Remedial Chemistry 101

TURI Continuing Education Conference

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Devens, MA

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Credits

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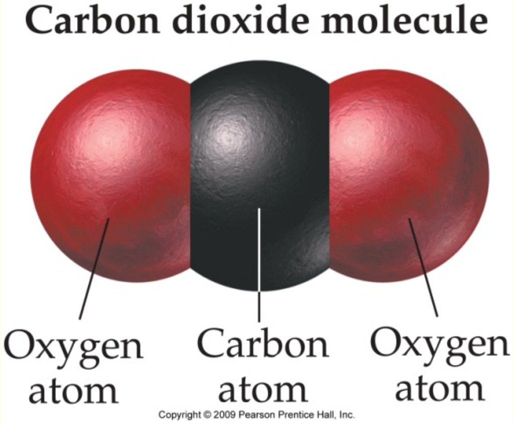
Introductory Chemistry, 3rd Edition
Nivaldo Tro
2009, Prentice Hall

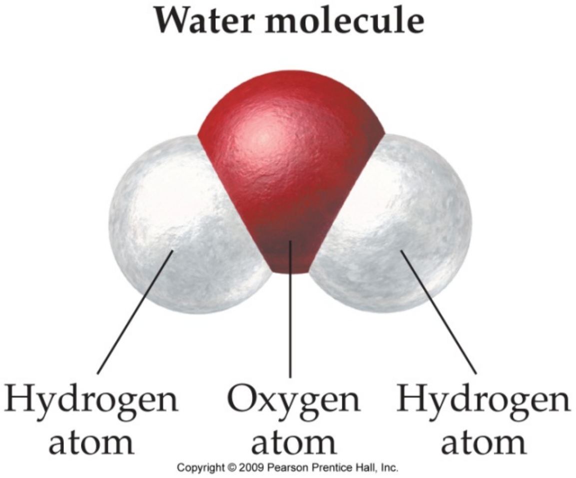
What Is Chemistry?

- Describes the relationships between composition and properties of matter.
  - Composition
    - Types & number of atoms, structure
  - Properties
    - Chemical: reactivity, ability to lose/gain electrons
    - Physical: state, temperature

Structure Determines Properties

- Everything is made of tiny particles called **atoms** and **molecules.**
- Chemists study these particles, looking at the kinds, numbers, structure, size which produce varying chemical and physical properties.





Why Do Some Things Burn? Phlogiston Theory

- Explanation of combustion in early/mid-1700s.
- Combustible substances contained a substance they called **phlogiston**.
- When a substance burned it released all or some of its phlogiston into the air .
- You can’t see it, feel it or measure it. (huh!)

A Better Theory of Combustion

- Lavoisier proposed an alternative theory of combustion.
  - When materials burn, they remove oxygen from the air and combine with it.
  - Discovers oxygen, hydrogen
  - Literally, rewrites all chemistry textbooks
  - Lavoisier’s idea starts modern chemistry based on experimentation---measurements

What Is a Measurement?

- Quantitative observation.
- Comparison to an agreed upon standard.
- Every measurement has a number and a unit.

Units

- Units tell the standard quantity to which we are comparing the measured property.
  - Without an associated unit, a measurement is without meaning.
- Scientists use a set of standard units for comparing all our measurements.
  - So we can easily compare our results.
- Each of the units is defined as precisely as possible.

Units

- Always write every number with its associated unit.
- Always include units in your calculations.
- You can do the same kind of operations on units as you can with numbers.
  - $cm \times cm = cm^2$
  - $cm + cm = 2cm$
  - $cm \div cm = 1$
- Using units as a guide to problem solving is called ***dimensional analysis***.

How important are units?

On 9/23/99, $125,000,000 Mars Climate Orbiter entered Mars' atmosphere 100 km lower than planned and was destroyed by heat.

1 lb $\neq$ 1 N

1 lb = 4.45 N

"This is going to be the cautionary tale that will be embedded into introduction to the metric system in elementary school, high school, and college science courses till the end of time."

Problem Solving and Dimensional Analysis Revisited

- Arrange conversion factors so the starting unit cancels.
  - Arrange conversion factor so the starting unit is on the bottom of the conversion factor.
- May string conversion factors.
  - So we do not need to know every relationship, as long as we can find something else the starting and desired units are related to :

$$\textbf{start unit} \times \frac{\textbf{desired unit}}{\textbf{start unit}} = \textbf{desired unit}$$

$$\textbf{start unit} \times \frac{\textbf{related unit}}{\textbf{start unit}} \times \frac{\textbf{desired unit}}{\textbf{related unit}} = \textbf{desired unit}$$

Problem 1: Unit conversion

You just got a deal on a used recycling unit. The specs for the unit give a processing rate of 1.8 liters per minute. The density of the solvent you will recycle is 0.879 grams per cubic centimeter. Your facility operates for two 8-hour shifts, 7 days a week, 50 weeks a year.

a. How many gallons of solvent can the unit recycle in one day?

b. How many pounds of solvent can be recycled in a year?

More Unit Conversion

Material Accounting Using Air Monitoring Data

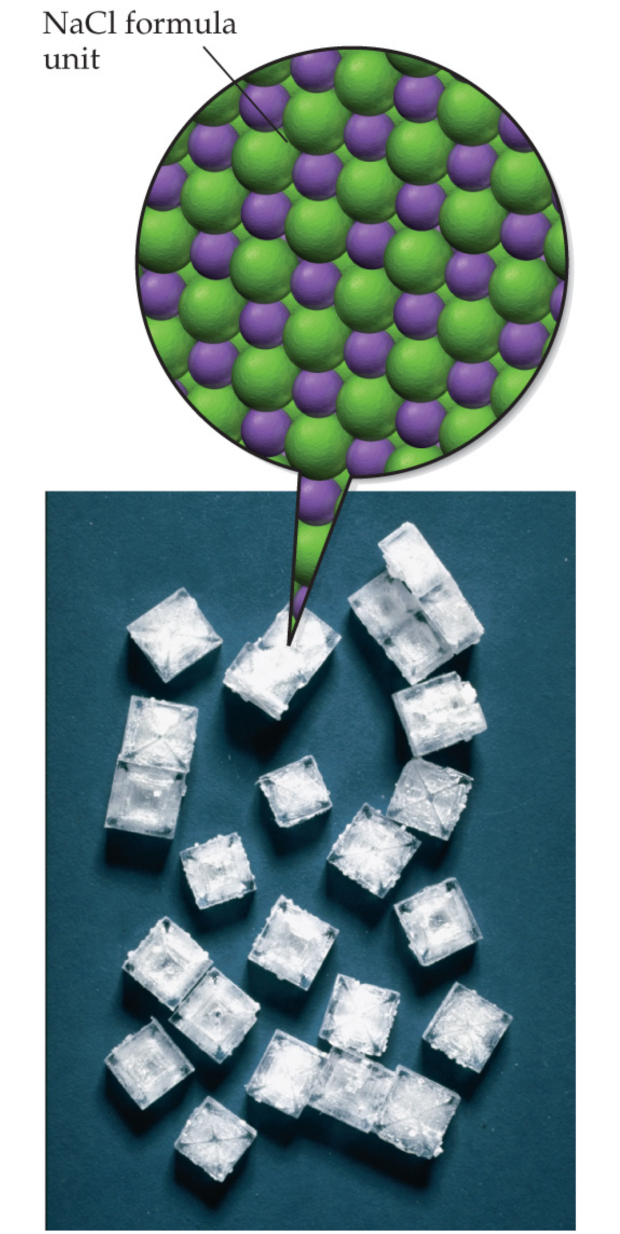
- Calculate the concentration of benzene (in lb/ft^3) given the following:
  - Concentration = 4500 ppm
  - M.W. = 78.1

Formulas Describe Compounds

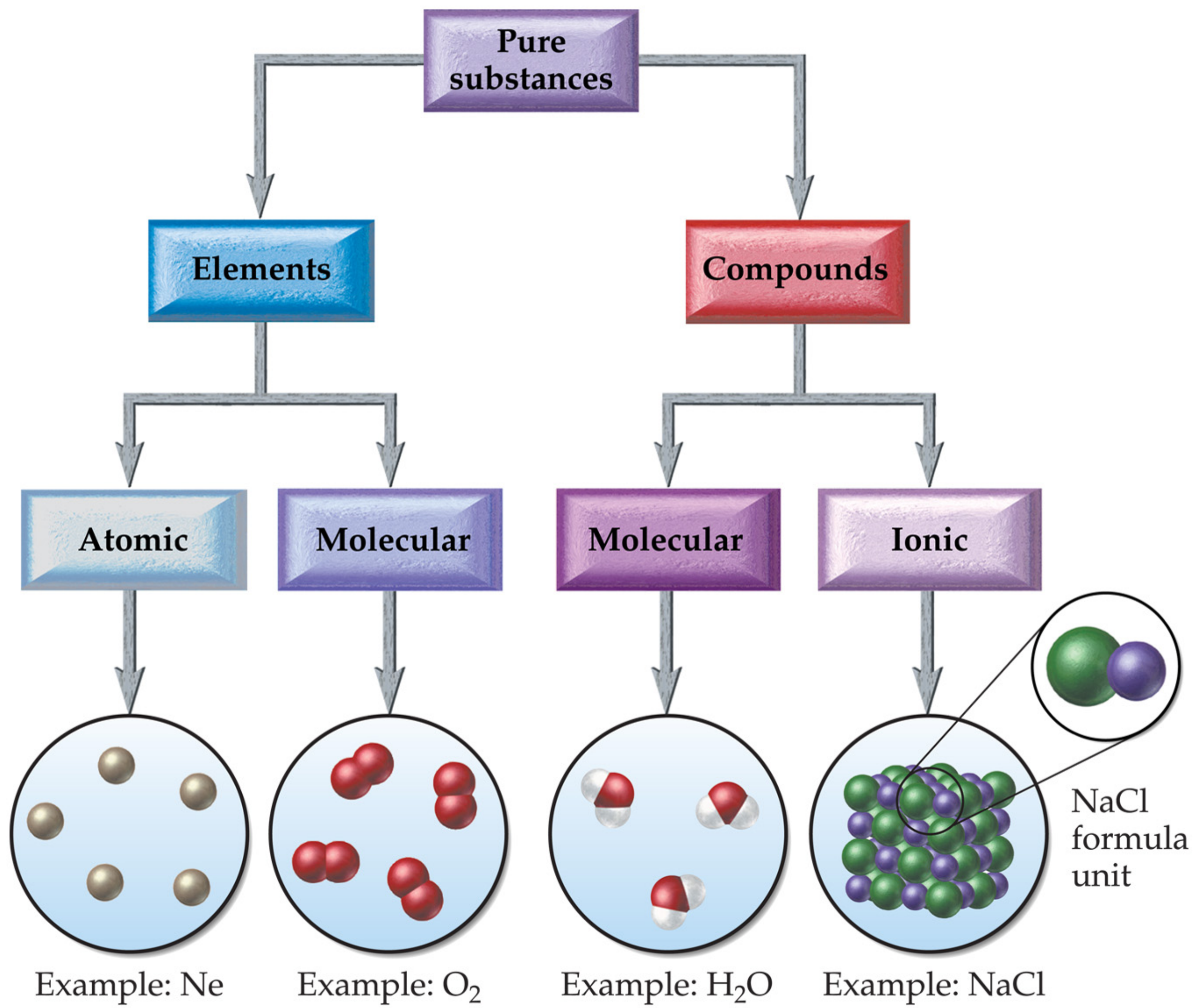
- Elements are represented by a letter symbol.
- A pure compound is composed of atoms of two or more elements.
- The relative quantity of each element is written to the right of the element as a subscript.
  - If there is only one atom, the 1 subscript is not written.
- Polyatomic groups are placed in parentheses.
  - If more than one.

Ionic Compounds

- Metals + nonmetals.
- No individual molecule units, instead have a 3-dimensional array of cations and anions made of **formula units**.



Molecular View of Elements and Compounds



Some Common Polyatomic Ions

Name	Formula
Acetate	$C_2H_3O_2^-$
Carbonate	CO_3^{2-}
Hydrogen carbonate (aka bicarbonate)	HCO_3^-
Hydroxide	OH^-
Nitrate	NO_3^-
Nitrite	NO_2^-
Chromate	CrO_4^{2-}
Dichromate	$Cr_2O_7^{2-}$
Ammonium	NH_4^+

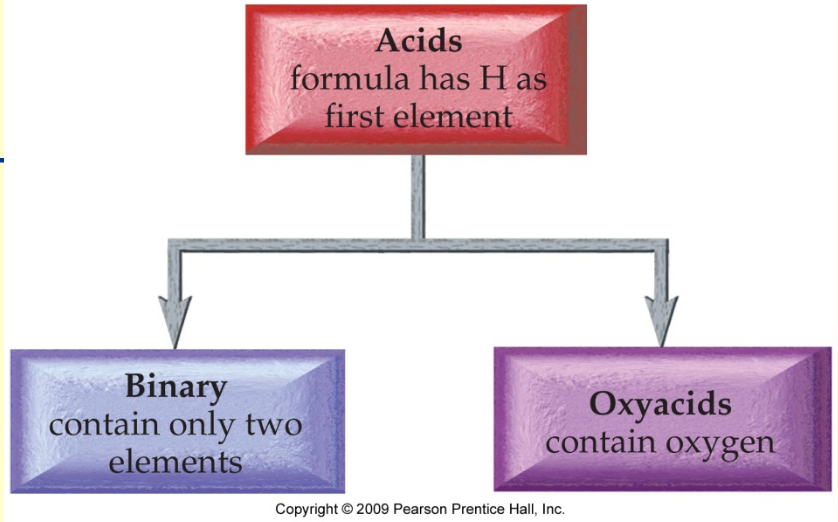
Name	Formula
Hypochlorite	ClO^-
Chlorite	ClO_2^-
Chlorate	ClO_3^-
Perchlorate	ClO_4^-
Sulfate	SO_4^{2-}
Sulfite	SO_3^{2-}
Hydrogen sulfate (aka bisulfate)	HSO_4^-
Hydrogen sulfite (aka bisulfite)	HSO_3^-

Acids

- Acids are molecular compounds that form H^+ when dissolved in water.
  - To indicate the compound is dissolved in water, (*aq*) is written after the formula.
    - Not named as acid if not dissolved in water.
- Sour taste.
- Dissolve many metals.
  - Zn, Fe, Mg, but not Au, Ag, Pt.
- Formula generally starts with H.
  - E.g., HCl, H_2SO_4.

Acids, Continued

- Contain H^{+1} cation and anion.
  - In aqueous solution.
- Binary acids have H^{+1} cation and nonmetal anion.
- Oxyacids have H^{+1} cation and polyatomic anion.



Common Acids

Chemical name	Formula	Old name	Strength
Nitric acid	HNO_3	Aqua fortis	Strong
Sulfuric acid	H_2SO_4	Vitriolic acid	Strong
Hydrochloric acid	HCl	Muriatic acid	Strong
Phosphoric acid	H_3PO_4		Moderate
Chloric acid	$HClO_3$		Moderate
Acetic acid	$HC_2H_3O_2$	Vinegar	Weak
Hydrofluoric acid	HF		Weak
Carbonic acid	H_2CO_3	Soda water	Weak
Boric acid	H_3BO_3		Weak

Practice—What Are the Formulas for the Following Acids?, Continued

1. H^+ with ClO_2^-

   $HClO_2$

2. H^+ with PO_4^{3-}

   H_3PO_4

3. H^+ with SO_4^{2-}

   H_2SO_4

Practice—What Are the Formulas for the Following Bases?,

1. Na^{+} with OH^{-}

   $NaOH$

2. Ca^{+2} with OH^{-}

   $Ca(OH)_2$

3. Mg^{+2} with OH^{-}

   $Mg(OH)_2$

Practice—Write Formulas for Each of the Following Compounds.

- Hematite—Composed of four oxide ions for every three iron ions.

  Fe_3O_4

- Acetone—Each molecule contains six hydrogen atoms, three carbon atoms, and one oxygen atom.

  C_3H_6O

Formula Mass

- The mass of an individual molecule or formula unit.
- Also known as molecular mass or molecular weight.
- Sum of the masses of the atoms in a single molecule or formula unit.
  - Whole = Sum of the parts.

Mass of 1 molecule of H_2O

= 2(1.01 amu H) + 16.00 amu O = 18.02 amu.

Practice—Calculate the Formula Mass of $Al_2(SO_4)_3$.

Practice—Calculate the Formula Mass of $Al_2(SO_4)_3$

$$
\begin{array}{lcrr}
\text{Al} & = & 2\times & 26.98\,\text{amu} \\
\text{S} & = & 3\times & 32.07\,\text{amu} \\
\underline{\text{O}} & = & \underline{12\times} & \underline{16.00\,\text{amu}} \\
\text{Al}_2(\text{SO}_4)_3 & = & & 342.17\,\text{amu}
\end{array}
$$

Mass Percent as a Conversion Factor

- The mass percent tells you the mass of a constituent element in 100 g of the compound.
  - The fact that NaCl is 39% Na by mass means that 100 g of NaCl contains 39 g Na.
- This can be used as a conversion factor.
  - 100 g NaCl ≡ 39 g Na

$$\text{g NaCl} \times \frac{39\text{ g Na}}{100\text{ g NaCl}} = \text{g Na} \qquad \text{g Na} \times \frac{100\text{ g NaCl}}{39\text{ g Na}} = \text{g NaCl}$$

Chemical Equations

- Short-hand way of describing a reaction.
- Provides information about the reaction.
  - Formulas of reactants and products.
  - States of reactants and products.
  - Relative numbers of reactant and product molecules that are required.
  - Can be used to determine masses of reactants used and products that can be made.

Quantities in Chemical Reactions

- The amount of every substance used and made in a chemical reaction is related to the amounts of all the other substances in the reaction.
  - Law of Conservation of Mass.
  - Balancing equations by balancing atoms.
- The study of the numerical relationship between chemical quantities in a chemical reaction is called **stoichiometry**.

Balancing Equations

When aluminum metal reacts with air, it produces a white, powdery compound called aluminum oxide.

- Reacting with air means reacting with O_2:

Aluminum(*s*) + oxygen(*g*) → aluminum oxide(*s*)

$$Al(s) + O_2(g) \rightarrow Al_2O_3(s)$$

$$4\ Al(s) + 3\ O_2(g) \rightarrow 2\ Al_2O_3(s)$$

Counting Atoms by Moles

- Because of these formulaic relationships, we need to know the number of atoms or molecules in a given mass of a substance.
- Because there are so many atoms, we use a special number, 6.022×10^{23} and we call this a **mole**.
  - 1 mole = 6.022×10^{23} things.
    - Like 1 dozen = 12 things.
  - Like a kilo = 1000 or a Google = 1×10^{100}
  - Unlike some of these numbers, a mole has a special significance
  - It is called Avogadro's number.

Chemical Packages—Moles

- Mole = Number of carbon atoms “in” 12 g of C-12.
  - 1 mole protons or 1 mole of neutrons = 1 amu
  - C-12 exactly 6 protons and 6 neutrons
  - 1 mole × 1 amu = 1 g.
  - 1 mole of C-12 (which is 12 amu) weighs exactly 12 g.
- In 12 g of C-12 there are 6.022 $x10^{23}$ C-12 atoms.

Relationship Between Moles and Mass

- The mass of one mole of atoms is called the **molar mass**.
- The molar mass of an element, in grams, is numerically equal to the element’s atomic mass in amu.
- The lighter the atom, the less a mole weighs.
- The lighter the atom, the more atoms there are in 1 g.

Molar Mass of Compounds

- The relative weights of molecules is given by atomic weights.

Formula mass = mass of 1 molecule of anything, e.g.

H_2O = 2(1.01 amu H) + 16.00 amu O = 18.02 amu.

- Since 1 mole of H_2O contains 2 moles of H and 1 mole of O.

Molar mass = 1 mole H_2O

= 2(1.01 g H) + 16.00 g O = 18.02 g.

Making Molecules
Mole-to-Mole Conversions

- The balanced equation is the “recipe” for a chemical reaction.
- The equation $3\ H_2(g) + N_2(g) \rightarrow 2\ NH_3(g)$ tells us that 3 molecules of H_2 react with exactly 1 molecule of N_2 and make exactly 2 molecules of NH_3 or:

$$3 \text{ molecules } H_2 + 1 \text{ molecule } N_2 \equiv 2 \text{ molecules } NH_3$$

- Since we count molecules by moles:

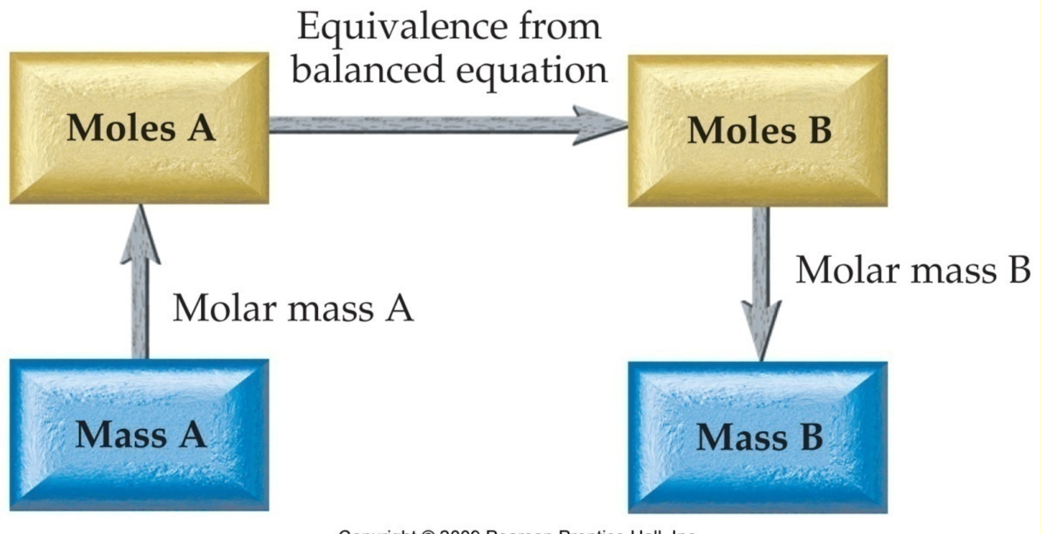
$$3 \text{ moles } H_2 + 1 \text{ mole } N_2 \equiv 2 \text{ moles } NH_3$$

Making Molecules
Mass-to-Mass Conversions

- We know there is a relationship between the mass and number of moles of a chemical.

  1 mole = Molar Mass in grams.

- The molar mass of the chemicals in the reaction and the balanced chemical equation allow us to convert from the amount of any chemical in the reaction to the amount of any other.



Practice—How Many Moles Are in 50.0 g of PbO_2? (Pb = 207.2, O = 16.00)

Given: **Find:**	50.0 g mol PbO_2 moles PbO_2
Solution Map: **Relationships:**	g PbO_2 $\xrightarrow{\frac{1\,\text{mol PbO}_2}{239.2\,\text{g}}}$ mol PbO_2 1 mol PbO_2 = 239.2 g $\begin{array}{lcll} \text{Pb} & = & 1\times & 209.2\,\text{amu} \\ \underline{\text{O}} & = & \underline{2\times} & \underline{16.00\,\text{amu}} \\ \text{PbO}_2 & = & & 239.2\,\text{amu} \end{array}$
Solution:	$$50.0\,\cancel{\text{g}}\,\text{PbO}_2 \times \frac{1\,\text{mol}}{239.2\,\cancel{\text{g}}}$$ $$= 0.20903\,\text{mol} = 0.209\,\text{mol PbO}_2$$
Check:	Since the given amount is less than 239.2 g, the moles being < 1 makes sense.

Acid–Base Reactions

- Also called **neutralization reactions** because the acid and base neutralize each other's properties.
- In the reaction of an acid with a base, the H^{+1} from the acid combines with the OH^{-1} from the base to make water.
- The cation from the base combines with the anion from the acid to make the salt.

acid + base → salt + water

$$2\ HNO_3(aq) + Ca(OH)_2(aq) \rightarrow Ca(NO_3)_2(aq) + 2\ H_2O(l)$$

- The net ionic equation for an acid-base reaction often is:

$$H^{+1}(aq) + OH^{-1}(aq) \rightarrow H_2O(l)$$

  – As long as the salt that forms is soluble in water.

Practice
Balancing Acid–Base Reactions.

$NH_4OH(aq) + H_2SO_4(aq) \rightarrow$

$(NH_4)_2SO_4(aq) + 2\ H_2O(l)$

$Al(OH)_3(aq) + H_2SO_3(aq) \rightarrow$

$Al_2(SO_3)_3(s) + 6\ H_2O(l)$

$Ba(OH)_2(aq) + H_2SO_4(aq) \rightarrow$

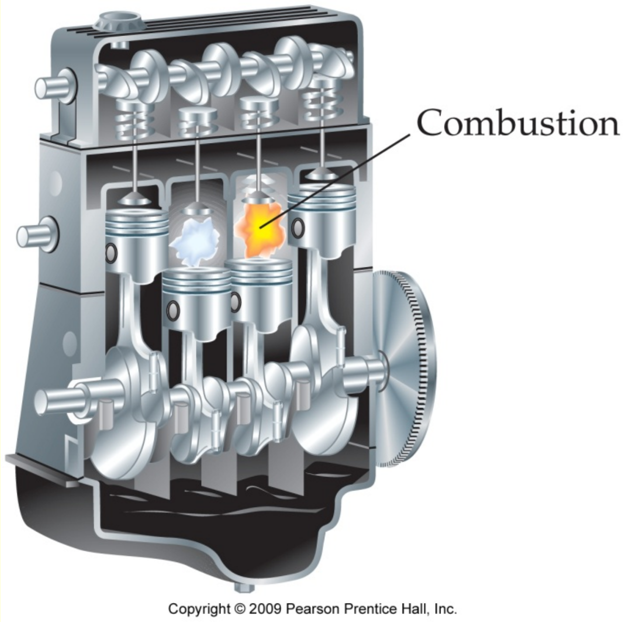
$BaSO_4(s) + 2\ H_2O(l)$

Oxidation–Reduction Reactions

- We say that the element that loses electrons in the reaction is **oxidized**.
- And the substance that gains electrons in the reaction is **reduced**.
- You cannot have one without the other.
- In combustion, the O atoms in O_2 are reduced, and the non-O atoms in the other material are oxidized.

Combustion Reactions

- Reactions in which $O_2(g)$ is a reactant are called **combustion reactions**.
- Combustion reactions release lots of energy. They are **exothermic.**
- Combustion reactions are a subclass of oxidation–reduction reactions.



$$2\ C_8H_{18}(g) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(g)$$

Synthesis Reactions

- Also known as **composition** or **combination** reactions.
- Two (or more) reactants combine together to make **one product**.
  - Simpler substances combining together.

$$2\ CO + O_2 \rightarrow 2\ CO_2$$

$$2\ Mg + O_2 \rightarrow 2\ MgO$$

$$HgI_2 + 2\ KI \rightarrow K_2HgI_4$$

Decomposition Reactions

- A large molecule is broken apart into smaller molecules or its elements.
  - Caused by addition of energy into the molecule.
- **Have only one reactant**, make 2 or more products.

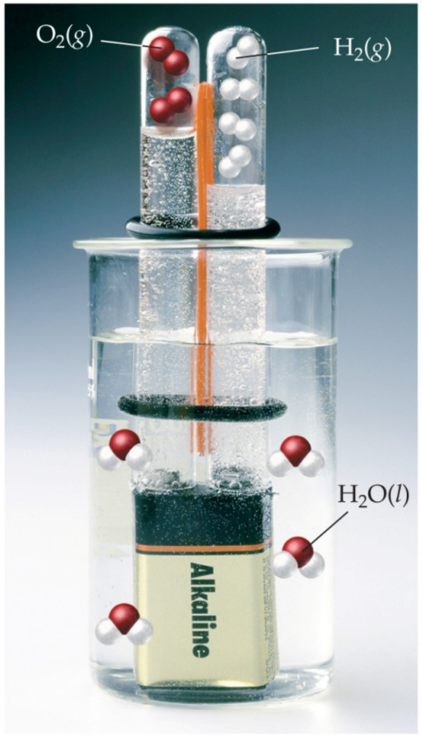
$$2\,FeCl_3(s) \xrightarrow{elec} 2\,FeCl_2(l) + Cl_2(g)$$

$$2\,HgO(s) \xrightarrow{\Delta} 2\,Hg(l) + O_2(g)$$

$$2\,O_3 \xrightarrow{h\upsilon} 3\,O_2$$

Decomposition of Water

$$2\,H_2O(l) \xrightarrow{\text{elec}} 2\,H_2(g) + O_2(g)$$

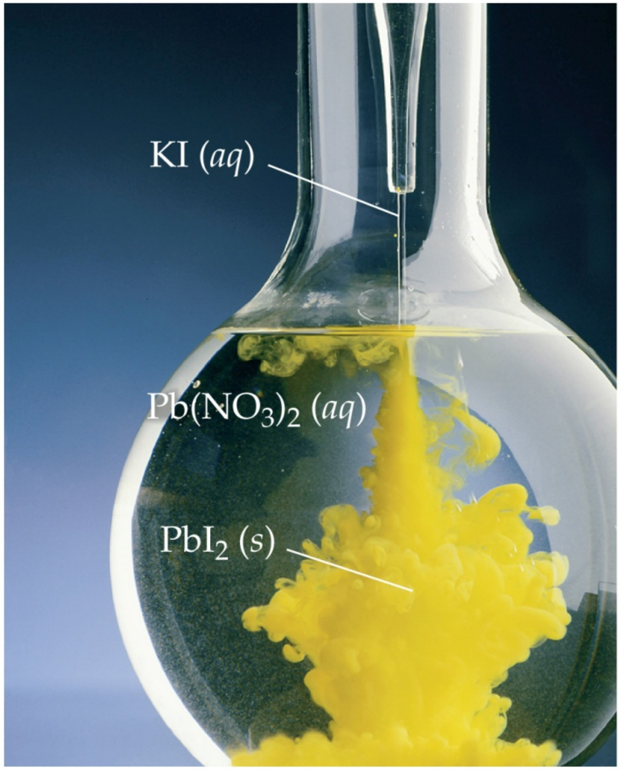


Precipitation Reactions

- Many reactions take place when aqueous solutions of electrolytes are mixed together.
- Often a reaction will take place between the cations and anions in the two solutions that are exchanging.
- If the ion exchange results in the formation of a compound that is insoluble in water, it will come out of solution as a **precipitate**.

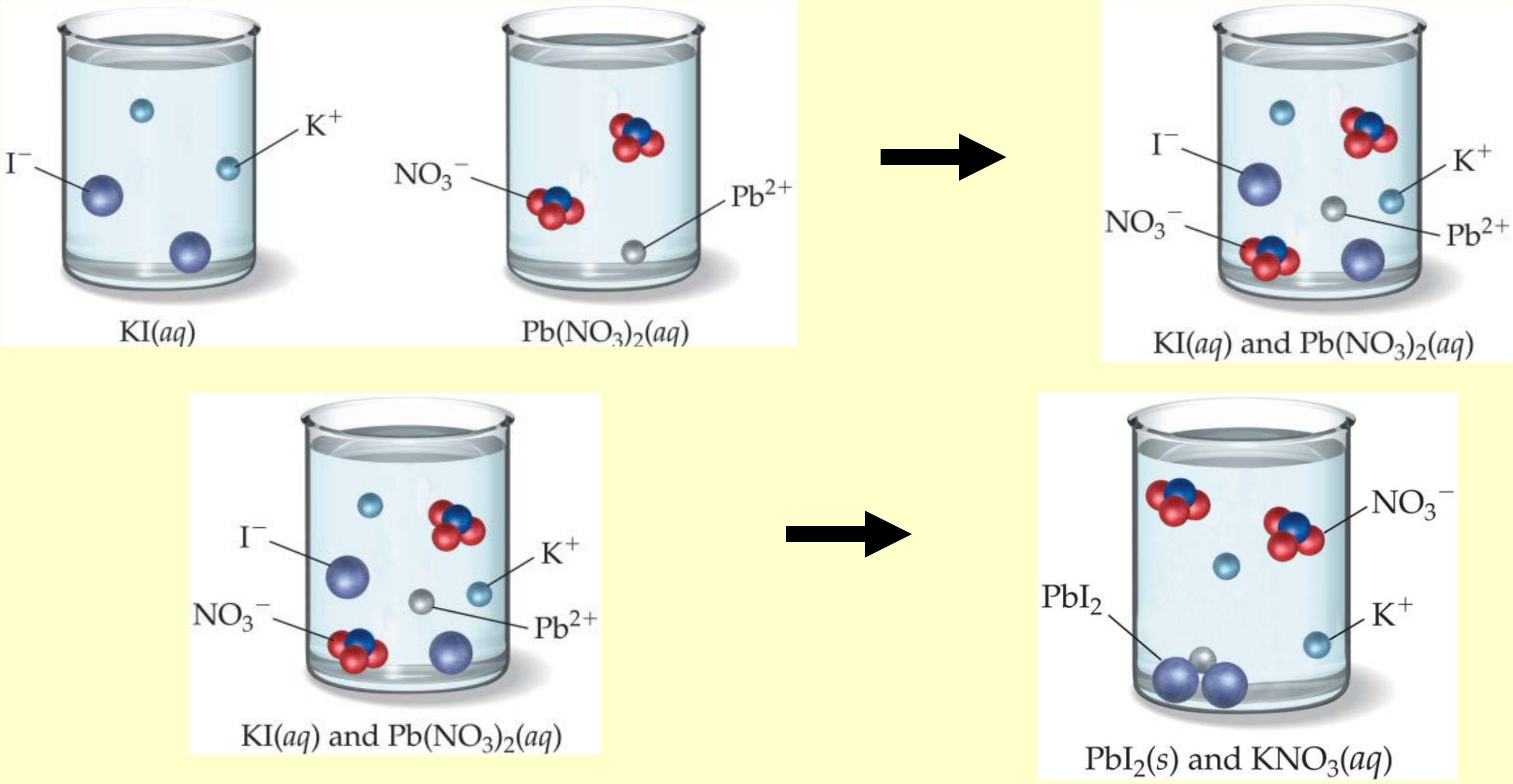
Precipitation Reactions, Continued

$$2\ KI(aq) + Pb(NO_3)_2(aq) \rightarrow 2\ KNO_3(aq) + PbI_2(s)$$



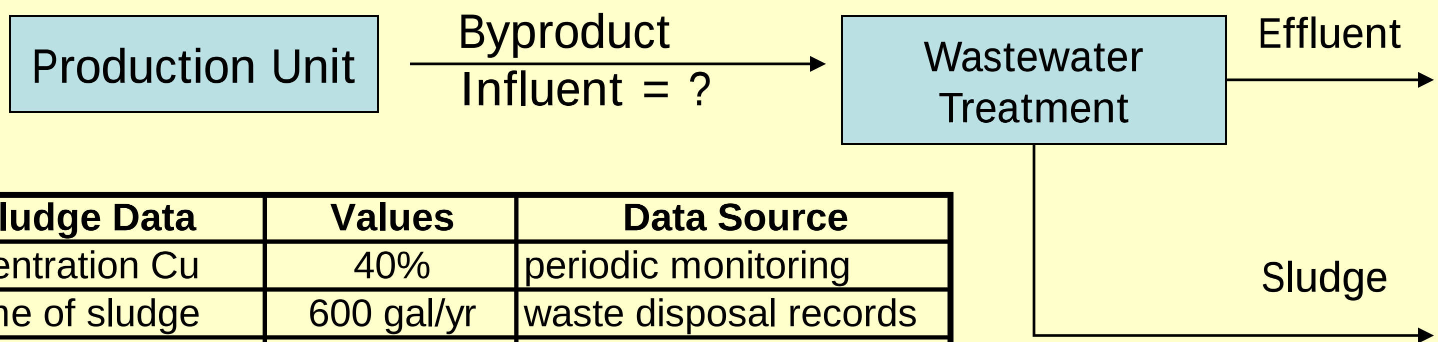
Precipitation Reactions, Continued

$$2\ KI(aq) + Pb(NO_3)_2(aq) \rightarrow 2\ KNO_3(aq) + PbI_2(s)$$



Problem: Calculating Byproduct from Treatment Records

Calculate the annual byproduct generation of copper



Sludge Data	Values	Data Source
concentration Cu	40%	periodic monitoring
volume of sludge	600 gal/yr	waste disposal records
density of sludge	30 lb/gal	lab results
Effluent Data		
Cu conc. in effluent	2.8 ppm	monitoring
avg flow of effluent	0.03 MGD	POTW, flow meter

Assumptions

Concentration by weight

Volume includes all constituents, not just copper

Production time is 255 days/year

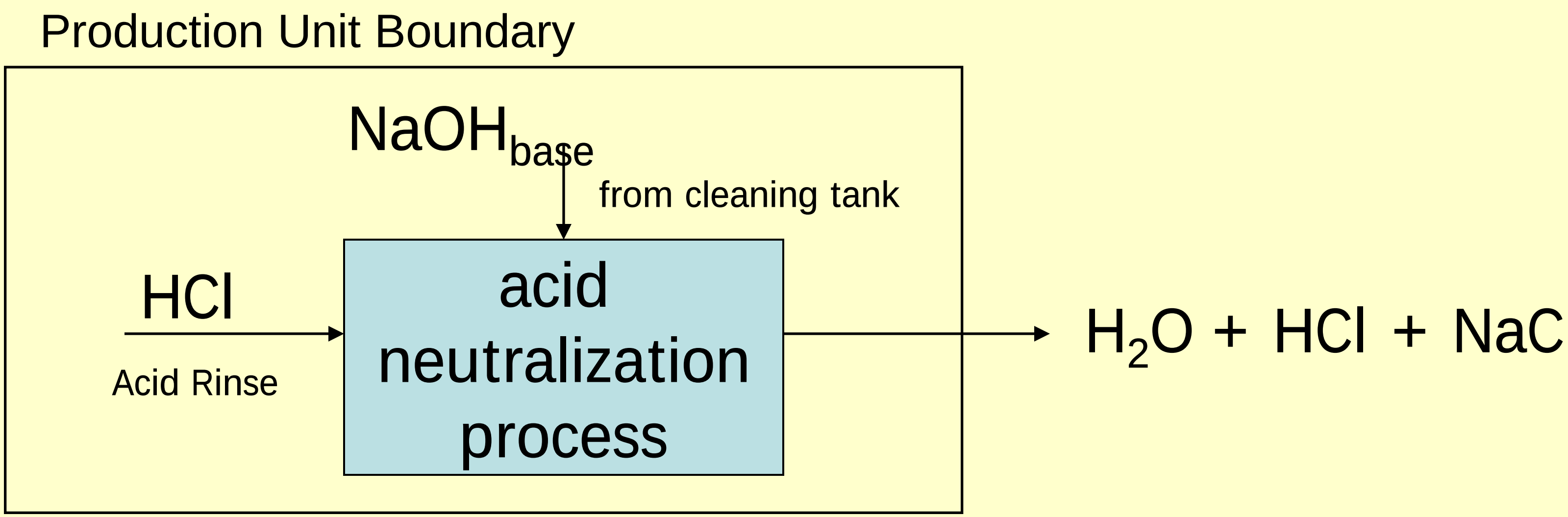
Problem: Material Accounting Using Air Monitoring Data

Pete's Pretty Good Poisons operates a vent to collect the vapors from a hexane manufacturing process. Measurements show the gas flow rate to be 85 ft^3/hr. The average concentration of the hexane is 10,000 ppm. The molecular weight of hexane is 86.2 gram/mole. Assume standard temperature and pressure.

(a) Calculate the concentration of hexane in the vent gas in lb/ft^3.

(b) Calculate the annual emissions into the neighboring residential area in pounds, if the operation ran 12 hours a day for 355 days a year.

Example: Byproduct from a Known Reaction

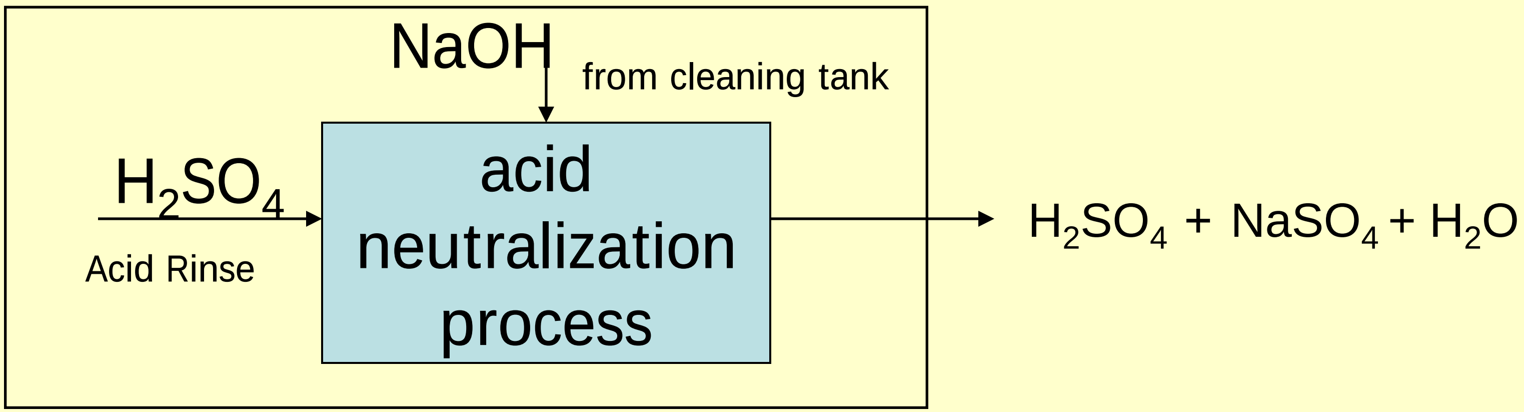


Determine the resulting byproduct if 1500 lb of NaOH is added to:
(1) 15,000 pounds of HCl

	Quantity added (lb)	**M.W. (lb/lb-mol)**
Base (NaOH)	1500	40
Acid (HCl)	15,000	36.5

Problem: Byproduct from a Known Reaction

Production Unit Boundary



Determine the resulting byproduct if 1500 lb of NaOH is added to:

(1) 13,000 pounds of H_2SO_4

	Quantity added (lb)	**M.W. (lb/lb-mol)**
Base (NaOH)	1500	40
Acid (H_2SO_4)	13,000	98.1

Units and Conversions

Quantity	SI Unit	Abbreviation	Alternate	English Unit	Conversion	
Length	meter	m	cm	foot	ft * 0.3048	m * 3.280
Mass	kilogram	kg	g	slug	slug * 14.59	kg * 0.06852
Time	second	s	s	second	1	1
Temp	degree Celsius	°C	°K	°F	(°F-32)*5/9	(°C *9/5) + 32
Volume	liter	L	m^3	ft3	ft^3 * 28.32	L * 0.03531
Volume	liter	L	cm^3	gallon	gal * 3.785	L * 0.264
Weight	newton	N	kg-m/s^2	lb_m-ft/s^2	lb_m-ft/s^2 * 0.1383	N * 7.233
Pressure	atmosphere	atm	N/m^2	lb/in^2 (psi)	psi * 0.06805	atm * 14.70
Density		kg/m3		lb/gal	lb/gal * 119.8	kg/m3 * 0.008345
Energy	newton-meter	N-m	joule	BTU	BTU(IT) * 1055.	N-m * 0.0009478
Power	watt	W	J/s	hp	BTU * 745.7	W * 0.001341