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

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

~~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

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

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

~~7~~ 5 | 4 + 1 = 5

We used a coefficient of 2 1/2 for the oxygen molecules, since we needed exactly five oxygen atoms on the left side. To get rid of the fraction, we need to multiply ALL the coefficients by the denominator of the fraction (in this case, 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, balance S (H shows up in two compounds on the left side)
2 - Avoid O, balance Na (O shows up in all compounds in this reaction)
3 - Balance H (H shows up less than O)
4 - Balance O (it's already done!)

CHEMICAL CALCULATIONS - RELATING MASS AND ATOMS

$$\_\,Na_2CO_3 + \_\,2HCl \rightarrow \_\,H_2O + \_\,CO_2 + \_\,2NaCl$$

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!

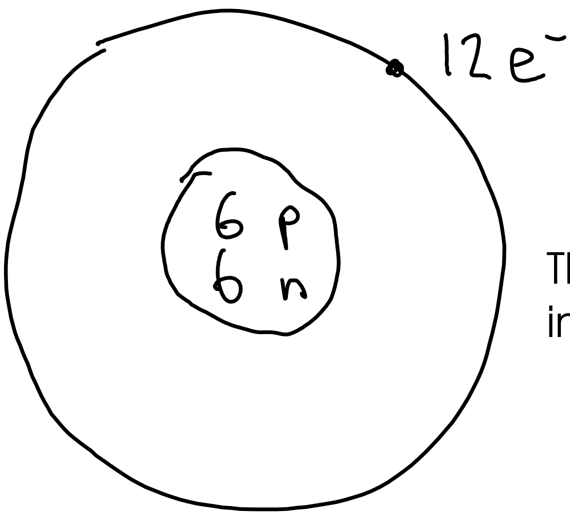
- measurements are usually MASS (and sometimes VOLUME), NOT number of atoms or molecules!

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~~ → 12.01 g

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 = 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

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

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

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

55.85 is Fe's atomic weight from the periodic table

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

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.

$18.016 g\ H_2O = mol\ H_2O$

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

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?

Find the FORMULA of barium chloride:

Ba^{2+} Cl^-

Cl^-

$BaCl_2$

Find the FORMULA WEIGHT

Ba: 1 x 137.3

Cl: 2 x 35.45

208.2 g $BaCl_2$ = mol $BaCl_2$

$$3.65 \text{ mol } BaCl_2 \times \frac{208.2 \text{ g } BaCl_2}{\text{mol } BaCl_2} = 760. \text{ g } BaCl_2$$

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 x 137.3 = 137.3
Cl: 2 x 35.45 = 70.90

208.2 g $BaCl_2$ = mol $BaCl_2$

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

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

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

As a check, these should sum to 100% within roundoff error!

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

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

(SOLUTE ← dissolved substance)

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

$$0.250 \text{ L} \times \frac{6.0 \text{ mol HCl}}{\text{L}} = \boxed{1.5 \text{ mol HCl}}$$

*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?

0.0555 mol HCl = L

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

11800 mL

In most lab situations, this solution wouldn't be practical if we needed 0.657 mol

What if we used 6.00 M HCl?

6.00 mol HCl = L

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

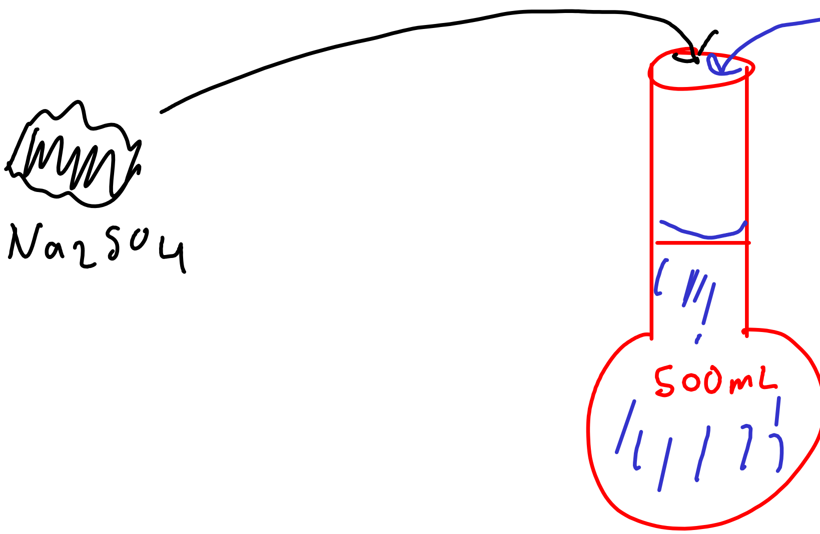
110. mL

This is a more lab-scale volume than the first one.

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.



volumetric flask

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

VOLUMETRIC FLASKS are used to prepare solutions.

We know that we need 500 mL of solution. We can use the concentration (0.500 M) to find out the moles sodium sulfate. Then, we can use the formula weight to find out the mass.

0.500 mol Na_2SO_4 = L | mL = 10^{-3} L | 142.05 g Na_2SO_4 = mol Na_2SO_4

$$500.\ \text{mL} \times \frac{10^{-3}\ \text{L}}{\text{mL}} \times \frac{0.500\ \text{mol}\ Na_2SO_4}{\text{L}} \times \frac{142.05\ \text{g}\ Na_2SO_4}{\text{mol}\ Na_2SO_4} = 35.5\ \text{g}\ Na_2SO_4$$

To make the solution, weigh out 35.5 grams sodium sulfate, put into a 500 mL volumetric flask, and add water to the mark.