conductors a force of 200 nN per meter of length.
mole (mol)	Grams (g) per dalton (Da) or atomic mass unit (u): mol = g/Da = g/u	As many elementary entities as there are atoms in 12 grams of carbon-12. The entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles. (Objects of unknown composition cannot be measured in moles.)
candela (cd)	The brightness of a standard candle	The luminous intensity in a given direction of a source that emits 1/683 watt per steradian of monochromatic radiation at a frequency of 540 terahertz.

<u>**Metric System Prefixes**</u>:

- prefixes are used to change SI units by powers of ten

- you need to know the prefixes ranging from nano (10^{-9}) to giga (10^{9})

Prefixes				
Symbol	Prefix	Power of Ten	Ordinary Notation	U.S. Name
Y	yotta	10^{24}	1 000 000 000 000 000 000 000 000	
Z	zetta	10^{21}	1 000 000 000 000 000 000 000	
E	exa	10^{18}	1 000 000 000 000 000 000	
P	peta	10^{15}	1 000 000 000 000 000	
T	tera	10^{12}	1 000 000 000 000	trillion
G	giga	10^{9}	1 000 000 000	billion
M	mega	10^{6}	1 000 000	million
k	kilo	10^{3}	1 000	thousand
h	hecto*	10^{2}	100	hundred
da	deka*	10^{1}	10	ten
		10^{0}	1	one
d	deci*	10^{-1}	0.1	tenth
c	centi*	10^{-2}	0.01	hundredth
m	milli	10^{-3}	0.001	thousandth
µ	micro	10^{-6}	0.000 001	millionth
n	nano	10^{-9}	0.000 000 001	billionth
p	pico	10^{-12}	0.000 000 000 001	trillionth
f	femto	10^{-15}	0.000 000 000 000 001	
a	atto	10^{-18}	0.000 000 000 000 000 001	
z	zepto	10^{-21}	0.000 000 000 000 000 000 001	
y	yocto	10^{-24}	0.000 000 000 000 000 000 000 001	

Scientific Notation:

- many of the numerical values of the multipliers are very small or very large; it becomes cumbersome to write out so many zeros, so we abbreviate them using scientific notation

- to convert a number to scientific notation, change the numerical part of a quantity to a number between one and ten; this number is then multiplied by a whole number power of ten

- the form is as follows: $M \times 10^{n}$ where $1 \le M < 10$

- Ex. the number 198,000,000,000 becomes 1.98×10^{11}

- Ex. the number 0.00000000082 becomes 8.2×10^{-10}

Converting Units:

- in order to convert a quantity expressed in one unit to another unit, you may use conversion factors

- a conversion unit is a multiplier equal to one

- Ex. $1 = \frac{1 \text{ kg}}{1000 \text{ g}}$ or $1 = \frac{1000 \text{ g}}{1 \text{ kg}}$

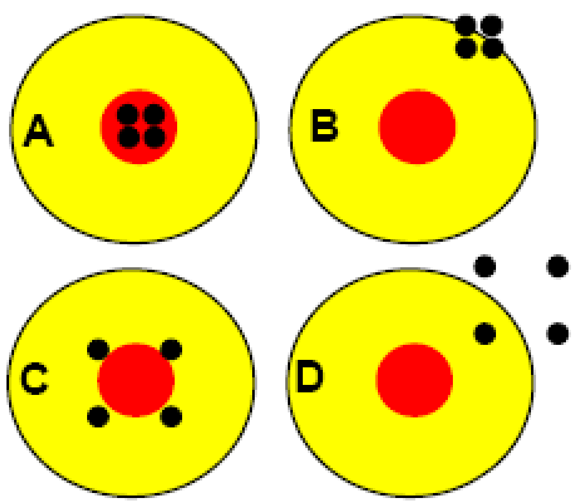
- Ex. Convert 465 g to kilograms.

$$465 \text{ g} = \left(\frac{465 \text{ g}}{1}\right)\left(\frac{1 \text{ kg}}{1000 \text{ g}}\right) = \frac{(465 \text{ g})(1 \text{ kg})}{1000 \text{ g}} = 0.465 \text{ kg}$$

Accuracy and Precision:

- experimental results may be classified by:
    A) Accuracy - how well the results of an experiment agree with the standard value

    B) Precision - degree of exactness of a measurement



- in the figure above, we have four dartboards; in each case a person has thrown four darts aimed at the center of the target

- the accuracy is high if the mean (the average position of the four darts) is close to the true value (the center of the target) and the precision is high if the individual values are all close to the mean

- the results shown in the figure are: A (high accuracy and precision), B (low accuracy and high precision), C (high accuracy and low precision) and D (low accuracy and precision).

- it is possible to make precise measurements with an instrument that are not accurate and visa versa

Measurement Techniques:

- to assure accuracy and precision, one must correctly read the measuring instrument

- a common problem is parallax; parallax is the apparent shift in the position of an object when it is viewed from different angles

- Ex. if you read a meter stick from the side, you may incorrectly read the length of an object; therefore, you need to read it directly above the stick

Significant Digits:

- significant digits are the valid digits in a measurement; the more precise an instrument, the more significant digits can be measured

- Ex. a meter stick with only decimeters marked will give you a less precise reading than one with both decimeters, centimeters, and millimeters marked

- to properly read significant digits on an analog (non-digital) instrument, you read it to the smallest marking and then estimate the last digit to the nearest tenth (0.1) of the smallest marking

Which Digits Are Significant:

- follow these rules for determining which digits are significant
  - A) Non-zero digits are always significant
    - Ex. 26.38 mm = 4 sig. digits
    - Ex. 7.94 mL = 3 sig. digits
  - B) Any zeros between two significant digits are significant
    - Ex. 406 g = 3 sig. digits
    - Ex. 28.09 nm = 4 sig. digits
  - C) A final zero or trailing zeros in the decimal portion only are significant
    - Ex. 0.00500 K = 3 sig. digits
    - Ex. 0.03040 m/s = 4 sig. digits
- these zeros are *not significant*
  - A) Space holding zeros on numbers less than one
    - Ex. 0.00500 N = 3 sig. digits (red zeros are not sig.)
  - B) Trailing zeros in a whole number
    - Ex. 200 km = one sig. digits
    - Ex. 25,000 A = two sig. digits

Addition/Subtraction with Sig. Digits:

- in any calculation with significant digits, your answer cannot be more precise than the least precise measurement
- to add or subtract measurements, first perform the operation, then round off the result to correspond to the least precise value involved

Ex. 24.686 m + 2.343 m + 3.21 m = 30.239 m
3.21 m is the least precise value (accurate to the hundredths of a meter, the other two terms are accurate to the thousandths); the above answer should be reported with the same amount of precision; this requires you to round-off the value, 30.239 m, to 30.24 m; you will report the correct calculated answer as **30.24 m**

Multiplication/Division:

- a different method is used to find the correct number of significant digits when multiplying or dividing measurements; after performing the calculation, note the factor that has the least number of significant digits; round the product or quotient to this number of digits

Ex. $3.22\text{ cm} \times 2.1\text{ cm} = 6.762\text{ cm}^2$ $\left(\text{corrected to } 6.8\text{ cm}^2\right)$

Uncertainty When Counting:

- sig. digits are only used in measurements and not with counting

Ex. if you count four pencils, this number has no uncertainty