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

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

$\cancel{2}$ 10   6 + 4 = 10

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

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

$$C_2H_2 + 2\tfrac{1}{2}O_2 \longrightarrow 2CO_2 + H_2O$$

$$2 \quad 5 \qquad 4 + 1 = 5$$

We had to use a fractional coefficient (2 1/2) to make the number of oxygen atoms balance out. We can get rid of the fraction by multiplying it by 2, but to make sure we have the same ratio, we need to multiply ALL the coefficents by 2.

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

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

1 - Avoid H (shows up twice on the left side). Balance S instead.
2 - Avoid O (shows up in all four compounds!). Balance Na instead.
3 - Balance H (shows up less than O).
4 - Balance O. (it's already done!)

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!

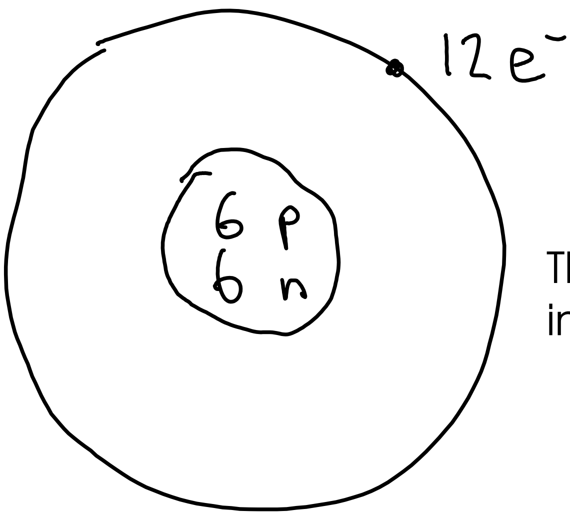
- measurements are usually MASS (and sometimes VOLUME), NOT number of atoms or molecules!

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?



carbon-12

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

$Mg : 24.31$

Atomic mass

$24.31\ g\ Mg = \underline{mol}\ Mg$

"mol" is the abbreviation for "mole"

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

$24.31\ g\ Mg = mol\ Mg$

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

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

Fe: $55.85 g\ Fe = mol\ Fe$

$$1.75\ mol\ Fe \times \frac{55.85 g\ Fe}{mol\ Fe} = \boxed{97.7 g\ Fe}$$

WHAT ABOUT COMPOUNDS? FORMULA WEIGHT

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

H_2O: H : 2 x 1.008 = 2.016
O : 1 x 16.00 = 16.00

18.016 ← FORMULA WEIGHT of water

FORMULA WEIGHT is the mass of one mole of either an element OR a compound.

$18.016\ g\ H_2O = mol\ H_2O$

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

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 barium chloride do we need to weigh out to get 3.65 moles of barium chloride?

First, find the formula of barium chloride:

Ba^{2+} Cl^-

Cl^-

$BaCl_2$

Next, find the FORMULA WEIGHT:

Ba: $1 \times 137.3 = 137.3$

Cl: $2 \times 35.45 = 70.90$

$208.2\ g\ BaCl_2 = mol\ BaCl_2$

Finally, convert moles to mass.

$$3.65\ mol\ BaCl_2 \times \frac{208.2\ g\ BaCl_2}{mol\ BaCl_2} = \boxed{76\bar{0}\ g\ BaCl_2}$$

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 barium chloride.

$BaCl_2$: Ba : $1 \times 137.3 = \boxed{137.3}$

Cl : $2 \times 35.45 = \boxed{70.90}$

These numbers are the masses of each element in a mole of the compound!

208.2 g $BaCl_2$ = mol $BaCl_2$

Ba: $\dfrac{137.3 \text{ g Ba}}{208.2 \text{ g } BaCl_2} \times 100 = \boxed{65.95\% \text{ Ba}}$

Cl: $\dfrac{70.90 \text{ g Cl}}{208.2 \text{ g } BaCl_2} \times 100 = \boxed{34.05\% \text{ Cl}}$

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

dissolved substance

$$M = \text{molarity} = \frac{\text{moles of SOLUTE}}{\text{L SOLUTION}}$$

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

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

$$0.250 \text{ L} \times \frac{6.0 \text{ mol HCl}}{\text{L}} = \boxed{1.50 \text{ mol HCl}}$$

*See SECTIONS 4.7 - 4.10 for more information about MOLARITY and solution calculations (p 154 - 162 - 9th edition) (p 156-164 - 10th edition)

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

$$\frac{0.0555 \text{ mol HCl}}{\text{L}}$$

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

(11 800 mL)

For lab-scale work, we'd choose the 6.00 M solution for this situation, since 11.8 L is far too large for our common glassware!

What if we used 6.00 M HCl?

$$\frac{6.00 \text{ mol HCl}}{\text{L}}$$

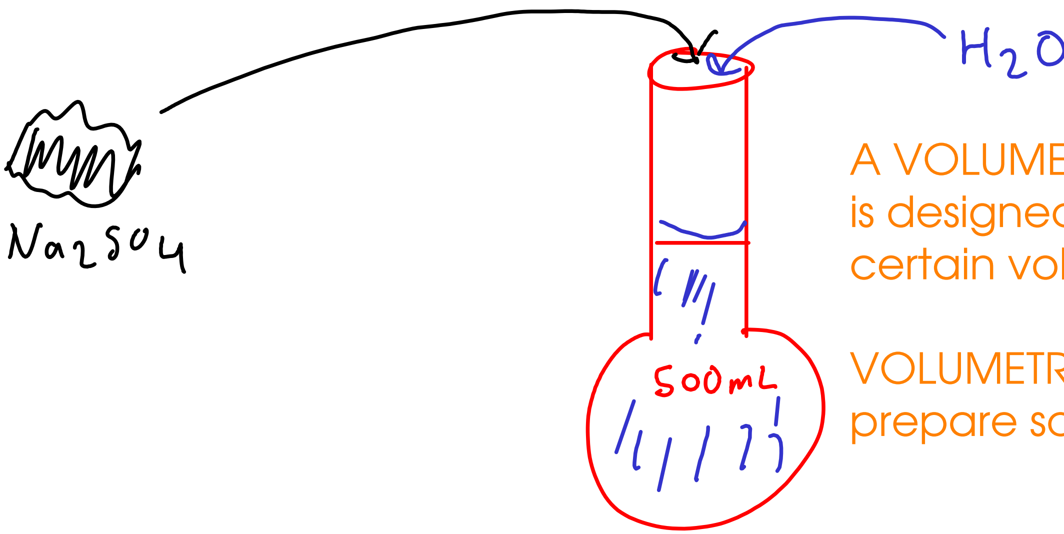
$$0.657 \text{ mol HCl} \times \frac{\text{L}}{6.00 \text{ mol HCl}} = \boxed{0.110 \text{ L}}$$

($11\bar{0}$ mL)

Example: How would we prepare 500. mL of 0.500 M sodium sulfate in water?

Na_2SO_4: 142.05 g/mol

Dissolve the appropriate amount of sodium sulfate into enough water to make 500. mL of solution.



A VOLUMETRIC FLASK is a flask that is designed to precisely contain a certain volume of liquid.

VOLUMETRIC FLASKS are used to prepare solutions.

volumetric flask

Find moles sodium sulfate from the MOLARITY and VOLUME of the solution.

$0.500 \text{ mol } Na_2SO_4 = L \qquad mL = 10^{-3} L$

$$500. \cancel{mL} \times \frac{10^{-3} \cancel{L}}{\cancel{mL}} \times \frac{0.500 \text{ mol } Na_2SO_4}{\cancel{L}} = 0.250 \text{ mol } Na_2SO_4$$

Convert moles sodium sulfate to mass using FORMULA WEIGHT.

$142.05 \text{ g } Na_2SO_4 = \text{mol } Na_2SO_4$

$$0.250 \text{ mol } Na_2SO_4 \times \frac{142.05 \text{ g } Na_2SO_4}{\text{mol } Na_2SO_4} = \boxed{35.5 \text{ g } Na_2SO_4}$$

Weigh out 35.5 grams of sodium sulfate solid into a 500 mL volumetric flask and add water to the mark.

More on MOLARITY

To prepare a solution of a given molarity, you generally have two options:

1. Weigh out the appropriate amount of solute, then dilute to the desired volume with solvent (usually water)

"stock solution"

2. Take a previously prepared solution of known concentration and DILUTE it with solvent to form a new solution

   - Use DILUTION EQUATION

The dilution equation is easy to derive with simple algebra.

$$M \times V$$

$$\frac{mol}{L} \times L = \text{moles solute}$$

... but when you dilute a solution, the number of moles of solute REMAINS CONSTANT. (After all, you're adding only SOLVENT)

$$M_1 V_1 = M_2 V_2$$

Since the number of moles of solute stays the same, this equality must be true!

before diution

after dilution

$$M_1V_1 = M_2V_2$$ ... the "DILUTION EQUATION"

M_1 = molarity of concentrated solution

V_1 = volume of concentrated solution

M_2 = molarity of dilute solution

V_2 = volume of dilute solution (total volume, not volume of added solvent!)

The volumes don't HAVE to be in liters, as long as you use the same volume UNIT for both volumes!

Example: Take the 0.500 M sodium sulfate we discussed in the previous example and dilute it to make 150. mL of 0.333 M solution. How many mL of the original solution will we need to dilute?

$$M_1V_1 = M_2V_2$$

$$(0.500\,M)V_1 = (0.333\,M)(150.\,mL)$$

$$V_1 = 99.9\,mL$$

$M_1 = 0.500\,M$

$V_1 = ?$

$M_2 = 0.333\,M$

$V_2 = 150.\,mL$

Measure out 99.9 mL of the 0.500 M solution, then add water until the total volume of solution is 150 mL ... (You can do this in a single graduated cylinder)