SCIENTIFIC METHOD

OBSERVATION

- controlled observation

HYPOTHESIS

- an explanation of observations, supported by limited data
- answer "why?" questions
- make predictions for future results

EXPERIMENTS

- observations in controlled conditions where a change in one variable is correlated with another

- experiments may support or falsify hypothesis. If hypothesis is falsified in some way, it must be modified or discarded.

- a hypothesis that is supported by a large amount of data and is accepted by the scientific community is called a THEORY. THEORIES are our best answers to "why?" questions.

- What about "laws"? LAWS are generalized observations. They address "what?" questions, not "why?" questions.

ACCURACY AND PRECISION

- Chemistry is a measurement-based science! (quantitative)

- measurements have two parts: MEASURED NUMBERS and UNITS

Two parameters:
- ACCURACY
- PRECISION

- ACCURACY: Correctness of the measurement. How close a measured number is to the TRUE VALUE of what is being measured.

    - Comparison to standards to determine accuracy
    - Calibration of instruments

- PRECISION: Reproducibility of measurements. How close a set of measurements of the same thing are to each other.

    - ERROR: Any measurement, even one done correctly, will contain some amount of ERROR (deviation from the TRUE VALUE)

    - SYSTEMATIC ERROR: error that affects measurements always in the same way. "bias". Detectable cause, can be corrected by modifying technique. Affect accuracy.

    - RANDOM ERROR: Undetectable cause. Affect measurements differently each time but can be "averaged out" by repeated experiments. The larger the amount of random error, the more repeat trials you need for it to average out.

PRECISION

- Can be represented by statistics: standard deviation, confidence limits, etc.

- Can also be represented by the concept of significant figures.

SIGNIFICANT FIGURES

- include all CERTAIN DIGITS and one UNCERTAIN DIGIT in a measurement.

A digit that normally varies from measurement to measurement

A digit that normally remains constant with repeat measurements.

UNCERTAIN digits

1.4741 g
1.4745 g
1.4746 g
1.4744 g

CERTAIN digits

Avg: 1.4744 g

uncertain

ZERO AND SIGNIFICANT FIGURES

- Zero may be used as an actual measured number, but it may also function as a PLACEHOLDER.
- How do we tell a measured zero from a placeholder?

1. BEGINNING zero: Any zero that comes before any nonzero digit in a number is NOT significant.

   0.0017 Km

   not significant

2. END zero: An end zero is significant IF the number contains a written decimal point.

   157.30 mg

   significant!

   13.00 g

   significant!

   15000 g

   NOT significant

   15000. g

   significant!

3. MIDDLE zero: Any zero that is between two nonzero (or otherwise significant) digits is also significant.

   15003 mg

   significant!

MATH WITH SIGNIFICANT FIGURES

- poor man's "propagation of error"

- Often, the last measured number in an experiment isn't "the answer". To get the answer we need, we need to do some calculations: addition, subtraction, multiplication, division.

- How does the math affect the uncertainty we're trying to represent? What is the uncertaintly in the answer?

ADDITION and SUBTRACTION

$$
\begin{array}{r}
157\ g \\
73.85\ g \\
1403.2\ g \\
\hline
1634.05\ g
\end{array}
$$

$\rightarrow$ 1634 g

When adding or subtracting, "follow the uncertainty down", OR round the answer to the same number of decimal places as the measurement with the fewest decimal places.

MULTIPLICATION AND DIVISION

-Round final answer to the same number of significant figures as the measurement with the fewest significant figures

$$\underset{3}{\underline{148}}\text{ cm} \times \underset{4}{\underline{0.5234}}\text{ cm} \times \underset{2}{\underline{1.6}}\text{ cm} =$$

123.94112 cm^3 (calculator answer)

$12|3.94112\ cm^3$

$120\ cm^3$

EXACT NUMBERS

- Not all numbers with units are measurements.

  - Most conversion factors (between metric units and metric/english units) do not contain any uncertainty. They are EXACT

  - COUNTED numbers are also EXACT.

  - In calculations, treat exact numbers as if they had an INFINITE number of both decimal places AND significant figures.

$$2.54\ cm = 1\ in \quad \underline{exact}$$

$$\underset{3}{\underline{137\ in}} \times \underset{\infty}{\underline{\frac{2.54\ cm}{1\ in}}} = 347.98\ cm = 348\ cm$$

CHEMICAL NOMENCLATURE

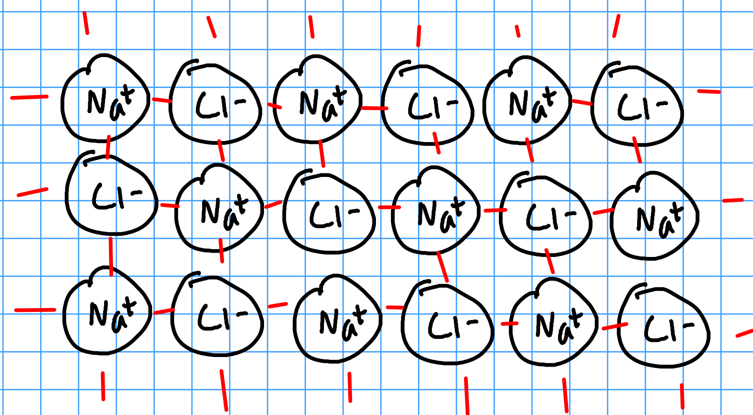
- Two kinds of compounds:

  1. IONIC compounds: held together by electrostatic attractions between ions

  2. MOLECULAR compounds: held together by electron sharing

IONIC compounds

- Overall, have no net charge even though they contain charged particles. So, an ionic formula contains enough positively charged ions to balance out the charge of the negatively-charged ions in the compound



Formulas for ionic compounds do not describe how many atoms are in each "unit" of the compound.

Ionic formulas give the RATIO of cation to anion in a compound. The simplest whole number ratio is always used.

Ionic formulas are "empirical" formulas. (Empirical formulas have the simplest ratio of one atom to another)

- properties:
    - high melting points
    - In liquid or dissolved states, they conduct an electric current due to the presence of IONS (which function as charge carriers)
    - almost all are solids at room temperature

WRITING IONIC FORMULAS

(1) - Figure out the charge on the ions IN the compound

(2) - Figure out the simplest ratio between the ions in the compound

GETTING THE CHARGE ON AN ION

Al: lose 3 electrons

Al^{3+}

Elements whose charge as ions can be easily predicted

Transition elements — most may take more than one charge!

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn (+2)	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag (+)	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La *	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac *	Rf	Db	Sg	Bh	Hs	Mt									

*"inner" transition metals go here

- For main-group elements, charge can be predicted using the periodic table
    - Count how many blocks one of these elements is from the nearest (in atomic number) NOBLE GAS (Group VIIIA). If you need to add electrons to get the same number of electrons as the noble gas, you have an anion. If you need to remove electrons, you have a cation.

S: gains 2 electrons S^{2-}

Sr: loses 2 electrons, Sr^{2+}

Other ions:

- POLYATOMIC ions: Really molecules that have gained or lost electrons

- Example: acetate ion $C_2H_3O_2^-$] This molecule has an overall charge of -1 !

- In ionic compounds, polyatomic ions behave just like monatomic (single-atom) ions do!

- Memorize common polyatomic ions (see web site for list)

WRITING AN IONIC FORMULA FROM IONS

Al^{3+} O^{2-}] What's the formula of the ionic compound containing these two ions?

Al^{3+} O^{2-}

O^{2-}

Al_2O_3] Ionic formulas are always written with CATION FIRST!

In the formula of the COMPOUND, leave off the charges on the ions.

~~$Al_2^{3+}O_3^{2-}$~~ COMPOUND is neutral!

Ti^{4+} SO_4^{2-}

SO_4^{2-}

$Ti(SO_4)_2$

Be careful! The "cross method" will give you the wrong answer for compounds like this one!

~~$Ti_2(SO_4)_4$~~

NAMING SYSTEM FOR IONIC COMPOUNDS

- The name of an ionic compound is simply the names of the ions IN the compound.

- So, how do we name the ions?

CATIONS

- main-group elements (elements that only form one cation): Use the ELEMENT NAME as the name of the ion

Al^{3+} : "aluminum ion"

- transition metals (elements that may form several different cations): Use the ELEMENT NAME and a Roman numeral indicating the charge.

Cu^{+} : "copper(I) ion"

Fe^{2+} : "iron (II) ion"

- polyatomic: memorize

NH_4^{+} : ammonium

ANIONS

- main-group anions: Named using the STEM NAME of the element plus "-ide" suffix

N^{3-}: nitride ion

O^{2-}: oxide ion

S^{2-}: sulfide ion

- polyatomic anions: memorize common ions

SO_4^{2-}: sulfate ion

SO_3^{2-}: sulfite ion

↑ "-ate" and "-ite" ions all contain oxygen.

Naming a compound: Just add the names of the ions together, and drop the "ion"

$FeCO_3$

Fe^{2+} CO_3^{2-}

iron(II) carbonate

$AlPO_4$

aluminum phosphate

Na_3N

sodium nitride ← no oxygen

transition element, use R.N.

Cu_2O

Cu^{+} O^{2-}

Cu^{+}

copper(I) oxide

Roman numeral indicates CHARGE, not subscript!
... what KIND of ion you have, not how many!

CuO

Cu^{2+} O^{2-}

copper(II) oxide

iron(II) phosphate

Fe^{2+} PO_4^{3-}

Fe^{2+} PO_4^{3-}

Fe^{2+}

$Fe_3(PO_4)_2$

ammonium carbonate

NH_4^+ CO_3^{2-}

NH_4^+

$(NH_4)_2CO_3$

titanium(IV) oxide

Ti^{4+} O^{2-}

O^{2-}

TiO_2

beryllium chloride

Be^{2+} Cl^-

Cl^-

$BeCl_2$

HYDRATES

- many ionic compounds are formed by crystallizing the compound from water. Sometimes, this causes water molecules to become part of the crystal structure.

- This water is present in a definite ratio to the ions in the compound. Can be removed by heating, but will NOT evaporate if the compound is left standing.

ex: $CuSO_4 \cdot 5H_2O$

water molecules per formula unit of compound

dot indicates that the water is weakly bound to the ionic compound

- many DESSICANTS are hydrates that have had their water molecules driven off. They will slowly reabsorb water from the air (and keep the environment in a dessicator at a low humidity)

- Hydrates are named using the name of the ionic compound, and a Greek prefix in front of the word "hydrate" to indicate how many water molecules are associated

copper (II) sulfate pentahydrate

MOLECULES

- In CHM 110, you're responsible for two kinds of molecules.

(1) BINARY MOLECULAR COMPOUNDS

(2) ACIDS

BINARY MOLECULAR COMPOUNDS

- contain only two elements.

- Named based on the elements they contain. BUT, since there are often several different compounds containing the same elements, we must indicate the number of atoms of each element that are in the molecule!

- Greek prefixes are used to indicate the number of atoms.

FIRST ELEMENT: name using the name of the element, but add a Greek prefix to indicate how many atoms of that element are in the molecule.

... but skip the prefix if there's only ONE atom.

SECOND ELEMENT: name using the STEM NAME of the element plus an "-ide" suffix, but add a Greek prefix to indicate the number of atoms of that element in the molecule.

... ALWAYS add a prefix, even if there's only one of the second element.

CO_2

carbon dioxide

CO

carbon monoxide

N_2F_4

dinitrogen tetrafluoride

dichlorine heptaoxide

Cl_2O_7

phosphorus pentachloride

PCl_5

ACIDS

- BINARY ACIDS

    - contain HYDROGEN and another element (Group VIIA - halogens)

HCl HYDROCHLORIC ACID

HF HYDROFLUORIC ACID

HBr HYDROBROMIC ACID

HI HYDROIODIC ACID

- OXYACIDS / OXOACIDS

    - contain HYDROGEN, OXYGEN, and another element.

    - HYDROGEN and a POLYATOMIC ION

H_2SO_4	SULFURIC ACID	from sulfate
H_3PO_4	PHOSPHORIC ACID	from phosphate
HNO_3	NITRIC ACID	from nitrate
HNO_2	NITROUS ACID	from nitrite
$HC_2H_3O_2$	ACETIC ACID	from acetate
H_2SO_3	SULFUROUS ACID	from sulfite

endings: -ate becomes -ic
- ite becomes -ous

hydrogens = charge of polyatomic