CHAPTER 3
COMPOSITION OF SUBSTANCES AND SOLUTIONS

3

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Formula Mass And The Mole Concept [3.1]

$$\frac{2\ H\ atom}{} \bullet \frac{1\ amu}{1\ H\ atom} = 2\ amu$$

$$\frac{1\ O\ atom}{} \bullet \frac{16\ amu}{1\ O\ atom} = 16\ amu$$

$$= 18\ amu$$

shorthand

H_2O

2H = 2 (1) = 2 amu
1O = 1 (16) = 16 amu
18 amu

H_2O_2

2H = 2 (1) = 2 amu
1O = 2 (16) = 32 amu
34 amu

NaCl (ionic: use empirical formula

1Na = 1 (22.99) = 22.99 amu
1Cl = 1 (35.45) = 35.45 amu
58.44 amu

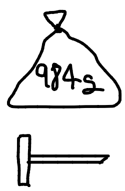
BASIS OF KEY FUTURE CHAPTER 4 TOPIC: STOICHIOMETRY

$$\underset{\square\,g}{2H_2} + \underset{128\,g}{O_2} \longrightarrow \underset{\square\,g}{2H_2O}$$

(2) Scale Up

(1) Count-by-Weighting

Count-by-Weighing: The Concept

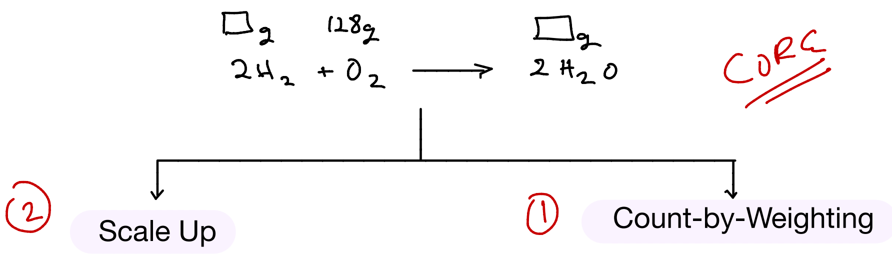


1 nail = 12 g

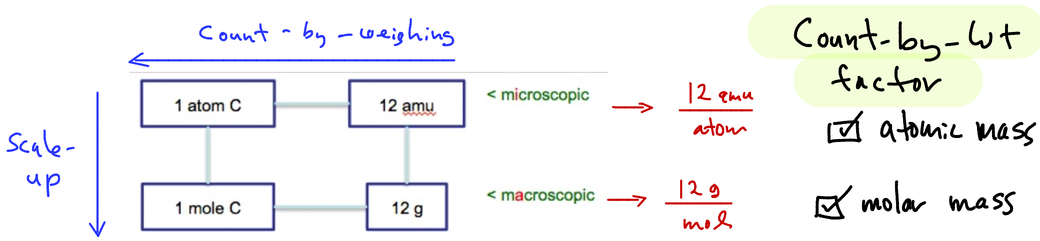
$$\frac{\square\, nails}{1} = \frac{984\ \cancel{g}}{} \Big| \frac{1\ nails}{12\ \cancel{g}} = 82\ nails$$

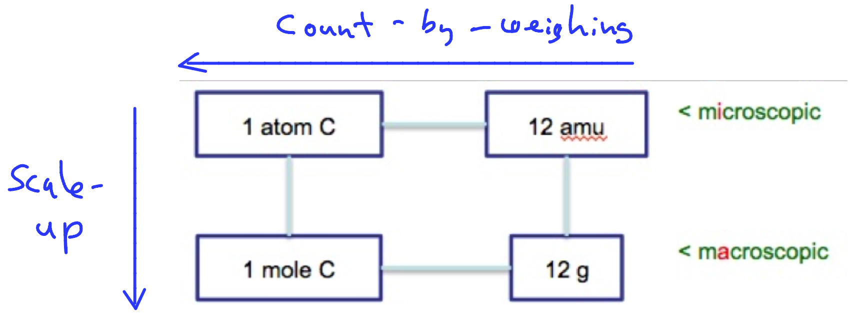
$$\frac{\square\, nails}{1} = \frac{984\ g}{1} \cdot \frac{1\ nail}{12\ g} = \frac{82\ nails}{1}$$

WEIGHT · CF (Conversion Factor) · COUNT



Scale-Up and Count-by-Weighing: The Mole, Molar Mass, and Avogadro's Number





Scale-up Factor: Avogadro's Number (6.02E23)

$$scale\ up\ factor = \frac{6.02E23\ items}{mole}$$

$$= \frac{6.02 \times 10^{23}\ items}{mole}$$

$$small\ scale\ up\ factor = \frac{12\ items}{dozen}$$

Count-by-Weight Factor: Molar Mass

↳ mass of 1 mole of a substance
↳ mass of 6.02E23 parts of a substance

↓ ASIDE ↓

FACTOIDS

① "Mole" derives from word meaning "mass," but it refers to the number of "particles" or "bits" or "pieces" or "entities" of mass
② Mole is one of 7 fundamental SI units
③ Definition: amount of material "discrete entities" as the number in exactly 12 g of Carbon of Carbon-12
④ N_A = AN = Avagadro's Number = 6.022×10^{23}

$$\frac{6.022\ x\ 10^{23}\ entities}{1\ mol}\ or\ \frac{1\ mol}{6.022\ x\ 10^{23}\ entities}$$

⑤ Mole is just a number with a name, just like the number 12

$$\frac{6.022\ x\ 10^{23}\ entities}{1\ mol}\ vs\ \frac{12\ entities}{1\ dozen}$$

Just how large is a 'mole' of something

$$
\begin{aligned}
1\ \textit{mole of stacked pennies} &= \textit{to moon and back} \ldots 100\ \textit{million times} \\
1\ \textit{mole of seconds} &= 1\ \textit{million ages of the supposed age of the universe} \\
1\ \textit{mole of human cells} &= 6\ \textit{billion people} \\
1\ \textit{mole of sand} &= \textit{cover entire USA} \ldots 2.4\ \textit{inches deep}
\end{aligned}
$$

Tue 9/17

$$? \ age = \frac{6.02E23\ s}{} \bullet \frac{1\ \text{min}}{60\ s} \bullet \frac{1\ hr}{60\ \text{min}} \bullet \frac{1\ day}{24\ hr} \bullet \frac{1\ yr}{365\ day} \bullet \frac{1\ age}{2E16\ yr} = 954,465\ ages$$

$$? \ humans = \frac{6.02E23\ cells}{} \bullet \frac{1\ body}{\underset{[100 trillion]}{100E12\ cells}} = \underset{[6 billion]}{6E9\ humans}$$

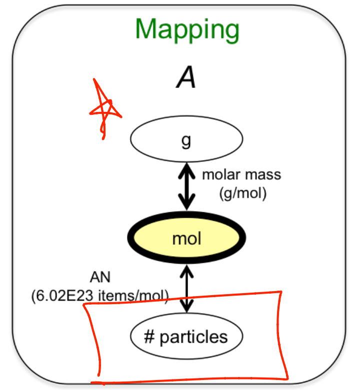
$$? \ in = \frac{6.02E23\ grains}{} \bullet \frac{10^{-12}\ m^3}{1\ grain} \bullet \frac{1\ USA}{10^{13}\ m^2} \bullet \frac{100\ cm}{1\ m} \bullet \frac{1\ in}{2.54\ cm} = 2.37\ in$$

↑ ASIDE ↑

USING MOLAR MASS AND AVOGADRO'S NUMBER IN "g–mole–particles" CALCULATIONS

(EX) g —> atoms
¿How many copper atoms are in 5.00 g of copper wire?

[Whitten ex 3.5]



$$\frac{\square\ atoms\ Cu}{1} =$$

(CF)(given)

$$\frac{\square\ atoms\ Cu}{1} = \frac{5.00\ g\ Cu}{1} \cdot$$

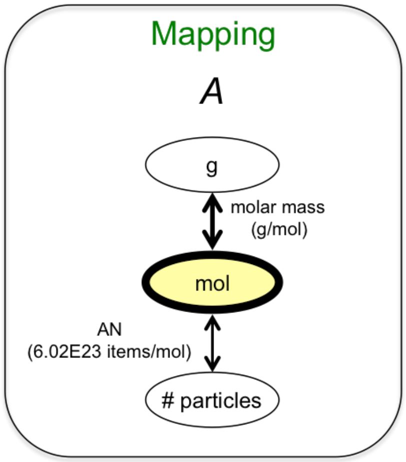
$$\frac{\square\ atoms\ Cu}{1} = \frac{5.00\ g\ Cu}{1} \cdot \frac{1\ mole\ Cu}{63.55\ g\ Cu} \cdot$$

$$\frac{\square\ atoms\ Cu}{1} = \frac{5.00\ g\ Cu}{1} \cdot \frac{1\ mole\ Cu}{63.55\ g\ Cu} \cdot \frac{6.023E23\ atoms\ Cu}{1\ mol\ Cu}$$

$$\frac{\square\ atoms\ Cu}{1} = \frac{5.00\ g\ Cu}{1} \cdot \frac{1\ mole\ Cu}{63.55\ g\ Cu} \cdot \frac{6.023E23\ atoms\ Cu}{1\ mol\ Cu} = \frac{4.74E22\ atoms\ Cu}{1}$$

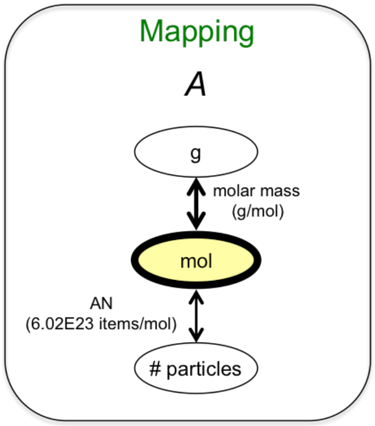
Flight Path Analogy

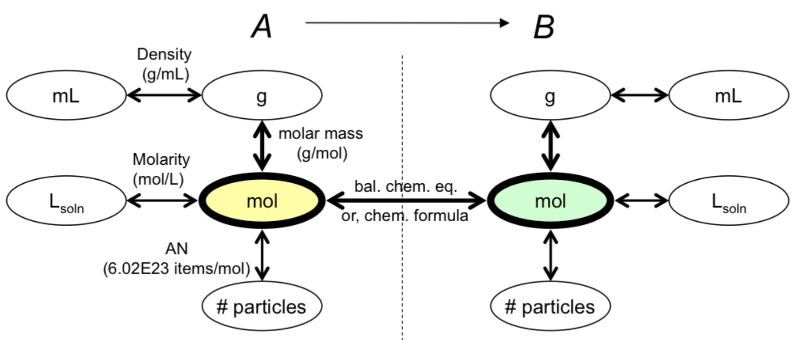
- start @ 5.00 g,Cu
- depart g,Cu —> arrive mol,Cu
- depart mol,Cu —> arrive # particles, Cu (your destinaton)

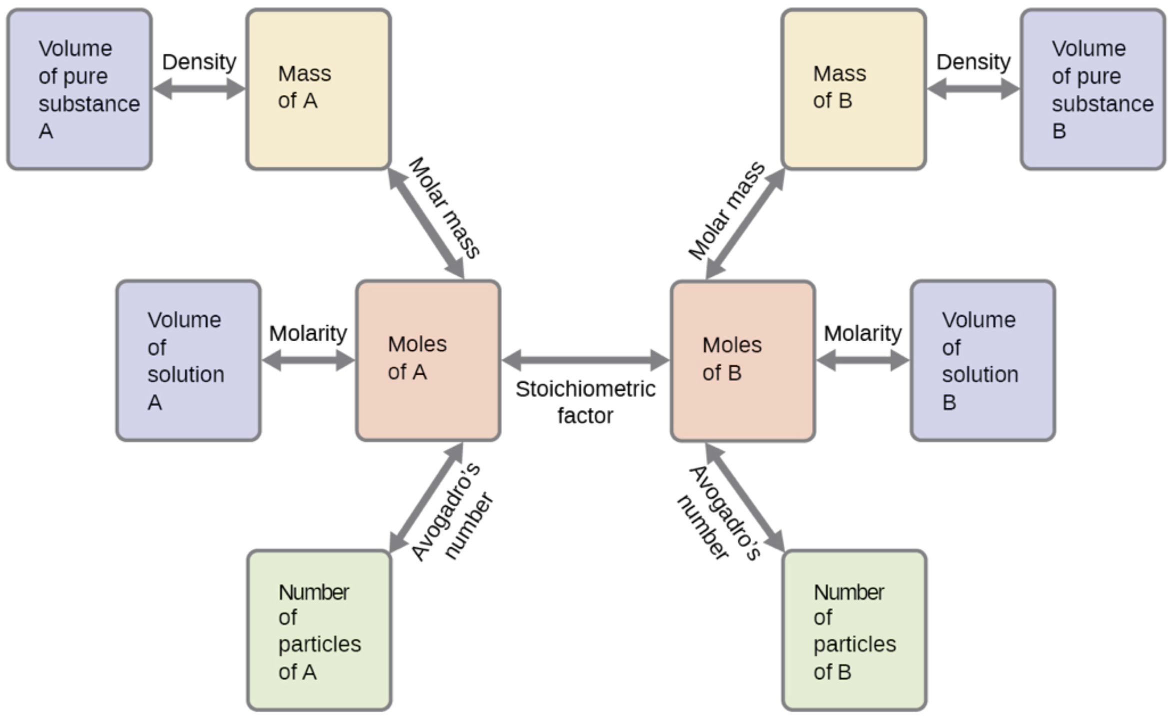


$$\frac{\square\ atoms\ Cu}{1} = \frac{5.00\ g\ Cu}{1} \cdot \frac{1\ mole\ Cu}{63.55\ g\ Cu} \cdot \frac{6.023E23\ atoms\ Cu}{1\ mol\ Cu} = \frac{4.74E22\ atoms\ Cu}{1}$$

LOOKING AHEAD INTO CHAPTER 04:
Why you need to fully understand g–mol–particle calculations



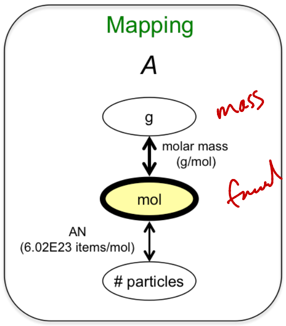




Volume of pure substance A
Density
Mass of A
Mass of B
Density
Volume of pure substance B
Molar mass
Molar mass
Volume of solution A
Molarity
Moles of A
Stoichiometric factor
Moles of B
Molarity
Volume of solution B
Avogadro's number
Avogadro's number
Number of particles of A
Number of particles of B

(EX) molecules —> gram

¿How many grams are there in 9.545E22 molecules of butane ($C4H8$) ?



$$\frac{\square\ g\ Bu}{1} = \frac{9.545E22\ molecules\ Bu}{1} \cdot \frac{1\ mole\ Bu}{6.022E23\ molecules\ Bu} \cdot \frac{???\ g\ Bu}{1\ mol\ Bu} = \frac{\square\ g\ Bu}{1}$$

1 mol C_4H_2

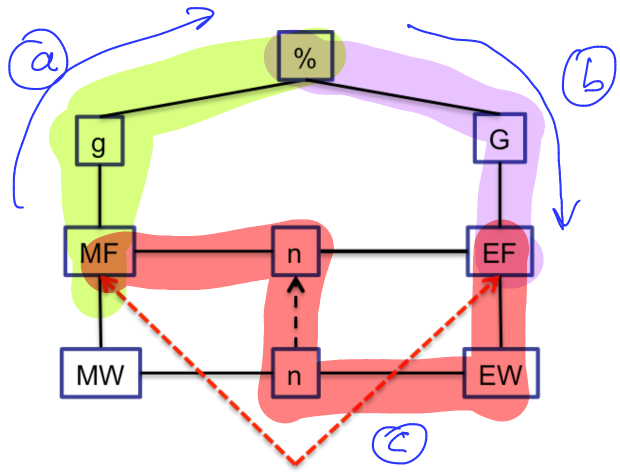
4C = 4 (12.01) = 48.04 g

10H = 10 (1.01) = 10.01 g

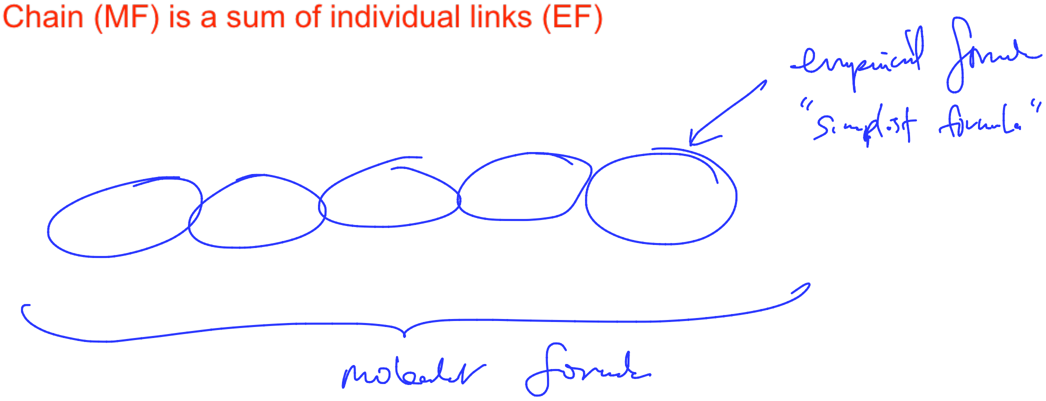
58.05 g

$$\frac{\square\ g\ Bu}{1} = \frac{9.545E22\ molecules\ Bu}{1} \cdot \frac{1\ mole\ Bu}{6.022E23\ molecules\ Bu} \cdot \frac{58.05\ g\ Bu}{1\ mol\ Bu} = \frac{9.201\ g\ Bu}{1}$$

Determining Empirical And Molecular Formulas [3.2]



Chain (MF) is a sum of individual links (EF)



$\%H = \frac{2.02}{34.0} = 5.9\%\ H$ (g)

$\%O = \frac{32.0}{34.0} = 94.1\%\ O$ (g)

assume 100 g sample

"% → g"

$\frac{2H \mid 1.01\ g}{1\ H\ mol} = 2.02\ g\ H$

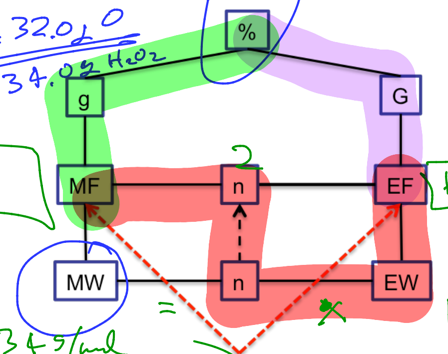
$\frac{2\ mol\ O \mid 16.0}{1\ mol\ O} = 32.0\ g\ O$

34.0 g H_2O_2

$\frac{5.9\ g\ H \mid 1\ mol\ H}{1.0\ g\ H} = 5.9\ mol\ H$

$\frac{94.1\ g\ O \mid 1\ mol\ O}{16\ g\ O} = 5.9\ mol\ O$

H_2O_2 (molar)



Chain (MF) is a sum of individual links (EF)

HO

34 g/mol = 17 g/mol

$H_{5.9}O_{5.9}$

÷ x

$H_{5.9}O_{5.9}$ / 5.9 → H_1O_1 → HO

H_2O — HO HO

$H_1X_{1.25}$

$H_1X_{1.3}$ → $H_3X_{3.9}$ → H_3X_4

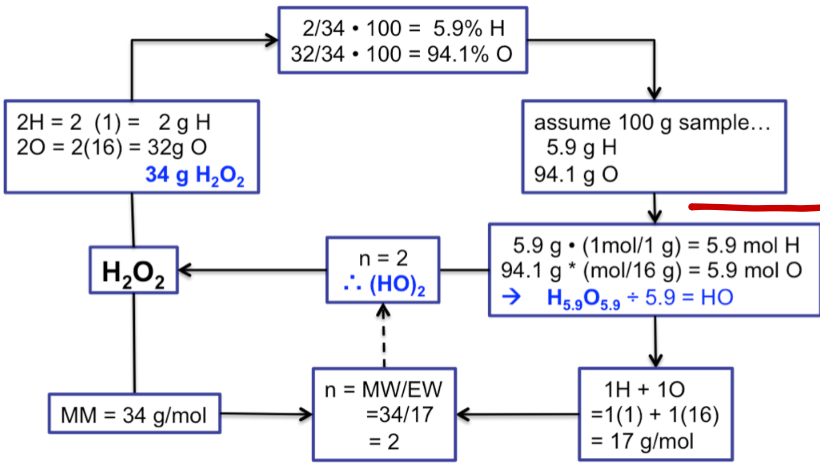
$H_1X_{1.5}$ ×2 → H_2X_3

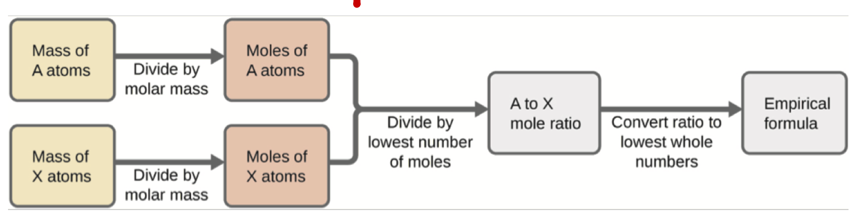
$$\% = \frac{part}{whole} \times 100$$

"$(HO)_2$" → H_2O_2

PERCENT COMPOSITION

↳ Determining Percent Composition from Formula Mass
↳ Deriving Empirical Formulas from Percent Composition
↳ Deriving of Molecular Formulas (MM given)

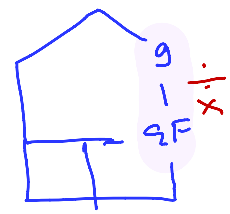




(EX) g —> EF

¿A sample of the black mineral hematite (Figure 3.12), an oxide of iron found in many iron ores, contains 34.97 g of iron and 15.03 g of oxygen. What is the empirical formula of hematite?

[ex 3.11b]



ⓐ Fe_xO_y

ⓑ Fe: $\frac{34.97\text{g}}{} \Big| \frac{1\text{ mol}}{55.85\text{g}} = \frac{0.6261}{0.6261} = 1.000$ → (×2) 2.000

O: $\frac{15.03\text{g}}{} \Big| \frac{1\text{ mol}}{16.00\text{g}} = \frac{0.9394}{0.6261} = 1.500$ → (×2) 3.000

Fe_2O_3

(EX) Wt% —> MF

¿What is the molecular formula of a compound with a percent composition of 49.47% C, 5.201% H, 28.84% N, and 16.48% O, and a molecular mass of 194.2 amu?

assume 100g (Intensive property)

(a) $C_xH_yN_zO_n$

(b)

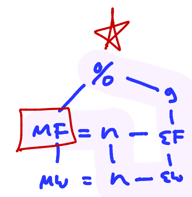
C: $\frac{49.47\,g \mid 1}{\mid 12.01\,g} = \frac{4.119}{1.030} = 4.000$

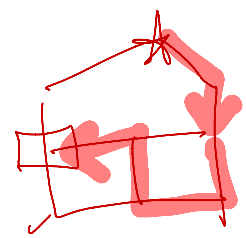
H: $\frac{5.201\,g \mid 1}{\mid 1.01\,g} = \frac{5.150}{1.030} = 5.000$

N: $\frac{28.84\,g \mid 1}{\mid 14.01\,g} = \frac{2.059}{1.030} = 2.000$

O: $\frac{16.48\,g \mid}{\mid 16.00\,g} = \frac{1.030}{1.030} = 1.000$

$C_4H_9N_2O$





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CHEM 1411 Lecture Schedule

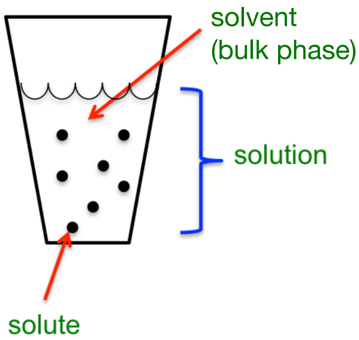
CHEM 1411 **Fall 2019**
v1 **Dr. Stephenson**

Class	Day	Date	Chapter/Section	Description
1	T	27-Aug	1.1-1.3	Matter, Physical and Chemical Properties
2	R	29-Aug	1.4-1.5	Measurements, Accuracy/Precision
3	T	3-Sep	1.6	Dimensional Analysis
4	R	5-Sep	2.1-2.3	Atomic Theory and Structure
5	T	10-Sep	2.4-2.5	Formulas and the Periodic Table
6	R	12-Sep	2.6-2.7	Molecular and Ionic Compounds, Nomenclature
7	T	17-Sep	3.1	Formula mass and The Mole
8	R	19-Sep	3.2-3.3	Empirical and Molecular Formulas, Molarity
9	T	24-Sep	3.4	Solution Concentrations
10	R	26-Sep		Exam 1
11	T	1-Oct	4.1-4.2	Balancing Equations; Ionic & Acid-Base Reactions
12	R	3-Oct	4.2-4.3	Redox; Stoichiometry
13	T	8-Oct	4.4-4.5	Reaction Yields; Quantitative Chemical Analysis
14	R	10-Oct	5.1-5.2	Energy and Calorimetry
15	T	15-Oct	5.3	Enthalpy
16	R	17-Oct	6.1	Electromagnetic Energy
17	T	22-Oct	6.2-6.3	Bohr Model and Quantum Theory
18	R	24-Oct	6.4-6.5	Quantum Numbers & Electronic Structure
19	T	29-Oct	6.5	Periodic Variations
20	R	31-Oct		Exam 2
21	T	5-Nov	7.1-7.3	Lewis Symbols and Structures
22	R	7-Nov	7.4	Formal Charge and Resonance
23	T	12-Nov	7.6	Molecular Structure and Polarity
24	R	14-Nov	8.1-8.3	Valance Bond Theory, Hybrid Orbitals, and Multiple Bonds
25	T	19-Nov	9.1-9.2	Gas Pressure and The Ideal Gas Law
26	R	21-Nov	9.3-9.4	Stoichiometry of Gases, Effusion/Diffusion of Gases
27	T	26-Nov	9.5-9.6	Kinetic-Molecular Theory and Non-Ideal Gas Behavior
	R	28-Nov		Thanksgiving Holiday
28	T	3-Dec		Exam 3
29	R	5-Dec		Final Exam Review
30		TBA		Final Exam

Note: Schedule is subject to change.
Last Day to drop with a "W" is April 1st

Molarity [3.3]

Solution: Beyond the "Homogeneous Mixture" Definition



$$M = \frac{mol_{solute}}{L_{solution}} = \frac{mmol_{solute}}{mL_{solution}}$$

KEY OBSERVATIONS
① Analogous to D=m/V
② can use DA

A very usefull form of the M = mol/L equation

$$M = \frac{mol_{solute}}{L_{solution}} \longrightarrow mol = M \cdot L$$

Three common types of Molarity problems

- ↳ Calculate Molarity from g
- ↳ Calculate g from Molarity (a stoichiometry problem in which M serves as CF)
- ↳ Dilution/Concentration ($M_1V_1 = M_2V_2$)

(EX) Calc M from g

¿Calculate molarity for a solution of 3.65 g HCl in 2.00 L of solution?

$$? \frac{mol_{HCl}}{L_{soln}} = \frac{3.65\ g_{HCl}}{1} \bullet \frac{1\ mol_{HCl}}{36.5\ g_{HCl}} \bullet \frac{1}{2.00\ L_{soln}} = 0.500\ \frac{mol_{HCl}}{L_{soln}} = 0.500\ M$$

$M = \frac{mal}{I}$

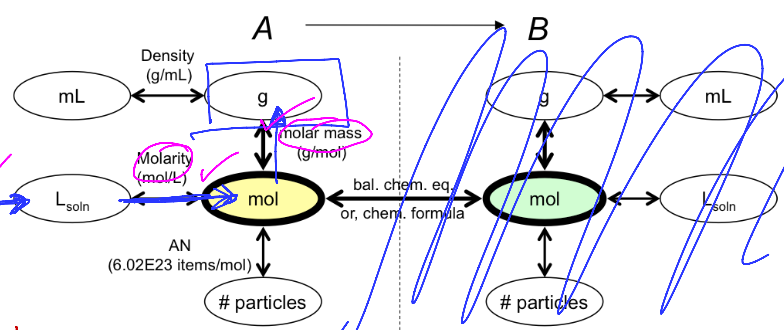
↑ ↑

$M = 0.5\bar{M}_o$

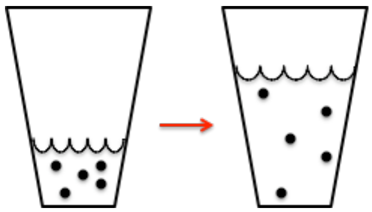
(EX) Use M to calc g (merely a Stoichiometry problem, using M as a CF)

¿How many grams of CaCl2 (MM = 110.98 g/mol) are contained in 250.0 mL of a 0.200 M solution?

$$\square\ g_{CaCl_2} = \frac{250.0\ mL_{CaCl_2}}{1} \bullet \frac{1\ L_{CaCl_2}}{1000\ mL_{CaCl_2}} \bullet \frac{0.200\ mol_{CaCl_2}}{1\ L_{CaCl_2}} \bullet \frac{110.98\ g_{CaCl_2}}{1\ mol_{CaCl_2}} = 5.55\ g$$



Concentration/Dilutions



$$mol\ solute_{(before)} = mol\ solute_{(after)}$$
$$mol_a = mol_b$$
$$M_b \bullet L_b = M_a \bullet L_a$$
$$M_b \bullet V_b = M_a \bullet V_a$$

$$M_b \bullet L_b = M_a \bullet L_a \qquad C_b \bullet V_b = C_a \bullet V_a$$

TOTAL VOL (not VOL "added")

(EX) C•V = C'•V' (calc Vol added)

¿A lab-tech wants to dilute 50. mL of 3.50 M sulfuric acid solution to 2.00 M. ~~(a) To whatvolume must the original solution be diluted?~~ (b) What volume of water (solvent) must be added to the original solution?

$$C_b \bullet V_b = C_a \bullet V_a$$
$$(3.50\ M)(50.0\ mL) = (2.00\ M)V_a$$
$$\frac{(3.50\ M)(50.0\ mL)}{(2.00.\ mL)} = V_a = 87.5\ mL$$

$$V_{total} = V_{initial} + V_{added}$$
$$V_{added} = V_{total} - V_{initial}$$
$$V_{added} = 87.5\ mL - 50.\ mL$$
$$V_{added} = 37.5\ mL$$

Analysis:
2-M's and 1-Vol given, and looking for a 2nd Vol
—> CV=C'V' problem

- Can use any unit of volume, or concentration, but must be consistent on both sides
- Use "M" as unit (but don't confuse with "M" used as variable)

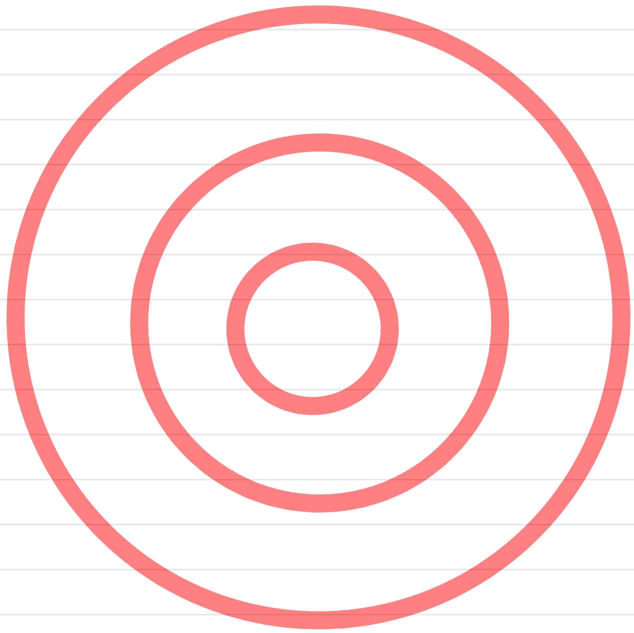
(EX) CV = C'V'
¿How many mL of 18.0 M H_2SO_4 are required to prepare 1.00 L of a 0.900 M solution of H_2SO_4?

Analysis:
2-M's and 1-Vol given, and looking for a 2nd Vol —> CV=C'V' problem

$$M\ V = M'\ V'$$

$$18.0\ x = (0.900)(1.00)$$
$$x = 50.0\ \text{mL}$$

Lecture



Target

Other Units For Solution Concentrations [3.4]

Mass Percentage

PERCENTAGE = % = (part/whole) × 100
= fraction × 100

(EX) Fraction vs. Percent

¿You have 3 red widgets and 17 black widgets. (a) What fraction of red widgets do you have? (b) What percentage of red widgets?

3/20 = 0.15

[3/(3+17)] • 100 = 3/20 • 100 = 0.15 • 100 = 15%

$\left(\frac{15 \text{ part a}}{100 \text{ parts TOTAL}}\right)$ $\left(\frac{57}{100}\right)$ $\left(\frac{100}{57}\right)$

(EX) Wt% of Solution Components

¿A bottle of a tile cleaner contains 135 g [of HCl] and 775 g water. What is the weight percent HCl? [Ex 3.22b]

$$fraction\ HCl = \frac{parts}{whole} = \frac{135 g_{HCl}}{135 g_{HCl} + 775 g_W} = \frac{135 g_{HCl}}{910.\, g_{total}} = 0.148$$

$$\% = fraction \bullet 100 = 0.148 \bullet 100 = 14.8\%$$

(EX) Wt% —> g, vol (harder)
¿What volume of 37.2% HCl solution, which has a density of 1.19 g/mL, contains 125 g of HCl? [Ex 3.23b]

$$? \frac{mL_{SOLN}}{1} = \frac{125\ g_{HCl}}{1} \bullet \frac{100\ g_{SOLN}}{37.2\ g_{HCl}} \bullet \frac{1\ mL_{SOLN}}{1.19\ g_{SOLN}} = 282\ mL_{SOLN}$$

KEY TO SUCCESS: do not confuse "HCl" with "HCl solution"

$$\left(\frac{37.2\ HCl}{100\ \text{pts}\ SOLN}\right)$$

Volume Percentage

(P 157 / 165)

↳ basic formula: (Part / whole) 100
↳ v/v = vol / vol [ex: mL (solute) / mL (solvent)]

Mass-Volume Percentage (Mixed Fractions)

↳ m/v = mass / vol [Ex: g (solute) / mL (solvent)]
↳ blood is reported in μg/deciliter (~ pp 100k)

Parts per Million and Parts per Billion

↳ Analogous to %, which is merely PPH !!
- 27% means 27-out-of-100, or pph

↳ Get pph (% by multiply by 100
ppt " 1000
ppm 1,000,000
ppb 1,000,000,000

(EX) Mass —> ppm

¿A 50.0-g sample of industrial wastewater was determined to contain 0.48 mg of mercury. Express the mercury concentration of the wastewater in ppm.

$$ppm = \frac{pt}{whole} \Big| \frac{10^6\ ppm}{} = \frac{0.48\ mg}{50.0\ g} \Big| \frac{10^6\ ppm}{} \Big| \frac{g}{10^3\ mg} = \boxed{9.6\ ppm}$$

(EX) ppm —> g(solute)

¿A 100. g sample of water is contaminated with 19.2 ppm of mercury. How milligrams of Hg are in the sample? [Ex 3.25z]

$$?\ \frac{mg_{Hg}}{1} = \frac{100.\ g_W}{1} \bullet \frac{19.2\ g_{Hg}}{10^6\ g_W} \bullet \frac{1000\ mg_{Hg}}{1\ g_{Hg}} = 1.92\ mg_{Hg}$$