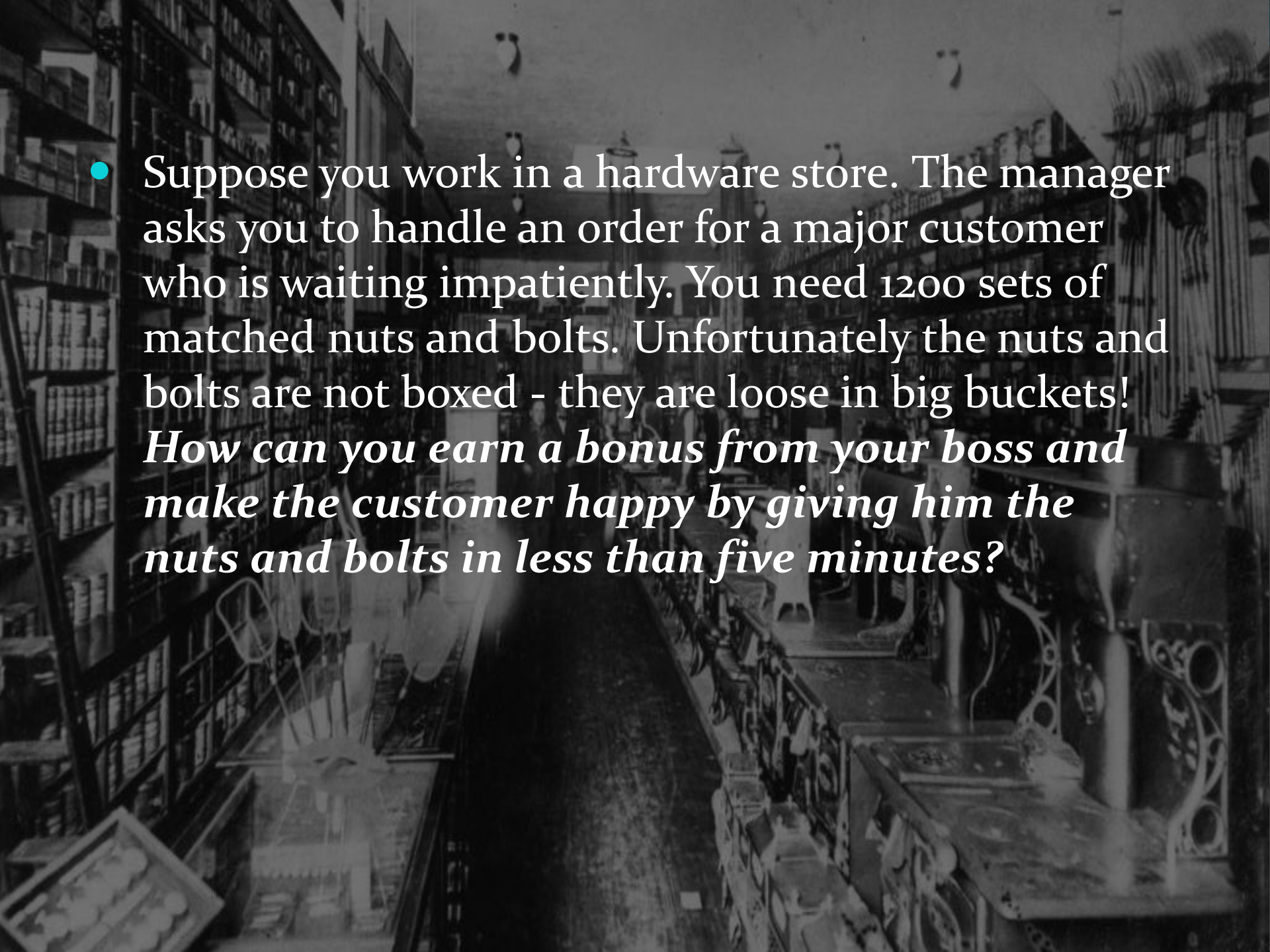
Chapter 3

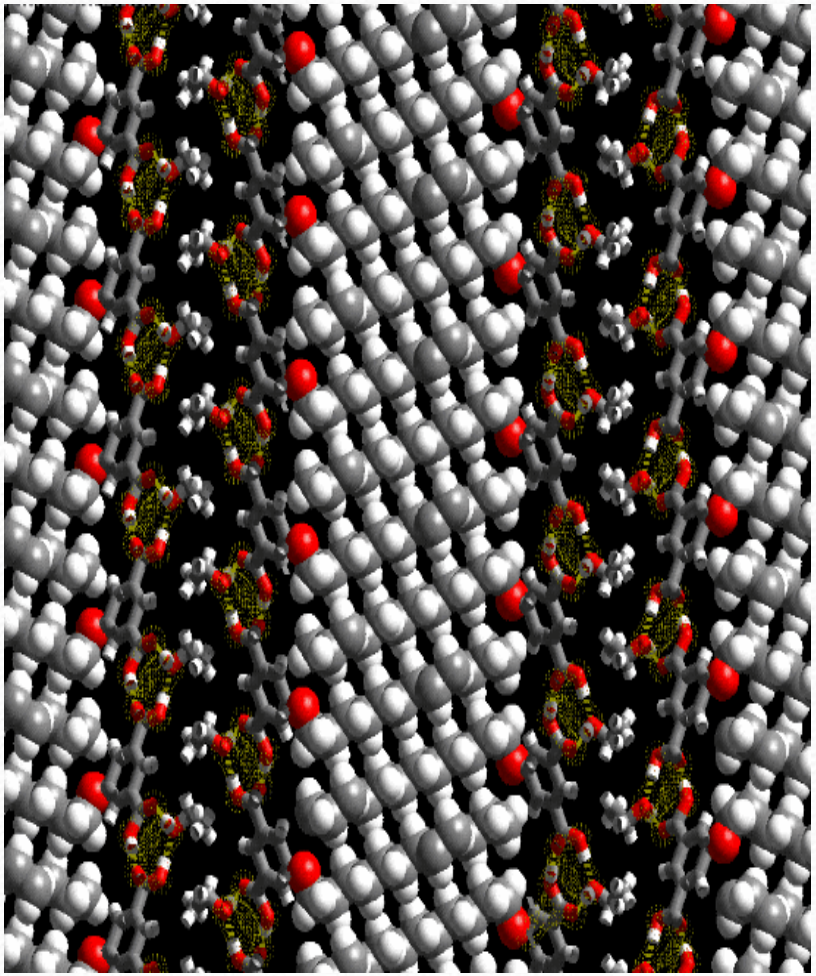
AP Chemistry

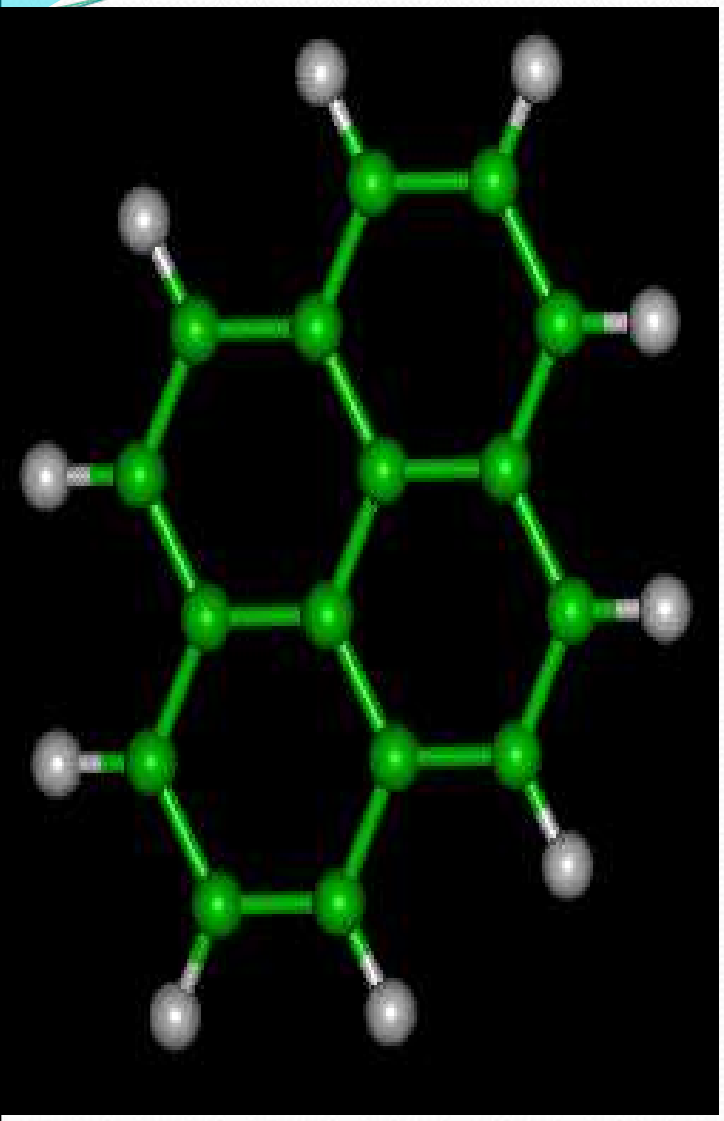


- Suppose you work in a hardware store. The manager asks you to handle an order for a major customer who is waiting impatiently. You need 1200 sets of matched nuts and bolts. Unfortunately the nuts and bolts are not boxed - they are loose in big buckets! ***How can you earn a bonus from your boss and make the customer happy by giving him the nuts and bolts in less than five minutes?***

6.2 Atomic Masses:
Counting atoms by weighing

- We do the same thing with tiny invisible atoms; ***we count by weighing!***
- All of chem. involves finding out **how many** of *these* are needed to react with a **certain number** of *those* to get **so many** of *them*.





- The mass of an atom is **unbelievably** small (e.g. a C atom weighs 1.99×10^{-23} g)
- So kg and g are **out**!
- We need a **new unit** small enough to deal with these tiny guys reasonably
- Chemists use the **atomic mass unit (amu)**
- $= 1.66 \times 10^{-24}$ g
- ***Atoms will weigh so many "amu's"***

Average Atomic Mass

- But all together they can give us an **average mass**
- The **average atomic mass** for hydrogen on this planet is 1.008 **amu** *(all the rest are listed on the PT)*
- Let's act, for the rest of chemistry, as if all atoms have this one average mass, ***the one listed on the Periodic Table…***

- Why isn't the **average** atomic mass of any element **a whole number**?
- (e.g. why isn't C = ***exactly*** 12 amu, O = ***exactly*** 16 amu, Mg = ***exactly*** 24 amu?)

Example

- What is the mass, in amu, of 75 Al atoms?
  (1 Al = 26.98 amu)

$$\frac{75 \text{ atoms}}{1} \times \frac{26.98 \text{ amu}}{1 \text{ atom}} = 2024 \text{ amu}$$

quick quiz

What is the mass (in amu) of a C sample w/ exactly 62 atoms? (1 C = 12.01 amu)
744.6 amu

What's the amu mass of exactly 15 iron atoms? (1 Fe = 55.85 amu)

837.8 amu

Example

- *How many atoms are in 1172.49 amu of Na atoms? (1 Na = 22.99 amu)*

$$1172.49 \text{ amu} \times \frac{1 \text{ Na atom}}{22.99 \text{ amu}} = 51.00 \text{ Na atoms}$$

quick quiz

How many Cu atoms are in a 1779.4 amu sample?

28.00 atoms

How many Ar atoms in 3755.3 amu?

94.00 atoms

Atomic Mass

- The **atomic mass** is an average of the masses of each isotope of a given element.
- The calculated average also takes into consideration the relative abundances of each isotope.

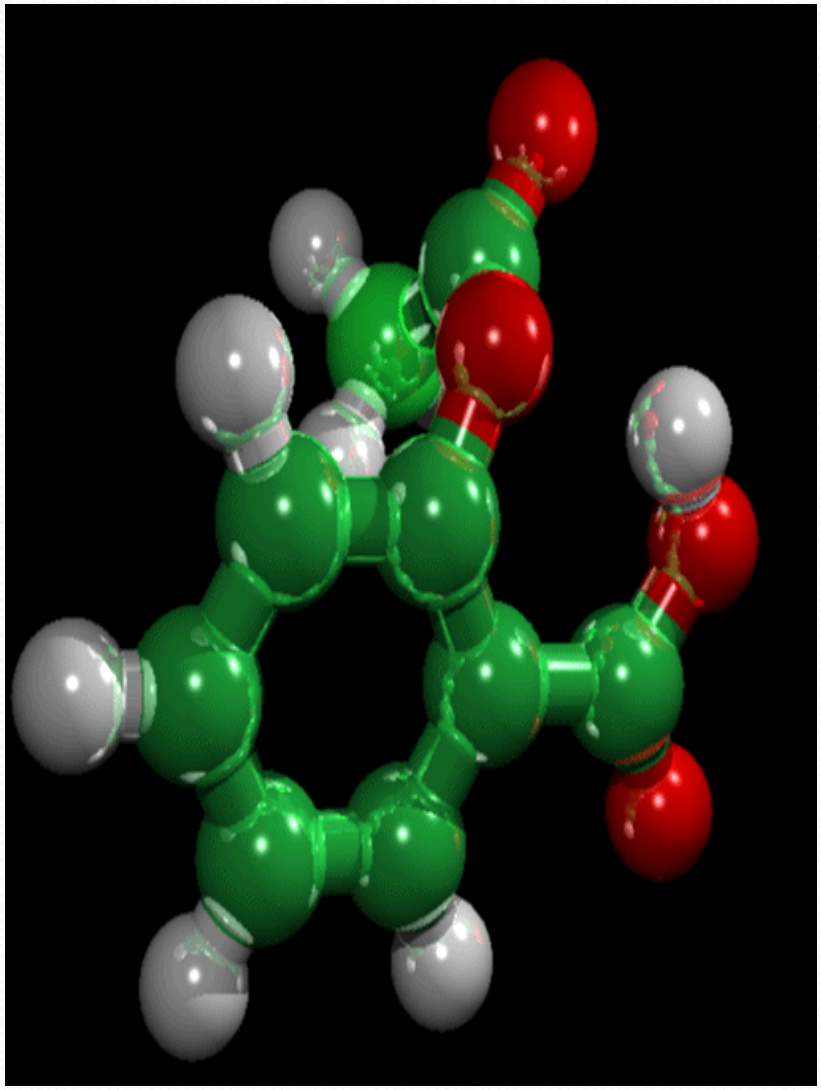
Practice Problem

- Chlorine has 2 natural isotopes.
- Chlorine 35: 35.00 amu, 75% abundance.
- Chlorine 37: 37.00 amu, 25% abundance.
- Calculate the atomic mass.
- 35.5 amu

You Try It!

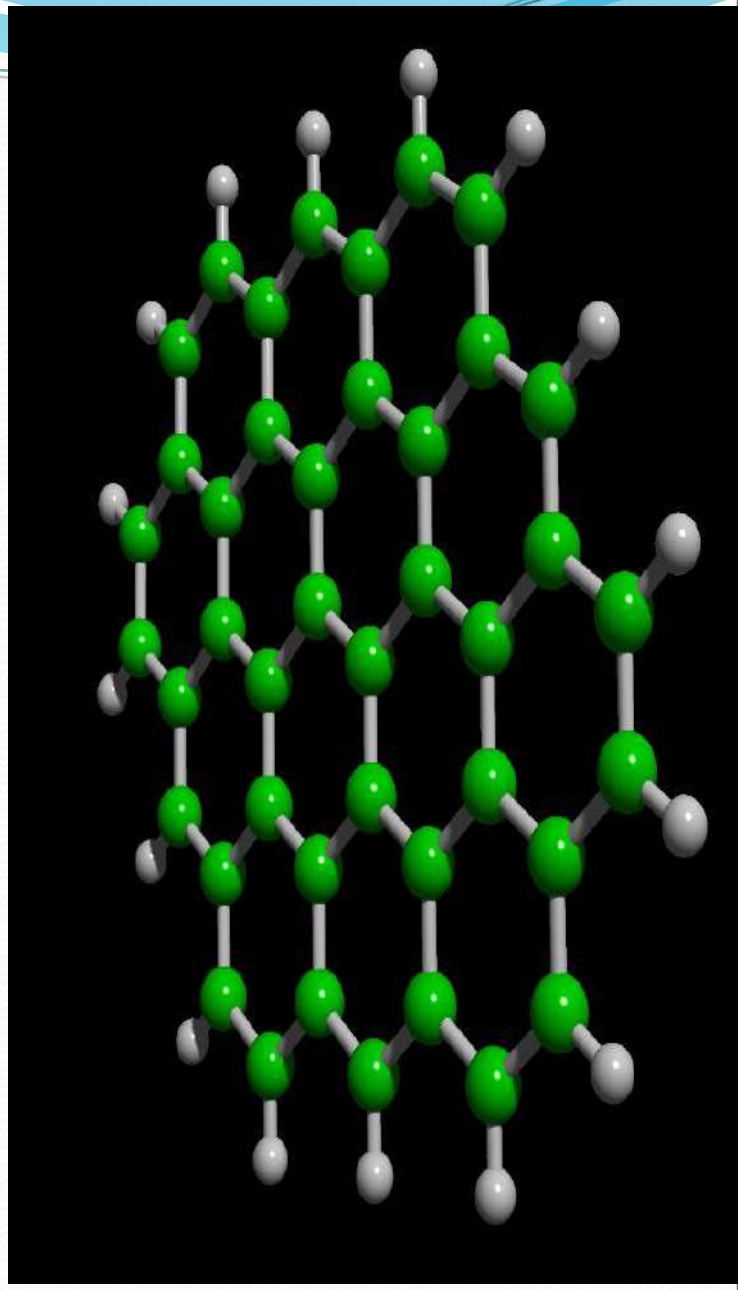
- Element X has 2 isotopes.
- X 10: 10.00 amu, 20.0% abundance.
- X 11: 11.00 amu, 80.0% abundance.
- Calculate the atomic mass.
- 10.8 amu

6.3 the mole

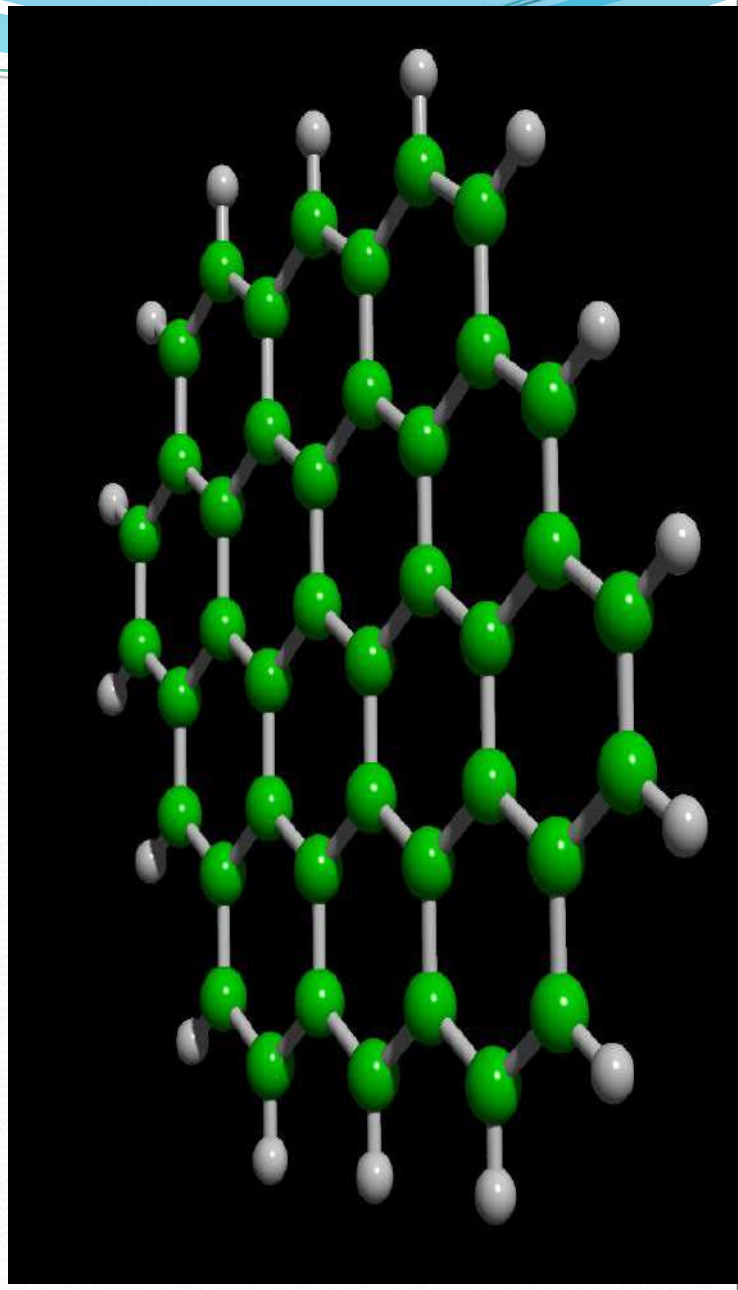


- Up until now we've used submicroscopic amounts of stuff
- ***What about realistic amounts?***
- Put on the seatbelt…

- How about we pick the number of atoms which will **change amu's directly to grams?**
- What quantity will take…
- *12.01 amu C → 12.01 g C*
- *26.98 amu Al → 26.98 g Al*
- *63.55 amu Cu → 63.55 g Cu*



- **Just one number will!**
  - **Avogadro's number**, the number all chemists throughout the world use every day of their miserable lives, the one, the only…



The MOLE

- 6.022×10^{23}
- 602,214,000,000,000,000,000,000

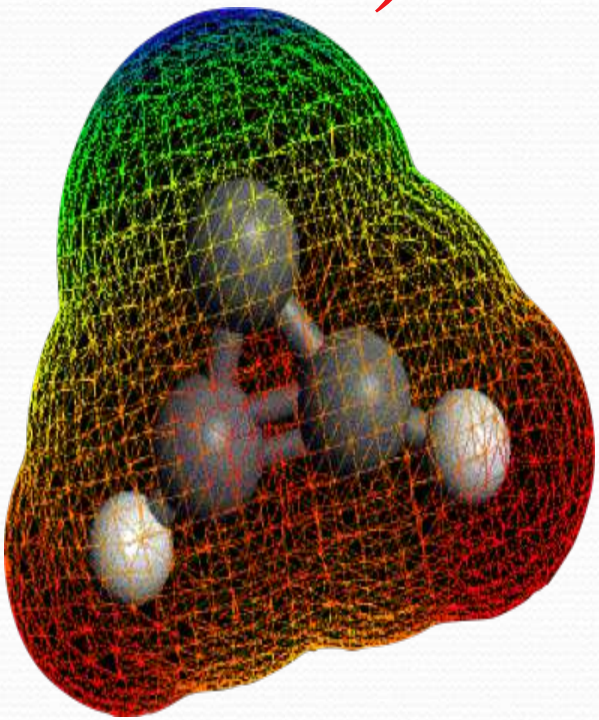
- **1 dozen = 12**
- **1 ream = 500**
- **1 pair = 2**
- **1 gross = 144**
- **1 mol = 6.022 x 10^{23}**
- Counting this number would take 2000 trillion years; a mole of sand could cover LA in 600 meters of sand; a mole of marbles would cover Earth 50 miles high in marbles; but!
- *A mole of water you can cup in one hand!*
- ***An element sample that weighs as much as the number of grams listed on the PT has a mol, 6.022 x 10^{23}, of atoms in it***

MUY IMPORTANTE

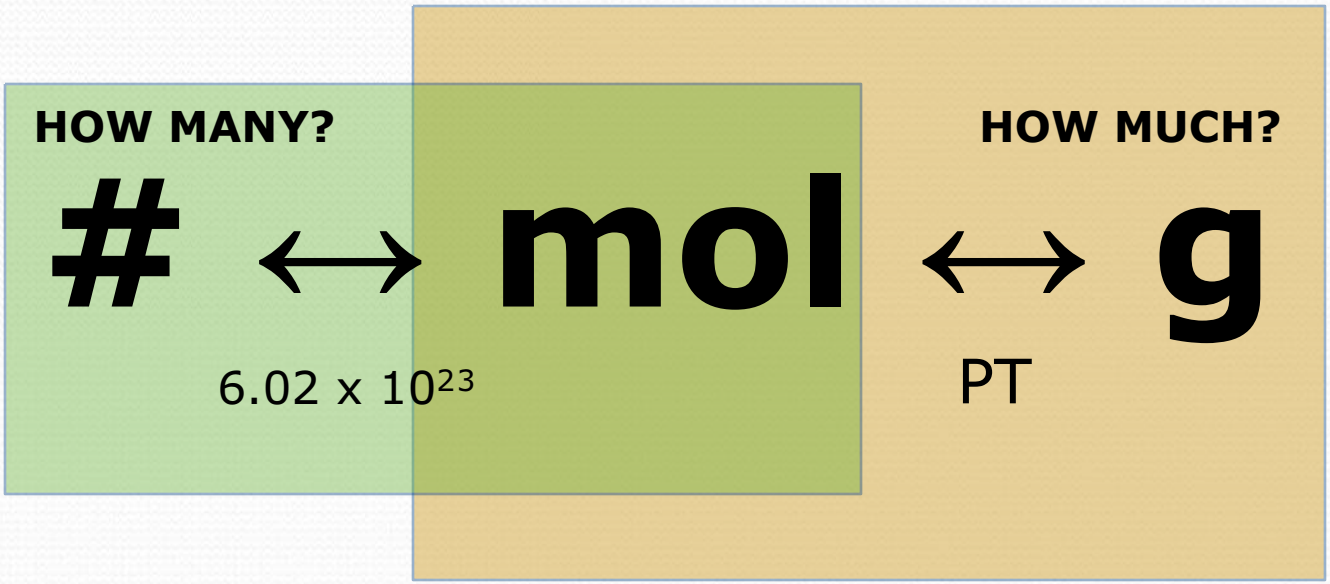
- *An element sample that weighs as many grams as the number listed on the PT has a mole, 6.022×10^{23}, of atoms in it*

- Now we can count atoms just by knowing:
- ***How much*** *we have (g)* **and** *that number on the PT which now represents a mol of stuff in grams* ***(molar mass)***
- **More than** the molar mass means > 1 mol of stuff
- **Less than** the molar
- mass means < 1 mol

of stuff



helpful hint



Example
(mols→atoms)

- ***How many atoms in 2.2 mol C?***

$$2.2 \text{ mol C} \times \frac{6.022 \times 10^{23} \text{ atoms C}}{1 \text{ mol C}} = 1.3 \times 10^{24} \text{ atoms C}$$

- ***1.0 mole of S?***
- ***0.50 moles of Ar?***

Example
(atoms→mols)

- ***How many moles in 1.204 x 10^{24} molecules of C?***

$$1.204 \times 10^{24} \text{ atoms C} \times \frac{1 \text{ mol C}}{6.022 \times 10^{23} \text{ atoms C}} = 2.000 \text{ mol C}$$

- ***3.02 x 10^{23} molecules of H?***
- ***1.806 x 10^{24} molecules of Ni?***

quick quiz
(g→mol)

- **26 g C = ? mol**

$$\frac{26\ \text{g}}{12.01\ \text{g C}} \times \frac{1\ \text{mol C}}{} = 2.2\ \text{mol C}$$

25 g Ni = ? mol — 0.43 mol

2.50 mol Cu = ? g Cu — 159 g

quick quiz (g→mol→atoms)

- **25.0 g Ca = ? mol = ? atoms**

$$25.0\text{g Ca} \times \frac{1\text{ mol Ca}}{40.08\text{g Ca}} = 0.624\text{ mol Ca}$$

$$0.624\text{ mol Ca} \times \frac{6.022 \times 10^{23}\text{ atoms}}{1\text{ mol Ca}} = 3.76 \times 10^{23}\text{ Ca atoms}$$

57.7 g S = ? mol S = ? atoms S

1.80 mol S

1.08×10^{24} S atoms

quick quiz (atoms→mol→g)

- **5.00×10^{20} Cr atoms = ? mol = ? g**

$$5.00 \times 10^{20} \text{ atoms} \times \frac{1 \text{ mol Cr}}{6.022 \times 10^{23} \text{ Cr atoms}} = 8.30 \times 10^{-4} \text{ mol Cr}$$

$$8.30 \times 10^{-4} \text{ mol Cr} \times \frac{52.00 \text{ g Cr}}{1 \text{ mol Cr}} = 4.32 \times 10^{-2} \text{ g Cr}$$

- Fill it in…

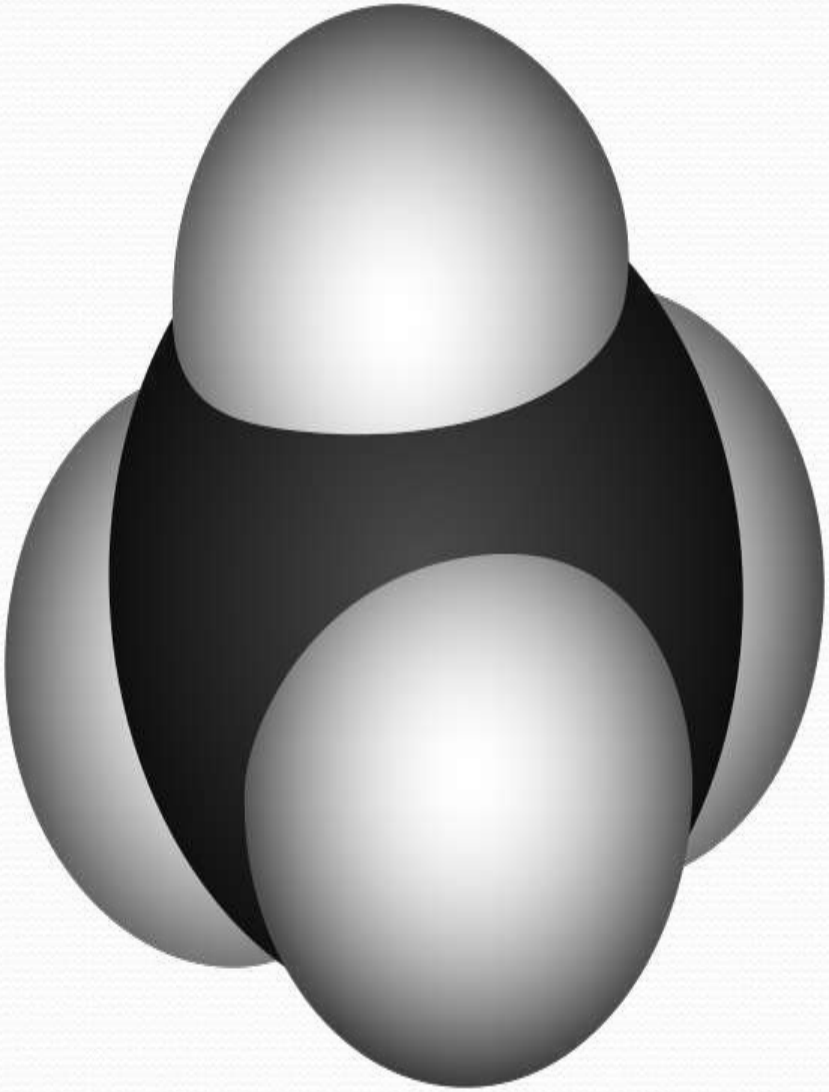
Mass of Sample ←PT→	Mols of Sample ←N_A→	Atoms in Sample
	0.250 mol Al	
25.4 g Fe		
		2.13×10^{24} atoms Au
	1.28 mol Ca	
4.28 mg Na		
		3.14×10^{23} atoms C

- Fill it in…

Mass of Sample	Mols of Sample	Atoms in Sample
6.7 g Al	0.250 mol Al	**1.51 x 10^{23} atoms Al**
25.4 g Fe	**0.455 mol Fe**	**2.74 x 10^{23} atoms Fe**
697 g Au	**3.54 mol Au**	2.13 x 10^{24} atoms Au
51.3 g Ca	1.28 mol Ca	**7.71 x 10^{23} atoms Ca**
4.28 mg Na	**1.86 x 10^{-4} mol Na**	**1.12 x 10^{20} atoms Na**
6.26 g C	**0.521 mol C**	3.14 x 10^{23} atoms C

Molar Mass

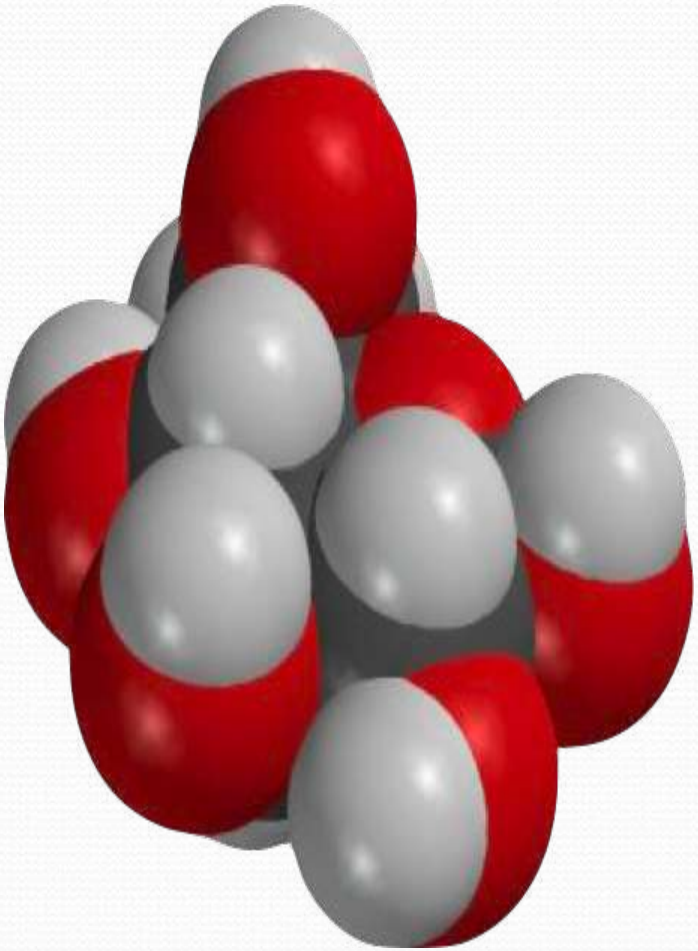
- Want to find the molar mass of **methane, CH_4**? (yes!)
- Just add up the little guys in the compound!
- For methane that would be:
- **12.01 + 1.01 + 1.01 + 1.01 + 1.01**
- **= 16.05 g/mol for methane**
- **= molar mass**
- Get me a **mass** of 16.05 g of methane, and you've given me a **mol** of it **(6.022×10^{23})**



Example

- *What is the molar mass of **sulfur dioxide?***
- (this is why you need to remember names/formulae)
- sulfur dioxide is SO_2
- A mol of SO_2 has **1 mol S** and **2 mol O**
- = (1 x 32.07) + (2 x 16.00)
- **= 64.07 g/mol**

Examples



- ***What is the molar mass of:***
  - water?
- **H_2O = 18.02 g/mol**
  - ammonia?
- **NH_3 = 17.03 g/mol**
  - propane, C_3H_8?
- **= 44.09 g/mol**
  - glucose, $C_6H_{12}O_6$?
- **= 180.2 g/mol**

quick quiz 2

- *can do the same with*
- *ionic compounds!*
- ***what is molar mass of:***
  - calcium sulfate?
  - **$CaSO_4$ = 136.3 g/mol**
  - sodium carbonate?
  - **Na_2CO_3 = 106.0 g/mol**
  - barium hydroxide?
  - **$Ba(OH)_2$ = 171.3 g/mol**

a mol of each

quick quiz 3

(mol → mass)

- ***(me first) calculate molar mass of calcium carbonate. what is the mass of 4.86 mol of this stuff?***
- molar mass $CaCO_3$ = 100.09 g/mol

$$4.86 \text{ mol } CaCO_3 \times \frac{100.09 \text{ g } CaCO_3}{1 \text{ mol } CaCO_3} = \mathbf{486 \text{ g } CaCO_3}$$

molar mass of sodium sulfate? **142.05 g**

300.0 g is how many mols? **2.112 mol Na_2SO_4**

quick quiz 4

(mass → mol)

- ***(me first) calculate molar mass of juglone***
- ***($C_{10}H_6O_3$). how many mol in 1.56 g?***
- molar mass $C_{10}H_6O_3$ = **174.1 g/mol**

$$1.56\ \text{g}\ C_{10}H_6O_3 \times \frac{1\ \text{mol}\ C_{10}H_6O_3}{174.1\ \text{g}\ C_{10}H_6O_3} = \textbf{0.00896 mol } C_{10}H_6O_3$$

how many mol formaldehyde (H_2CO) in 7.55-g sample?

0.251 mol

how many mols tetraphosphorus decoxide in a 250.0-g sample?

0.8805 mol

quick quiz 5

(mass → mol → molecules)

- ***how many molecules of Teflon (C_2F_4) are in a 135-g sample?*** *(hint: do you expect a little or gigantic answer?)*
- think! g → mol → molecules
- you'll need molar mass C_2F_4 = 100.02 g/mol

$$135\ \text{g}\ C_2F_4 \times \frac{1\ \text{mol}\ C_2F_4}{100.02\ \text{g}\ C_2F_4} = \mathbf{1.35\ \text{mol}\ C_2F_4}$$

$$1.35\ \text{mol}\ C_2F_4 \times \frac{6.022 \times 10^{23}\ \text{molecules}}{1\ \text{mol}\ C_2F_4} = 8.13 \times 10^{23}\ C_2F_4\ \text{molecules}$$

Chapter Questions/Homework

- **#37, 51, 54, 58,**

6.5 Percent composition of compounds

- Which score is better? 28/50 or 32/75?
  - *Percent* can answer the question
  - ***Percent*** is merely taking a **part** and dividing by **total** (then multiplying by 100)
- Same with **% comp**…
- Take **mass contributed by one element** and divide by **total mass of compound** (x 100)

Percent Composition

- Can you tell the % comp just from looking at a formula?
- *e.g.: **is SO_2 33% S and 67% O?***
- NO! % comp is a **gram** ratio thing not a **mol** ratio thing!!!
- So first change the mol in the formula to grams, then find %…

Example

- ***What is the % composition of SO_2?***

- SO_2 weighs in at 64 g/mol
- S contributes 32 of it, O contributes 2 x 16

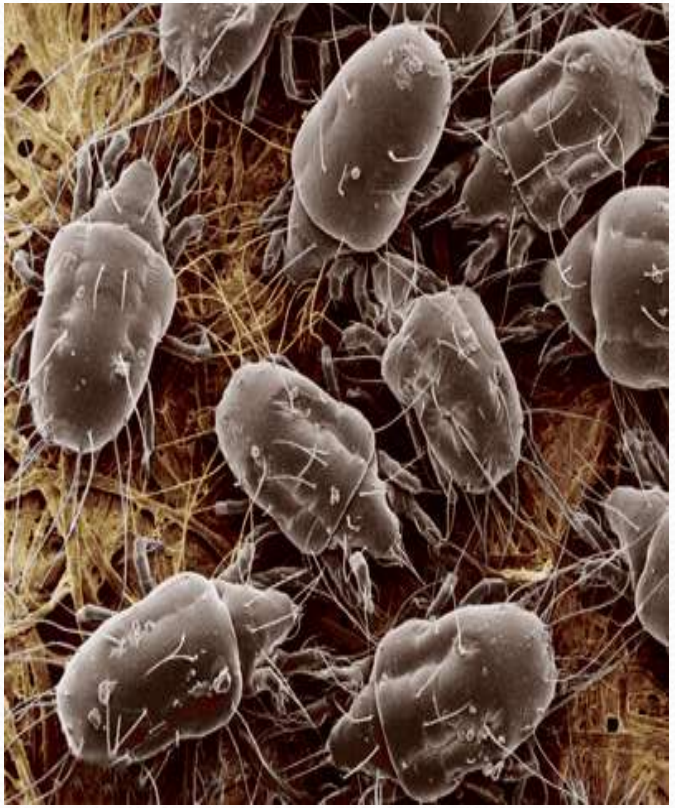
- %S = (32/64) • 100 = **50%**
- %O = (32/64) • 100 = **50%**

Example

- ***What is the % composition of $C_{10}H_{14}O$ (a mold mite pheromone)?***

- **$C_{10}H_{14}O$** weighs in at 150 g/mol
- C contributes 120 of it, H gives it 14, and O 16

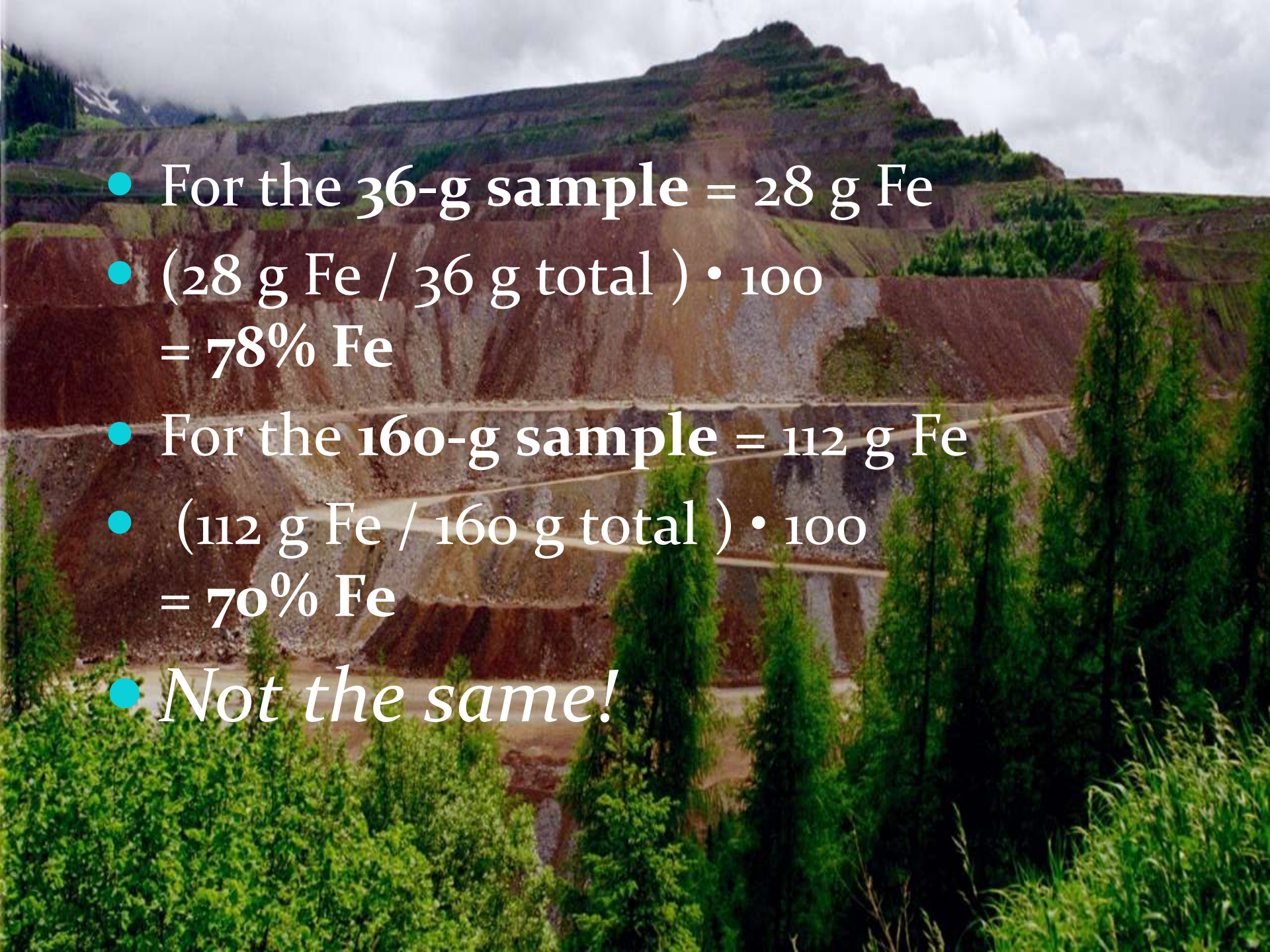
- %C = (120/150) • 100 = **80%**
- %H = (14/150) • 100 = **9.33%**
- %O = (16/150) • 100 = **10.67%**



Example

- You have:
- A 36-g sample = 28 g Fe, 8 g O
- A 160-g sample = 112 g Fe, 48 g O

- *Are they the same substance?*
- CAN'T TELL FROM JUST LOOKING AT GRAMS!!!!
- BUT, if they have the same % comp… They are the same thing!…



- For the **36-g sample** = 28 g Fe
- (28 g Fe / 36 g total) • 100
  = **78% Fe**
- For the **160-g sample** = 112 g Fe
- (112 g Fe / 160 g total) • 100
  = **70% Fe**
- *Not the same!*

Example

- **#1**: 45.0-g sample = 35.1 g Fe, 9.9 g O
- **#2**: 215-g sample = 167.7 g Fe, 47.3 g O
- *Are they the same?*
- (35.1 g Fe / 45.0 g total)•100 = **78% Fe**
- (167.7 g Fe / 215g total)•100 = **78% Fe**
- ***They are probably the same!***
- (The oxygen percents will be the same, too)

example

- **#1**: 75.0-g sample = 20.5 g C, 54.5 g O
- **#2**: 135.0-g sample = 67.5 g C, 67.5 g O
- *are they the same?*
- (20.5 g C / 75.0 g total)•100 = **27.3% C**
- (67.5g C / 135.0 g total)•100 = **50.0% C**
- *they are not the same!*

Chapter Questions (Homework)

#59, 61

Empirical Formula

Simplest whole # ratio of atoms in a compound

1. **% to mass**
2. **Mass to mol**
3. **Divide by small**
4. **Multiply until whole**

Empirical Formula

1.

- 92.26% Carbon
- 7.74% Hydrogen

- MM= 26.02g/mol

2.

- 63.15% Carbon
- 5.30% Hydrogen
- 31.55% Oxygen

- MM= 152.14g/mol

Molecular Formula

Exact formula of a compound

1. **Find molar mass of empirical formula**
2. **MM of molecule / MM of empirical form.**
3. **Should give a whole #**
4. **Distribute this # to empirical formula.**

- **Empirical Formula CH_2**
- **MM=28g/mol**
- **28/14 = 2**
- **$2(CH_2) = C_2H_4$**

Molecular Formula

- **Maleic Acid is 41.39% carbon, 3.47% hydrogen, and the rest Oxygen. If 0.129 mol of maleic acid has a mass of 15.0 g, what are the empirical and molecular formulas of maleic acid?**

Chapter Questions/Homework

- **#65, 68,**
- **79 we will do this one together right now**

Balancing Chemical Rxns

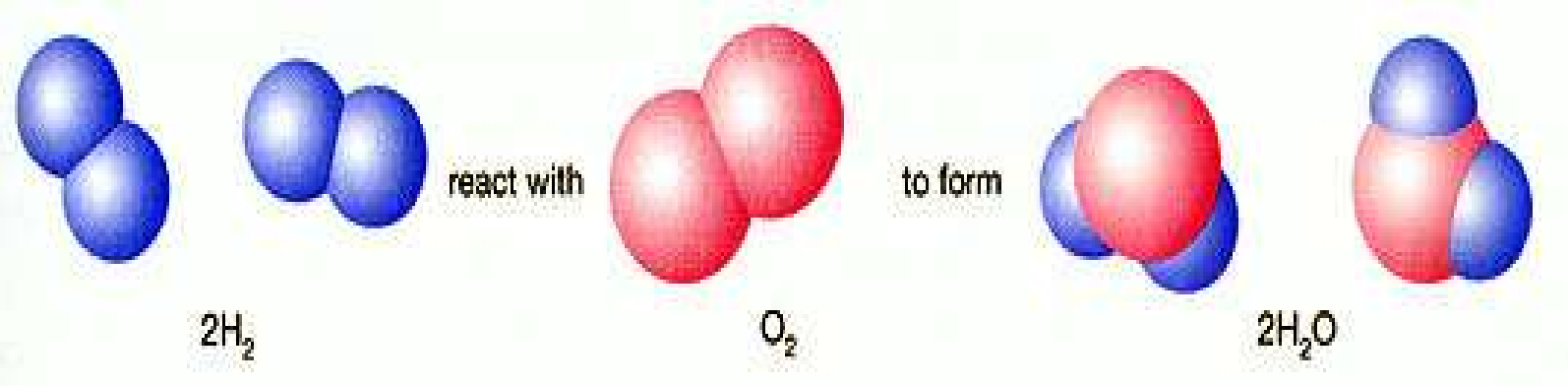
- *There are rules; They are simple but you must follow them - ready?...*

- **Law of Conservation of Mass** = *in a chemical rxn atoms are neither created nor destroyed*
- Discovered by **Antoine Laurent Lavoisier** w/ experiments in a **closed system**

- better way of stating it:
- ***All atoms are accounted for in a typical chemical reaction***
- ***A correct chemical equation will obey the Law of Conservation of Mass!***

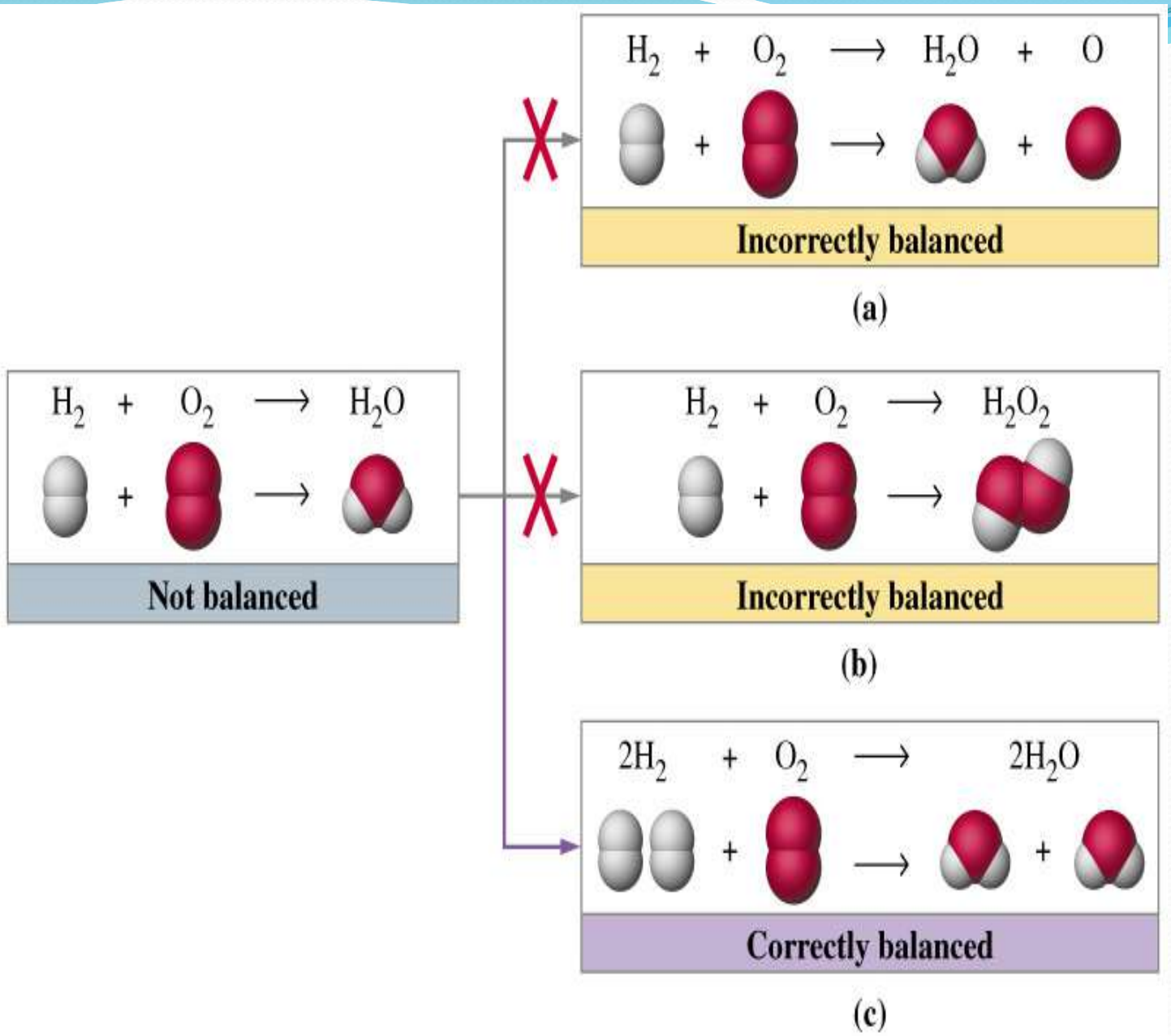
- $C + O_2 \rightarrow CO_2$
- $12g + 32g \rightarrow 44g$

- Lookie here…
- **$H_2 + O_2 \rightarrow H_2O$**
- *What's wrong here?*
- **All O's not accounted for!** how to fix?
- Play w/ ***coefficients!***
- **$2H_2 + O_2 \rightarrow 2H_2O$**

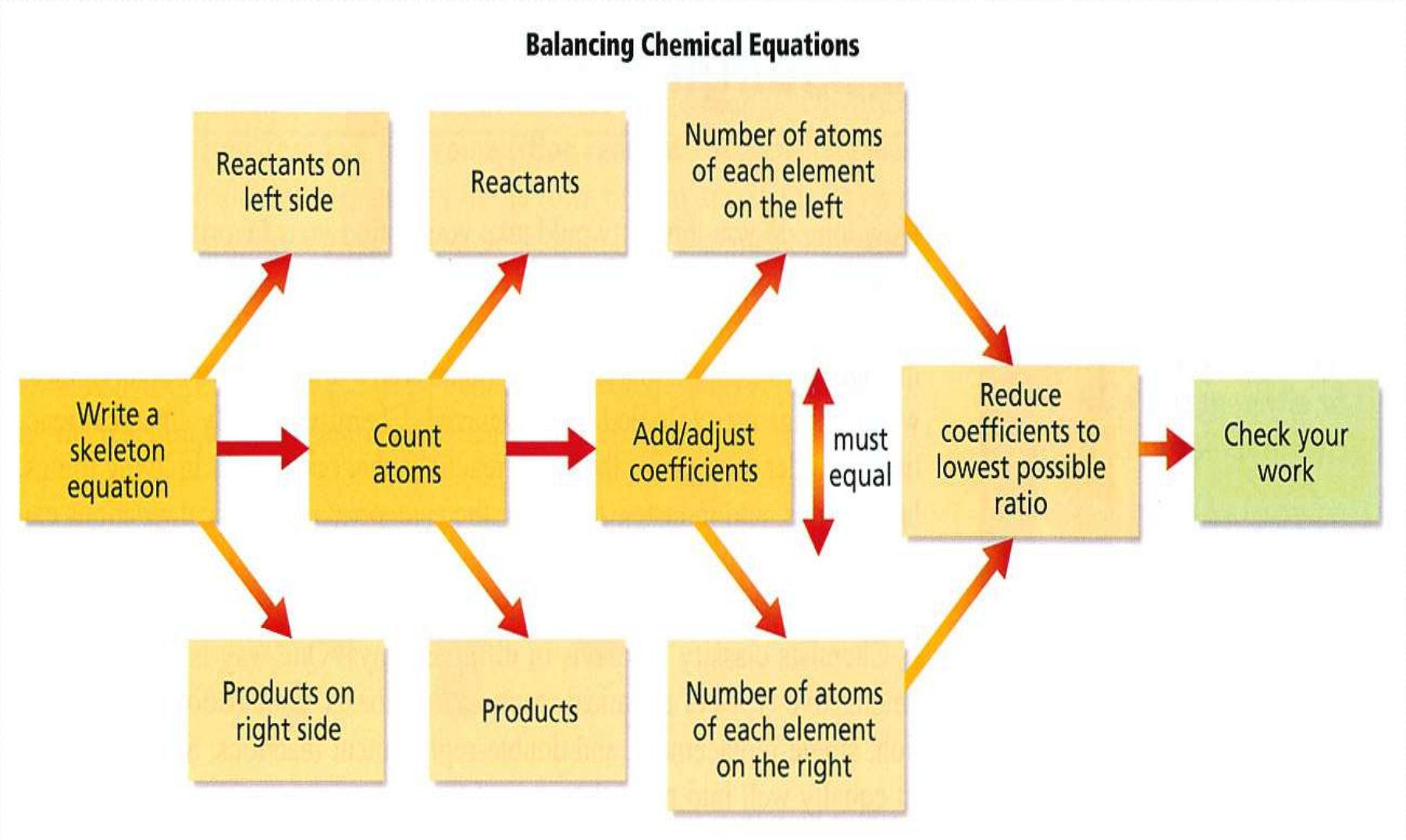


- Coefficients (the numbers in front) will show the number **proportion** (**ratios**) of the diff cmpds, e.g.:
- **$2H_2 + O_2 \rightarrow 2H_2O$**
  - 2 hydrogens : 1 oxygen (or)
  - 2 zillion hydrogens : 1 zillion oxygens (or)
  - 2 **mol** hydrogen : 1 **mol** oxygen

Relationships Derived from a Balanced Chemical Equation				
Iron	+	**Oxygen**	→	**Iron(III) oxide**
$4Fe(s)$	+	$3O_2(g)$	→	$2Fe_2O_3(s)$
4 atoms Fe	+	3 molecules O_2	→	2 formula units Fe_2O_3
4 moles Fe	+	3 moles O_2	→	2 moles Fe_2O_3
223.4 g Fe	+	96.0 g O_2	→	319.4 g Fe_2O_3
		319.4 g reactants	→	319.4 g product


$H_2 + O_2 \longrightarrow H_2O + O$
Incorrectly balanced
(a)
$H_2 + O_2 \longrightarrow H_2O$
Not balanced
$H_2 + O_2 \longrightarrow H_2O_2$
Incorrectly balanced
(b)
$2H_2 + O_2 \longrightarrow 2H_2O$
Correctly balanced
(c)

or… for the visual learners



Example

- *C_2H_4 burns in oxygen **to form** carbon dioxide and water*
- **$C_2H_4 + O_2 \rightarrow CO_2 + H_2O$**
- **$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$**

- *sodium and water **react to form** sodium hydroxide and hydrogen gas*
- **$Na + H_2O \rightarrow NaOH + H_2$**
- **$2Na + 2H_2O \rightarrow 2NaOH + H_2$**

Quick Quiz 1

- *Nitrogen monoxide gas **reacts with** hydrogen gas **to form** nitrogen gas and water*
- **$NO + H_2 \rightarrow N_2 + H_2O$**
- **$2NO + 2H_2 \rightarrow N_2 + 2H_2O$**

- *Lithium metal reacts with chlorine gas to form solid lithium chloride*
- **$Li + Cl_2 \rightarrow LiCl$**
- **$2Li + Cl_2 \rightarrow 2LiCl$**

Quick Quiz 2

- *Magnesium nitride is **formed from** its elements (first, what is magnesium nitride?)*
- **Mg_3N_2**
- **$Mg + N_2 \rightarrow Mg_3N_2$**
- **$3Mg + N_2 \rightarrow Mg_3N_2$**

- *Solid ammonium nitrite is heated **to produce** nitrogen gas and water vapor*
- **$NH_4NO_2 \rightarrow N_2 + H_2O$**
- **$NH_4NO_2 \rightarrow N_2 + 2H_2O$**

Quick Quiz 3

- *Diboron trioxide reacts with water to form boric acid, $B(OH)_3$*
- **$B_2O_3 + H_2O \rightarrow B(OH)_3$**
- **$B_2O_3 + 3H_2O \rightarrow 2B(OH)_3$**

- *Solid iron(III) oxide reacts with aqueous nitric acid to form aqueous iron(III) nitrate and water*
- **$Fe_2O_3 + HNO_3 \rightarrow Fe(NO_3)_3 + H_2O$**
- **$Fe_2O_3 + 6HNO_3 \rightarrow 2Fe(NO_3)_3 + 3H_2O$**

quick quiz II

- Write a balanced chm rxn for this:
- *gaseous chlorine reacts with an aqueous soln of potassium bromide to form liquid bromine and an aqueous soln of potassium chloride*
- **Cl_2 + KBr → Br_2 + KCl**
- **Cl_2 + 2KBr → Br_2 + 2KCl**

quick quiz III

- **Write a balanced chm rxn for this:**
- ***solid aluminum reacts with solid iodine to produce solid aluminum iodide***
- **$Al + I_2 \rightarrow AlI_3$**
- **$2Al + 3I_2 \rightarrow 2AlI_3$**

quick quiz IV

- **Write a balanced chm rxn for this:**
- ***solid magnesium reacts with an aqueous soln of hydrochloric acid to form an aqueous soln of magnesium chloride and bubbles of hydrogen gas***
- **Mg + HCl g $MgCl_2$ + H_2**
- **Mg + 2HCl g$MgCl_2$ + H_2**

Homework

- #81, 83, 87,
- #84 (optional if you need more practice)

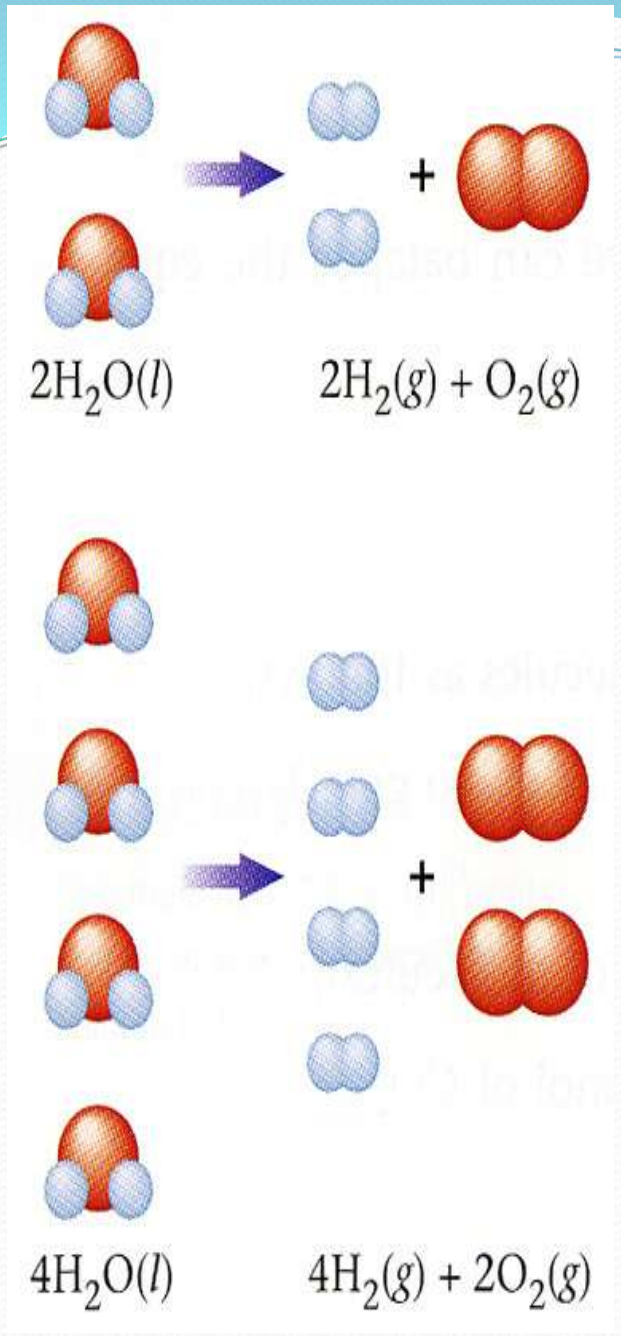
9.2 Mole-Mole Relationships

Remember!

The most common

number ratio in chemistry is the

Mole Ratio!



- What is the similarity between these two rxns?
- The ***ratio*** is the same!
- These little baby microscopic ratios are also the mighty **mol ratios**…

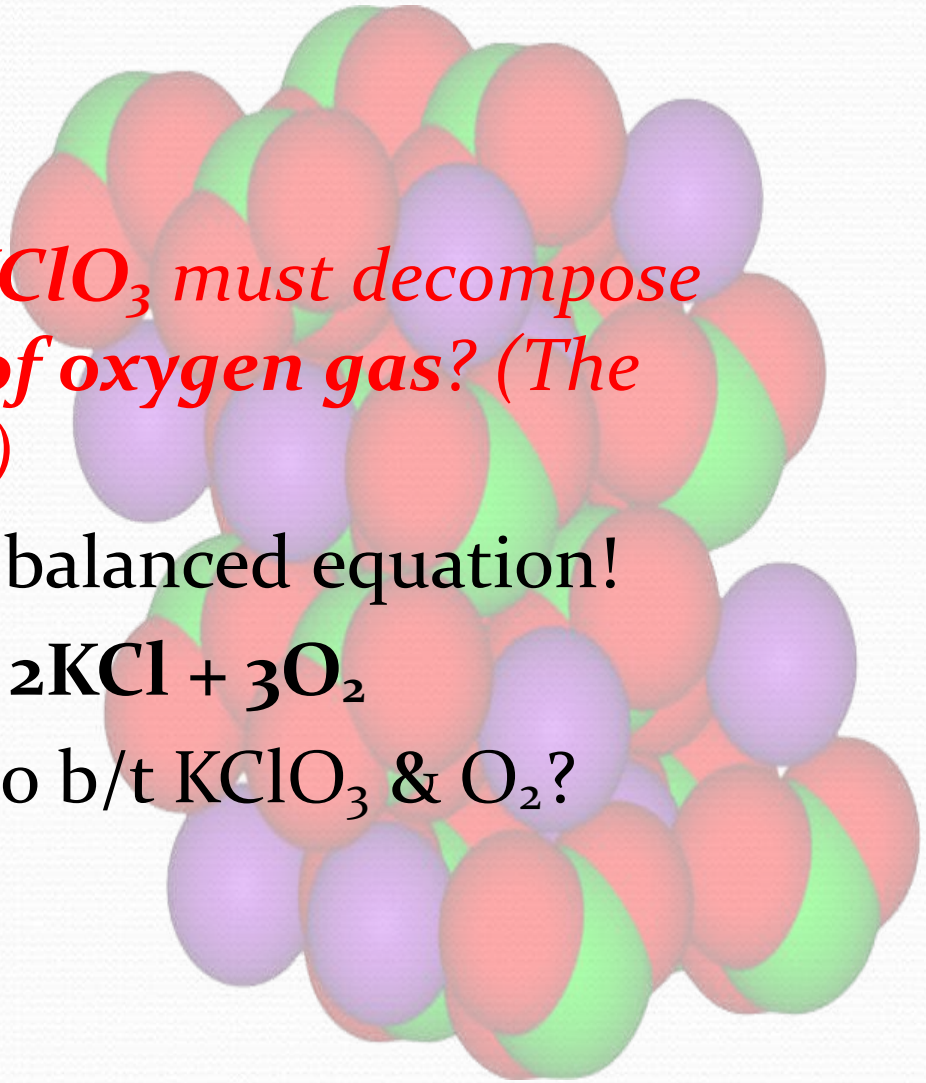
Example

*How many **moles of $KClO_3$** must decompose to produce **9 moles of oxygen gas**? (The other product is KCl.)*

1) As always, first get a balanced equation!

$$\mathbf{2KClO_3 \rightarrow 2KCl + 3O_2}$$

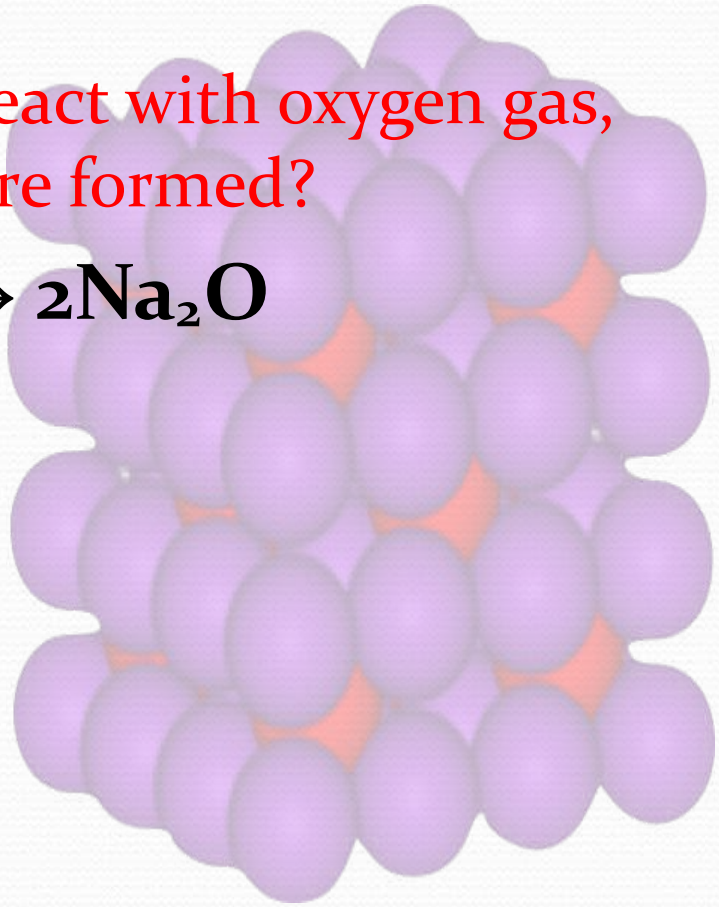
2) What is the mol ratio b/t $KClO_3$ & O_2?



Example

- When 5.00 mols sodium react with oxygen gas, how many mols of Na_2O are formed?

$$4Na + O_2 \rightarrow 2Na_2O$$



9.3 Mass Calculations

- ***The study of amt of subs consumed and produced =***
  stoichiometry
  (*stoicheio* element + *metria* measuring)
- Remember that chm eqs tell you **number ratios**, not mass amts!

9.3 Mass Calculations

- Your 3 friends now:
  - ***Balanced chm eq,***
  - ***Mol ratios,***
  - ***Math relationships***

Example

- *CaC_2 and water get together to make acetylene, C_2H_2, and calcium hydroxide. How many **grams** of water do you need to make 1.55 **mol** C_2H_2?*
- ***What should you always do first?***

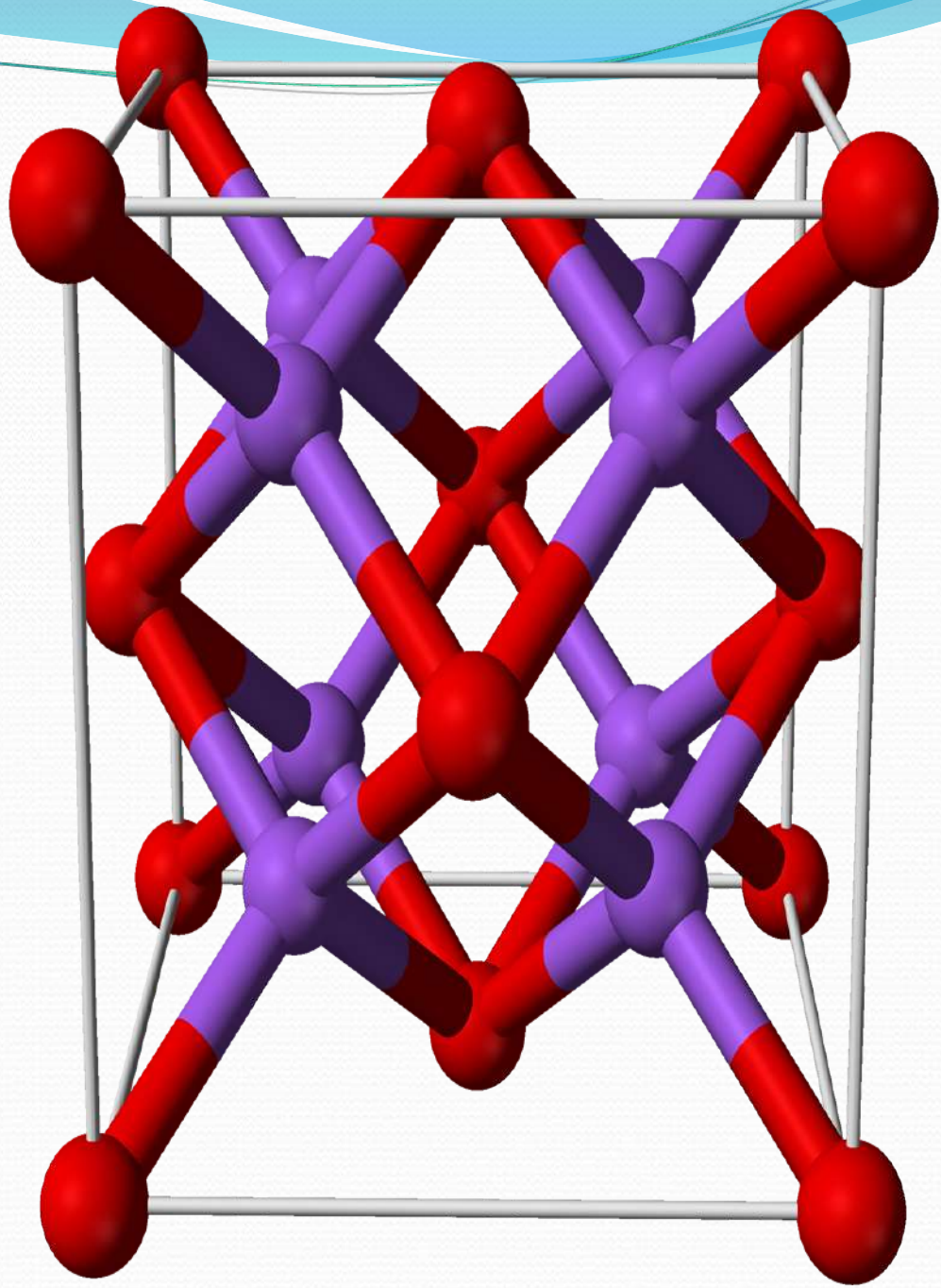
- This is for big people only; here I give you **mass** of one you tell me **mass** of the other
- Key? Start and end w/ grams; ***but must cross thru mol bridge!!!***
- Basic method?

$$(grams_A \rightarrow mols_A) \rightarrow (mols_B \rightarrow grams_B)$$

PT BEq PT

Example

- How many **grams** of oxygen gas are required to completely react with **14.6 g** of solid sodium to form sodium oxide, Na_2O?



Example

- When 20.4 **grams** of **sodium** metal is mixed with **chlorine** gas, how many **g** of **sodium chloride** are produced?

Example

- Limestone, **$CaCO_3$**, is heated to produce lime (**calcium oxide**) and **carbon dioxide**. How **much** limestone (g) is required to produce **10.0 g** of lime?

Homework

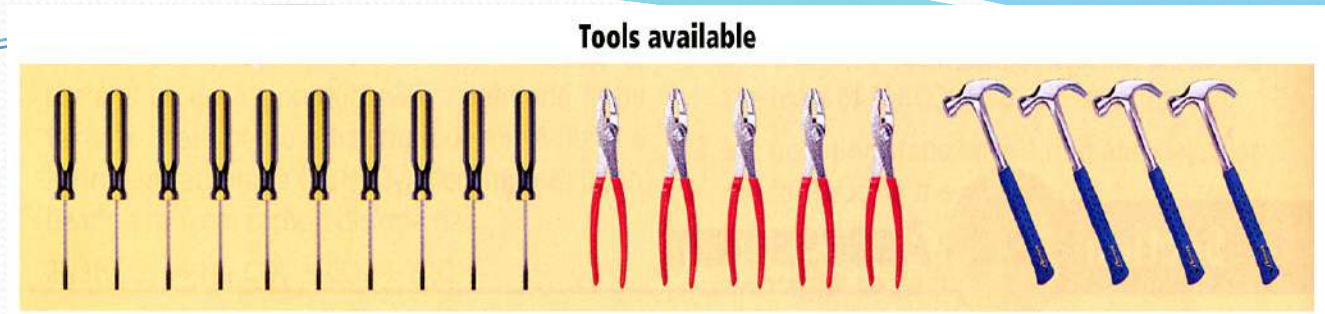
#89, 91, 93, 95

9.6 The Concept of Limiting Reactants

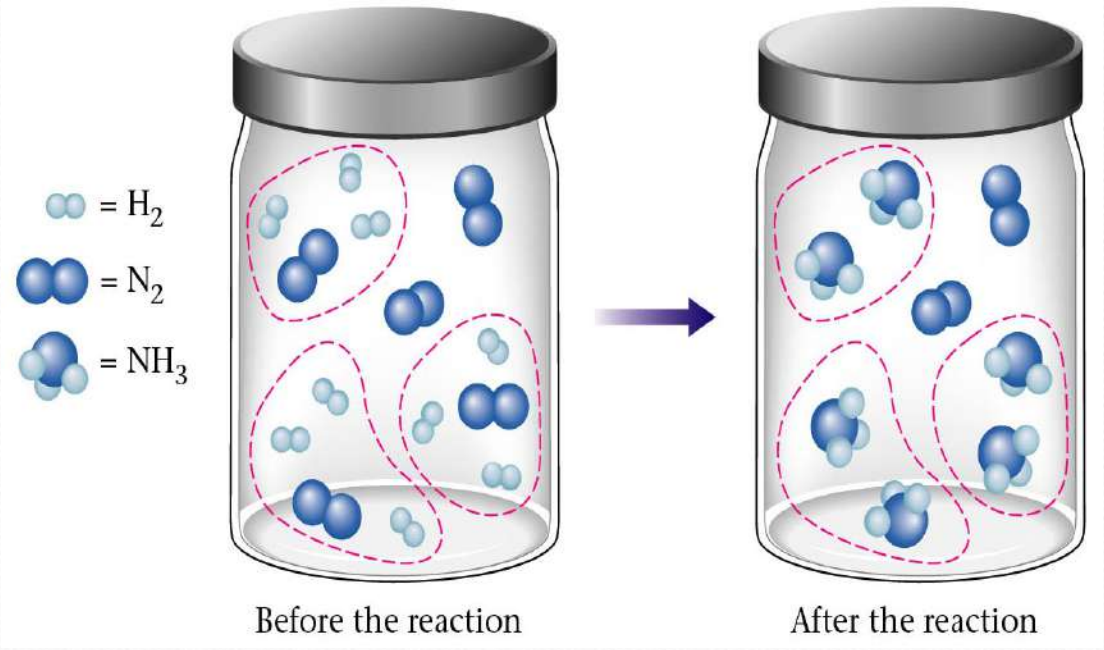
- just as when you were to make 100 sandwiches there will be *something* left over of at least *one* of the ingredients, so…
- it's impossible for ***every*** atom/molecule to react, so…

10. ***must add one reactant in there intentionally in excess (xs) to react as much of the other as possible***

- **what was the limiting *ingredient* here?**
  i.e. what stopped this person from making more sandwiches?



- how many sets of **1 pliers, 2 screwdrivers, and 1 hammer** can you make, ***and*** what is left over?



- leftovers! There are nitrogens left! What limited this rxn???

9.7 Calculations Involving a Limiting Reactant

- if reactants in a rxn are not present in their mol ratios, one will be used up before the other = **l/r**; the other one = **xs**
- but you can *still predict how much prod will be made*; yippee!

⑩*[hint: l/r probs betray themselves in asking how much prod you can get when they give* ***amts of 2 reactants****]*

example

- What if reactants are given in ***grams***?
- No problem! Just change to mols first…

10. **25.0 g N_2** react with **5.00 g H_2**.
    1) Which is LR?
    2) How much ammonia will be produced?

example

- **79.1 g Zn** react with **76.5 g HCl**.

  1) Which is LR?

  2) How much H_2 will be formed?

example

- **1.00 g Zn** reacts with **6.2 x 10^{-3} mol $Pb(NO_3)_2$** to form $Zn(NO_3)_2$ and Pb...
  1) Which is LR?
  2) How much Pb will be formed?
- first, the balanced equation!...

Homework

- **#109, 119, 101, 99, 104a-c**

Percent Yield

Actual yield of product as a % of theoretical yield.

- **Theoretical Yield - Maximum amount of product possible.**
- **Actual Yield – Amount actually produced. This is always less than the theoretical yield**

$$\% \text{ Yield} = \frac{\text{Actual Yield (g)}}{\text{Theoretical Yield (g)}} \times 100\%$$

Examples

1. A group of students collect 38.2g of water during a distillation experiment. Calculate the percent yield of water if the students should have been able to collect 39.6g of water.

2. The rxn of 23.1 g NH3 and 18.3 g O2 produces 4.10 g NO. What is the % yield?

$$NH_3 + O_2 \rightarrow NO + H_2O$$

Homework

- **#104 d, 103,**