CHEMICAL EQUATIONS

- are the "recipes" in chemistry
- show the substances going into a reaction, substances coming out of the reaction, and give other information about the process

"yields"

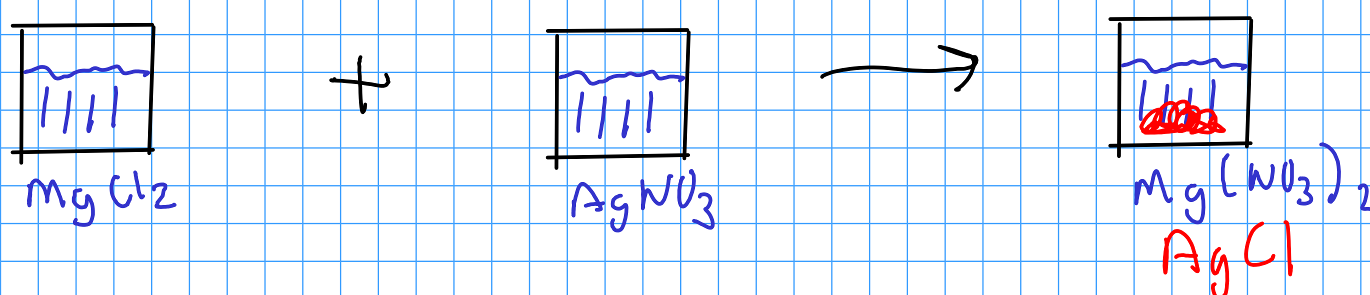
$$MgCl_2(aq) + 2AgNO_3(aq) \longrightarrow 2AgCl(s) + Mg(NO_3)_2(aq)$$

REACTANTS - materials that are needed fot a reaction

PRODUCTS - materials that are formed in a reaction

COEFFICIENTS - give the ratio of molecules/atoms of one substance to the others

PHASE LABELS - give the physical state of a substance:
(s) -solid
(l) - liquid
(g) - gas
(aq) - aqueous. In other words, dissolved in water



CHEMICAL EQUATIONS

$$2\,Mg_{(s)} + O_{2(g)} \xrightarrow{\Delta} 2\,MgO_{(s)}$$

REACTION CONDITIONS - give conditions necessary for chemical reaction to occur. May be:

- Δ apply hear
- catalysts - substances that will help reaction proceed faster
- other conditions, such as required temperatures

- Reaction conditions are usually written above the arrow, but may also be written below if the reaction requires several steps or several different conditions

COEFFICIENTS

- Experimentally, we can usually determine the reactants and products of a reaction

- We can determine the proper ratios of reactants and products WITHOUT further experiments, using a process called BALANCING

- BALANCING a chemical equation is making sure the same number of atoms of each element go into a reaction as come out of it.

- A properly balanced chemical equation has the smallest whole number ratio of reactants and products.

- There are several ways to do this, but we will use a modified trial-and-error procedure.

BALANCING

$$C_3H_8 + 5\,O_2 \rightarrow 3\,CO_2 + 4\,H_2O$$

1. Pick an element. Avoid (if possible) elements that appear in more than one substance on each side of the equation.

2. Change the coefficients on substances containing this element so that the same number of atoms of the element are present on each side. CHANGE AS LITTLE AS POSSIBLE!

3. Repeat 1-2 until all elements are done.

4. Go back and quickly VERIFY that you have the same number of atoms of each element on each side, If you used any fractional coefficients, multiply each coefficient by the DENOMIMATOR of your fraction.

Use SMALLEST WHOLE NUMBER RATIOS!

BALANCING

$$3\,MgCl_2 + 2\,Na_3PO_4 \longrightarrow Mg_3(PO_4)_2 + 6\,NaCl$$

2 5 4 2

$$C_2H_2 + \frac{5}{2}O_2 \longrightarrow 2\,CO_2 + H_2O$$

4 1

5

To eliminate 5/2 , multiply ALL coefficients by 2!

$$\boxed{2\,C_2H_2 + 5\,O_2 \longrightarrow 4\,CO_2 + 2\,H_2O}$$

$$H_2SO_4 + 2\,NaOH \longrightarrow Na_2SO_4 + 2\,H_2O$$

CHEMICAL CALCULATIONS - RELATING MASS AND ATOMS

$\_Na_2CO_3 + \underline{2}HCl \rightarrow \_H_2O + \_CO_2 + \underline{2}NaCl$

Chemical equations are written and balanced in terms of ATOMS and MOLECULES

- While chemical equations are written in terms of ATOMS and MOLECULES, that's NOT how we often measure substances in lab!

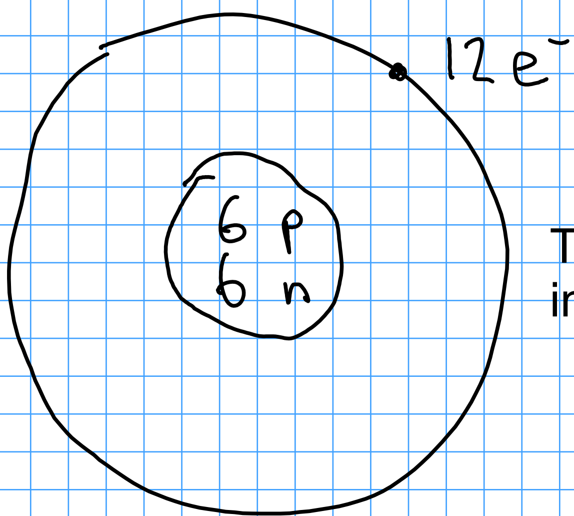
- measurements are usually MASS (and sometimes VOLUME), NOT number of atoms or molecules!

THE MOLE CONCEPT

- A "mole" of atoms is 6.022×10^{23} atoms

Why so big? Because atoms are so small!

- Why - in the metric dominated world of science - do we use such a strange number for quantity of atoms?



The mole is also defined as the number of carbon-12 atoms in exactly 12 g of carbon-12

carbon-12

THE MOLE CONCEPT

- Why define the mole based on an experimentally-measured number?

- The atomic weight of an element (if you put the number in front of the unit GRAMS) is equal to the mass of ONE MOLE of atoms of that element!

Carbon (C): Atomic mass 12.01 ~~amu~~ → $\boxed{12.01\ g}$

the mass of ONE MOLE of naturally-occurring carbon atoms

Magnesium (Mg): 24.31 g = the mass of ONE MOLE OF MAGNESIUM ATOMS

- So, using the MOLE, we can directly relate a mass and a certain number of atoms!

RELATING MASS AND MOLES

- Use DIMENSIONAL ANALYSIS (a.k.a "drag and drop")

- Need CONVERSION FACTORS - where do they come from?

- We use ATOMIC WEIGHT as a conversion factor.

$Mg : 24.31$ | $24.31\ g\ Mg = 1\ mol\ Mg$

"mol" is the abbreviation for "mole"

Example: How many moles of atoms are there in 250. g of magnesium metal?

$24.31\ g\ Mg = 1\ mol\ Mg$

$$250.\ \cancel{g\ Mg} \times \frac{1\ mol\ Mg}{24.31\ \cancel{g\ Mg}} = \boxed{10.3\ mol\ Mg}$$

Example: You need 1.75 moles of iron. What mass of iron do you need to weigh out on the balance?

$55.845 \text{ g Fe} = 1 \text{ mol Fe}$

$$1.75 \text{ mol Fe} \times \frac{55.845 \text{ g Fe}}{1 \text{ mol Fe}} = \boxed{97.7 \text{ g Fe}}$$

WHAT ABOUT COMPOUNDS? FORMULA WEIGHT

Example: 25.0 g of WATER contain how many MOLES of water molecules?

H_2O

$$\text{H: } 2 \times 1.008 = 2.016$$
$$\text{O: } 1 \times 16.00 = 16.00$$
$$18.016$$

formula weight of water!

Formula weight = mass of one mole of an element OR compound

$$18.016\text{ g } H_2O = 1 \text{ mol } H_2O$$

$$25.0\text{ g } \cancel{H_2O} \times \frac{1 \text{ mol } H_2O}{18.016\text{ g } \cancel{H_2O}} = \boxed{1.39 \text{ mol } H_2O}$$

Formula weight goes by several names:

- For atoms, it's the same thing as ATOMIC WEIGHT
- For molecules, it;s called MOLECULAR WEIGHT
- Also called "MOLAR MASS"

Example: How many grams of ammonium carbonate do we need to weigh out to get 3.65 moles of ammonium carbonate?

NH_4^+ CO_3^{2-}

NH_4^+

$(NH_4)_2CO_3$

284.7 g ~ 285 g

350 g

N : 2 x 14.01

H : 8 x 1.008

C : 1 x 12.01

O : 3 x 16.00

96.094

First, write the correct CHEMICAL FORMULA ... then find the FORMULA WEIGHT!

$$96.094\ g\ (NH_4)_2CO_3 = 1\ mol\ (NH_4)_2CO_3$$

$$3.65\ mol\ (NH_4)_2CO_3 \times \frac{96.094\ g\ (NH_4)_2CO_3}{1\ mol\ (NH_4)_2CO_3} = \boxed{351\ g}$$

PERCENTAGE COMPOSITION

- sometimes called "percent composition" or "percent composition by mass"

- the percentage of each element in a compound, expressed in terms of mass

Example: Find the percentage composition of ammonium nitrate.

$NH_4^+ \quad NO_3^-$

NH_4NO_3 : N : 2 x 14.01 = 28.02

H : 4 x 1.008 = 4.032

O : 3 x 16.00 = 48.00

80.052 g NH_4NO_3 per mole

$$\%N = \frac{28.02}{80.052} \times 100\% = 35.0\%\ N$$

$$\%H = \frac{4.032}{80.052} \times 100\% = 5.0\%\ H$$

$$\%O = \frac{48.00}{80.052} \times 100\% = 60.0\%\ O$$

So far, we have

- looked at how to determine the composition by mass of a compound from a formula
- converted from MASS to MOLES (related to the number of atoms/molecules)
- converted from MOLES to MASS

Are we missing anything?

- What about SOLUTIONS, where the desired chemical is not PURE, but found DISSOLVED IN WATER?
- How do we deal with finding the moles of a desired chemical when it's in solution?

MOLAR CONCENTRATION

- unit: MOLARITY (M): moles of dissolved substance per LITER of solution

$$M = \text{molarity} = \frac{\text{moles of solute}}{\text{L solution}}$$

6.0 M HCl solution: $\dfrac{6.0 \text{ mol HCl}}{\text{L}}$

If you have 0.250 L (250 mL) of 6.0 M HCl, how many moles of HCl do you have?

$6.0 \text{ mol HCl} = 1 \text{ L solution}$

$$0.250 \text{ L } \cancel{\text{solution}} \times \frac{6.0 \text{ mol HCl}}{1 \text{ L } \cancel{\text{solution}}} = 1.5 \text{ mol HCl}$$

If you need 0.657 moles of hydrochloric acid, how many liters of 0.0555 M HCl do you need to measure out?

$$0.0555 \text{ mol HCl} = 1 \text{ L solution}$$

$$0.657 \text{ } \cancel{\text{mol}} \text{ HCl} \times \frac{1 \text{ L solution}}{0.0555 \text{ } \cancel{\text{mol}} \text{ HCl}} = \boxed{11.8 \text{ L solution}}$$

What if we used 6.00 M HCl?

$$6.00 \text{ mol HCl} = 1 \text{ L solution}$$

$$0.657 \text{ mol HCl} \times \frac{1 \text{ L solution}}{6.00 \text{ mol HCl}} = \boxed{\begin{array}{c} 0.110 \text{ L solution} \\ (110 \text{ mL}) \end{array}}$$

CHEMICAL CALCULATIONS CONTINUED: REACTIONS

- Chemical reactions proceed on an ATOMIC basis, NOT a mass basis!

- To calculate with chemical reactions (i.e. use chemical equations), we need everything in terms of ATOMS ... which means MOLES of atoms

$$\underline{2}\,Al(s) + \underline{3}\,Br_2(l) \longrightarrow \underline{2}\,AlBr_3(s)$$

coefficients are in terms of atoms and molecules!

2 atoms Al = 3 molecules Br_2 = 2 formula units $AlBr_3$

2 mol Al = 3 mol Br_2 = 2 mol $AlBr_3$

- To do chemical calculations, we need to:
  - Relate the amount of substance we know (mass or volume) to a number of moles
  - Relate the moles of one substance to the moles of another using the equation
  - Convert the moles of the new substance to mass or volume as desired

$$2Al(s) + 3Br_2(l) \longrightarrow 2AlBr_3(s)$$

* Given that we have 25.0 g of liquid bromine, how many grams of aluminum would we need to react away all of the bromine? How many grams of aluminum bromide would be produced?

(1) Convert grams of bromine to moles: Need formula weight

$Br_2: 2 \times 79.90 = 159.80$

$159.80\ g\ Br_2 = 1\ mol\ Br_2$

$$25.0\ g\ Br_2 \times \frac{1\ mol\ Br_2}{159.80\ g\ Br_2} = 0.15645\ mol\ Br_2$$

(2) Use the chemical equation to relate moles of bromine to moles of aluminum

$2\ mol\ Al = 3\ mol\ Br_2$

$$0.15645\ mol\ Br_2 \times \frac{2\ mol\ Al}{3\ mol\ Br_2} = 0.10430\ mol\ Al$$

(3) Convert moles aluminum to mass: Need formula weight

$Al: 26.98$

$26.98\ g\ Al = 1\ mol\ Al$

$$0.10430\ mol\ Al \times \frac{26.98\ g\ Al}{1\ mol\ Al} = \boxed{2.81\ g\ Al}$$

You can combine all three steps on one line if you like!

$$25.0\,g\,Br_2 \times \frac{1\,mol\,Br_2}{159.80\,g\,Br_2} \times \frac{2\,mol\,Al}{3\,mol\,Br_2} \times \frac{26.98\,g\,Al}{1\,mol\,Al} = \boxed{2.81\,g\,Al}$$

1 2 3

$$\begin{array}{r} 25.0\,g\,Br_2 \\ +\;\; 2.81\,g\,Al \\ \hline 27.8\,g\,AlBr_3 \end{array}$$

But ...

...what would you have done to calculate the mass of aluminum bromide IF you had NOT been asked to calculate the mass of aluminum FIRST?

$$25.0\,g\,Br_2 \times \frac{1\,mol\,Br_2}{159.80\,g\,Br_2} \times \frac{2\,mol\,AlBr_3}{3\,mol\,Br_2} \times \frac{266.694\,g\,AlBr_3}{1\,mol\,AlBr_3} = 27.8\,g$$

Example:
How many milliliters of 6.00M hydrochloric acid is needed to completely react with 25.0 g of sodium carbonate?

$$2HCl(aq) + Na_2CO_3(s) \longrightarrow H_2O(l) + CO_2(g) + 2NaCl(aq)$$

- Convert mass of sodium carbonate to moles using formula weight
- Convert moles of sodium carbonate to moles hydrochloric acid using chemical equation
- Convert moles of hydrochloric acid to volume using concentration (M = moles/L)

- Convert mass of sodium carbonate to moles using formula weight

Na_2CO_3: Na : 2 × 22.99
C : 1 × 12.01
O : 3 × 16.00
105.99

$$105.99\,g\ Na_2CO_3 = 1\ mol\ Na_2CO_3$$

$$25.0\,g\ Na_2CO_3 \times \frac{1\ mol\ Na_2CO_3}{105.99\,g\ Na_2CO_3} = 0.235871\ mol\ Na_2CO_3$$

Example:
How many milliliters of 6.00M hydrochloric acid is needed to completely react with 25.0 g of sodium carbonate?

$$2HCl(aq) + Na_2CO_3(s) \longrightarrow H_2O(l) + CO_2(g) + 2NaCl(aq)$$

- Convert moles of sodium carbonate to moles hydrochloric acid using chemical equation

$$2 \text{ mol } HCl = 1 \text{ mol } Na_2CO_3$$

$$0.235871 \text{ mol } Na_2CO_3 \times \frac{2 \text{ mol } HCl}{1 \text{ mol } Na_2CO_3} = 0.471743 \text{ mol } HCl$$

- Convert moles of hydrochloric acid to volume using concentration (M = moles/L)

$$6.00 \text{ M } HCl: \quad 6.00 \text{ mol } HCl = 1 \text{ L}$$

$$0.471743 \text{ mol } HCl \times \frac{1 \text{ L}}{6.00 \text{ mol } HCl} = 0.0786 \text{ L of solution}$$

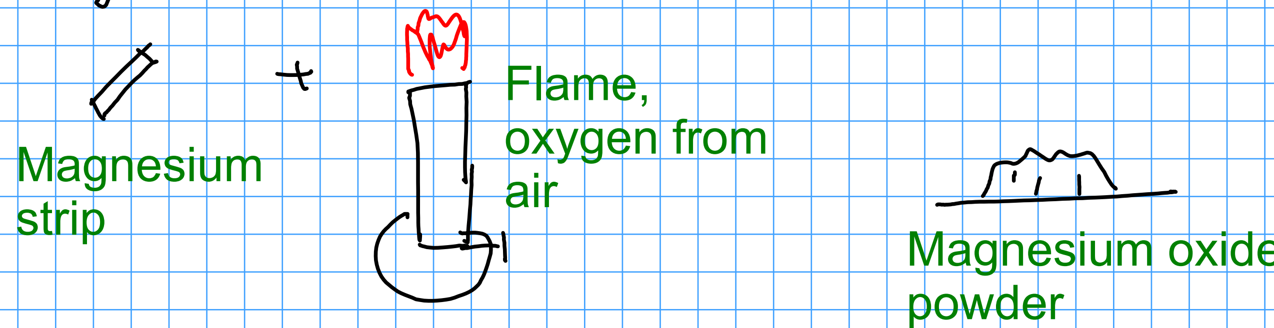
$mL = 10^{-3} L$ Convert liters to milliliters!

$$0.0786 \text{ L of solution} \times \frac{mL}{10^{-3} L} = \boxed{78.6 \text{ mL solution}}$$

CONCEPT OF LIMITING REACTANT

- When does a chemical reaction STOP?

$$2Mg(s) + O_2(g) \xrightarrow{\Delta} 2MgO(s)$$



- When does this reaction stop? When burned in open air, this reaction stops when all the MAGNESIUM STRIP is gone. We say that the magnesium is LIMITING.

- This reaction is controlled by the amount of available magnesium

- At the end of a chemical reaction, the LIMITING REACTANT will be completely consumed, but there may be amount of OTHER reactants remaining. We do chemical calculations in part to minimize these "leftovers".

LIMITING REACTANT CALCULATIONS

- To find the limiting reactant, calculate how much product would be produced from ALL given reactants. Whichever produces the SMALLEST amouht of product is the limiting reactant, and the smallest anount of product is the actual amount of product produced.

Example:

$$CaO(s) + 3C(s) \xrightarrow{\Delta} CaC_2(s) + CO(g)$$

If you start with 100. g of each reactant, how much calcium carbide would be produced?

C: 12.01 g/mol

CaO: 56.08 g/mol

CaC_2: 64.10 g/mol

CaO, 114 g

CaO:

$$100\,g\,CaO \times \frac{mol\,CaO}{56.08\,g\,CaO} \times \frac{1\,mol\,CaC_2}{1\,mol\,CaO} \times \frac{64.10\,g\,CaC_2}{mol\,CaC_2} =$$

$= 114\,g$

$\boxed{\text{CaO is limiting, 114 g } CaC_2 \text{ prod}}$

C:

$$100\,g\,C \times \frac{mol\,C}{12.01\,g\,C} \times \frac{1\,mol\,CaC_2}{3\,mol\,C} \times \frac{64.10\,g\,CaC_2}{mol\,CaC_2} =$$

$= 178\,g$