Matter / Measurement______ Z Appendix 1, 2, Ch 1; H Ch 0–1-1, 3-1–3-3

"... those sciences are vain and full of errors that are not born from experiment, the mother of all certainty, and that do not end with one clear experiment." **Leonardo da Vinci, 1452-1519**

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge but you have scarcely, in your thoughts, advanced to the stage of science." **William Thomson, Lord Kelvin, 1891**

Scientific Method

SI Units and Prefixes - KNOW

Precision and Accuracy

Significant Figures

Atomic Theory

Familiarize yourself with our website on Blackboard. In particular the LABORATORY and LECTURE NOTES AND HANDOUTS

FRIDAY

"W" OWL homework due

TA OFFICE HOURS

under Zoom sessions on Blackboard

LAB SESSIONS

no social distancing required, everyone doing Exp 1 this week – do prelab assignment sent Sunday a week ago

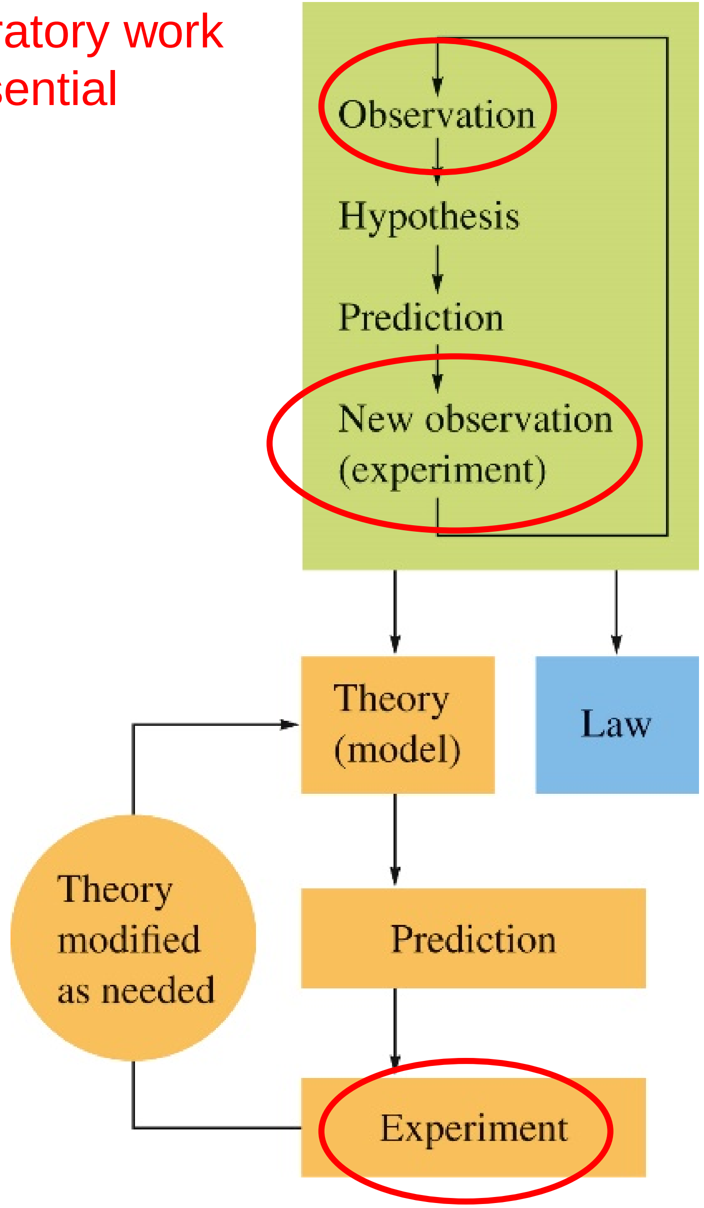
Scientific Method

Laboratory work
is essential

Science (Latin *scientia*, *scire*, to know) provides a framework for systematically studying ourselves, our environment, and the universe. Progress in science is cumulative – building upon and extending prior knowledge via what has come to be known as the scientific method: the interplay of observations, judicious reason-ing, predictions and new experiments to test the predictions.

Chemistry is broadly concerned with the analysis of substances (composition, structure, properties), their transformation into other substances (chemical reactions), and the energy changes that accompany these transformations.

Experiments require the ability to transform, characterize, and/or measure matter – anything that occupies space and has mass.



SI Units - Système international (d'unités)

Table 1-1 Fundamental SI units (from Harris text)

Quantity	Unit (symbol)	Definition
Length	meter (m)	One meter is the distance light travels in a vacuum during $\frac{1}{299\ 792\ 458}$ of a second.
Mass	kilogram (kg)	One kilogram is the mass of the prototype kilogram kept at Sèvres, France.
Time	second (s)	One second is the duration of 9 192 631 770 periods of the radiation corresponding to a certain atomic transition of ^{133}Cs.
Electric current	ampere (A)	One ampere of current produces a force of 2×10^{-7} newtons per meter of length when maintained in two straight, parallel conductors of infinite length and negligible cross section, separated by 1 meter in a vacuum.
Temperature	kelvin (K)	Temperature is defined such that the triple point of water (at which solid, liquid, and gaseous water are in equilibrium) is 273.16 K, and the temperature of absolute zero is 0 K.
Luminous intensity	candela (cd)	Candela is a measure of luminous intensity visible to the human eye.
Amount of substance	mole (mol)	One mole is the number of particles equal to the number of atoms in exactly 0.012 kg of ^{12}C (approximately $6.022\ 141\ 5 \times 10^{23}$).
Plane angle	radian (rad)	There are 2π radians in a circle.
Solid angle	steradian (sr)	There are 4π steradians in a sphere.

derived units:
volt – electric potential
coulomb – quantity of electricity
hertz – frequency

non-SI:
1 liter ≡ 1.0×10^{-3} m^3

Prefixes

every third power of 10

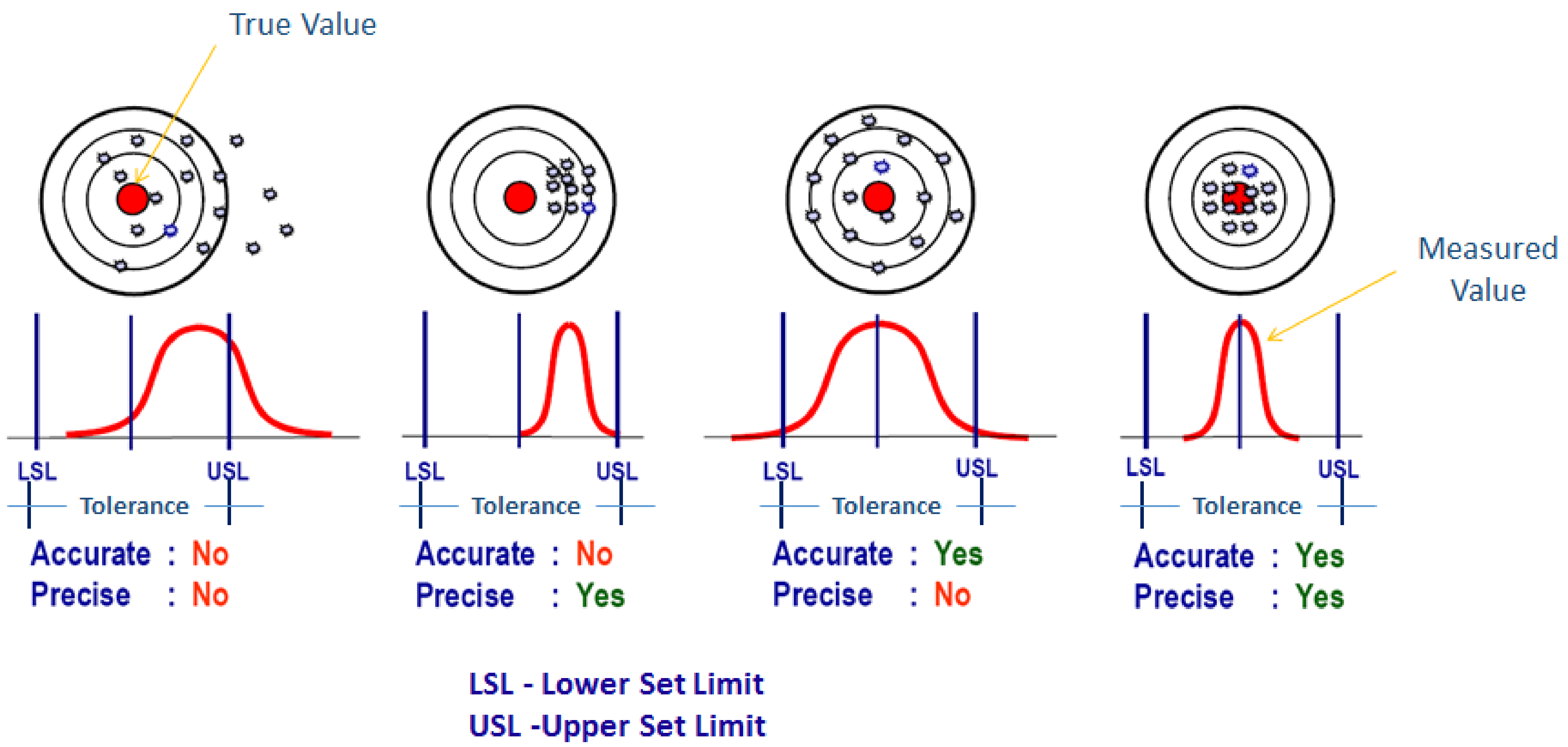
Table 1-3 Prefixes

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

usually ends in __a

usually ends in __o

Precision, Accuracy, and Experimental Error



accuracy – deviation from true value (systematic error)
precision – agreement of replicate measurements (random error)
standard deviation, $s = \sqrt{\sum_i[(x_i - \langle x \rangle)^2]/(n-1)}$

Significant Figures

scientific notation – all digits given are significant figures

Harris frequently carries extra nonsignificant digits written as subscripts to prevent round off errors

significant figures

all nonzero digits significant: 489 has 3 sig figs, 111.1 four
constants, exact numbers, defined quantities – infinite number of sig figs
zeros
leading – preceding first nonzero digit, not significant: 0.0046 has two sig fig
captive – surrounded by nonzero digits, significant: 1005 has four sig fig
trailing – at end of number, significant when a decimal point is present: 13.620 has five, 150 two

rounding – never round off intermediate results, only at the end of the calculation

significant figures in calculations

multiplication and division – sig fig of final result same as least precise number used in the calculation
addition and subtraction – sig fig of final result has the same number of decimal places as the least precise number used in the calculation

Calculating a Standard Deviation

EX 1. A student makes the following six independent measurements of pressure, *P*, in torr

762.2, 761.8, 762.0, 761.5, 762.2, and 760.0

Calculate the average value of *P* and its standard deviation. (NOTE: useful for lab reports!)

$$\langle P \rangle = (762.2 + 761.8 + 762.0 + 761.5 + 766.2 + 760.0)/6 = 761.6166 \Rightarrow 761.6$$

mean to report

standard deviation

$$s = \sqrt{\textstyle\sum_i [(x_i - \langle x \rangle)^2]/(n-1)} = \sqrt{[(762.2 - 761.6166)^2 + \ldots]/5}$$

$$= \{ [(0.583)^2 + (0.183)^2 + (0.383)^2 + (0.116)^2 + (0.583)^2 + (1.616)^2] / 5 \}^{1/2}$$

$$= \sqrt{3.488/5} = 0.835 \Rightarrow 0.84$$ **standard deviation to report**

$= 761.6 \pm 0.84$ torr (**Harris 761.6 ± 0.8**)

result to report

Harris p. 54 The *Real* Rule for Significant Figures:

first digit of uncertainty = last digit of answer

Significant Figures in Calculations

EX 2. Concentration Calculations: A solution is made by transferring 1 mL of a 0.1245_3 M solution, using a volumetric pipet, into a 200-mL volumetric flask. Calculate the final concentration.

Remember that concentration is

moles / liter, $c = n/L$

where the number of moles is given by

volume × molarity, $n = VM$

***Solution*:** The volume of the flask has 5 significant figures and all other values have 4. The calculations all involve multiplication and division, so the final answer should be expressed with 4 significant figures. The volume contained in volumetric glassware is significant to the tenths or hundredths place and transfer pipets to the hundredths or thousandths place.

$$1.000 \times 0.1245_3 \text{ M} / 200.00 = 0.0006226_5 \text{ M} = \mathbf{6.227 \times 10^{-4} \text{ M}}$$

Atoms, Molecules, and Ions

"According to convention there is a sweet and a bitter, a hot and a cold, and according to convention there is a color. In truth there are atoms and a void." **Democritus, 5th century B.C.**

"... there must be some point beyond which we cannot go in the division of matter. The existence of these ultimate particles of matter can scarcely be doubted, though they are probably much too small ever to be exhibited by micro-scopic improvements. I have chosen the word atom to signify those ultimate particles ... [which for] all homogeneous bodies are perfectly alike in weight, figure, etc. In other words, every particle of hydrogen is like every other particle of hydrogen ...." **John Dalton, 1808**

Atomic Theory of Matter (Dalton)

Conservation of Mass

Laws of
- Definite Proportions
- Multiple Proportions

Avogadro's Hypothesis

Building Blocks of the Atom

Periodicity

Nomenclature (Elements, Ions, Compounds) - **KNOW**

Pre-Atomic Theory of Matter

concept: infinite indivisibility of matter

ancient Greek, Indian, Chinese philosophy – matter composed of four "elements": air, earth, fire, water

Heraclitus (535-475 BC; Greek philosopher in Asia Minor) everything in a state of flux, becoming, element fire; Parmenides (515-450 BC, Greek philosopher in southern Italy) change is impossible, being

Leucippus (480-420 BC; Greek philosopher) and his student Democritus (460-371 BC; mathematician, astronomer, physicist; traveled to India, Babylon, Persia, Egypt, Ethiopia?) – postulated existence of atoms – tiny particles always in motion, interacted by collision; all change due to motion of atoms

Epicurus (341–270 BC, Greek philosopher) refined Democritus theory, he and Pythagoreans atomists

6^{th} century BC – Hindu Kanada – cannot infinitely divide matter, Jainas (3^{rd} century AD) were atomists

Socrates → Plato → **Aristotle** (384-322 BC, Greek philosopher, physicist, biologist) – knowledge proceeds from observation, only four elements, atoms rejected as implausible since could not be perceived by the senses; Stoics, Cicero, Seneca, **St. Augustine** (354-430 AD) **opposed atomism**

Lucretius (99-55 BC; Roman poet, philosopher) explained numerous natural processes by **atoms**, even **negating necessity of a supreme being** – branded an **atheist,** atomism condemned.

Venerable Bede (762-735 AD) was an atomist

medieval Arabic speaking world the intellectual tradition of kalam supported atomism; Rhazes - Abu Bakr al-Razi (841-926; Persian physician, philosopher, astronomer, alchemist)

“Modern” Pre-Atomic Theory

in 12^{th} century works of **Aristotle** rediscovered, brought back concept of an atom, controversy heightened in 14^{th} century; Epicureanism contradicted orthodox Christian teachings, it was a “heresy”

Pierre Gassendi (1592-1655) got around the objection by stating that atoms were created by God

Rene Descartes (1596-1650), Issac Newton (1642-1727), Robert Boyle (1627-1691) defended atomism; generally accepted by end of 17^{th} century.

1775 – Lavoisier (combustion of Hg) => **law of conservation of mass**

1799 – Proust (amount of O in Fe oxide) => **law of definite proportions:** “In a given chemical compound the proportions by mass of the elements that comprise it are fixed ...”

1803 – Dalton **law of multiple proportions** (“When two elements form a series of compounds the masses of one element that combine with a fixed mass of the other element are in the ratio of small integers to each other.”)

Dalton used atomic theory to explain via an empirical process of experimentation and analysis – flaw did not realize that some elements were composed of more than one atom and that simplest combination was not always 1 atom of each element