PREDICTING SINGLE REPLACEMENT REACTIONS

$$Pb(s) + 2HCl(aq) \rightarrow PbCl_2(s) + H_2(g)$$

Lead is MORE ACTIVE than hydrogen,so we would expect lead to replace hydrogen in hydrochloric acid.

$$Pb(NO_3)_2(aq) + Zn(s) \rightarrow Zn(NO_3)_2(aq) + Pb(s)$$

Since zinc is MORE ACTIVE than lead, we expect it to replace lead in lead(II) nitrate.

$$Ag(s) + H_2SO_4(aq) \rightarrow$$ NO REACTION

Silver is LESS ACTIVE that hydrogen, so it would not be able to give its electrons to hydrogen and replace it in sulfuric acid.

$$Mg(s) + ZnSO_4(aq) \rightarrow MgSO_4(aq) + Zn(s)$$

We expect magnesium to replace zinc .. it's more active.

Activity ↑

- Sodium Na^+
- Magnesium Mg^{2+}
- Aluminum Al^{3+}
- Zinc Zn^{2+}
- Iron Fe^{2+}
- Lead Pb^{2+}
- Hydrogen H^+
- Copper Cu^{2+}
- Silver Ag^+
- Gold Au^{3+}

CHEMICAL CALCULATIONS - RELATING MASS AND ATOMS

$$\_\ Na_2CO_3 + \_2\ HCl \rightarrow \_\ H_2O + \_\ CO_2 + \_2\ NaCl$$

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!

MASS ← Na_2CO_3 solid; VOLUME ← HCl solution

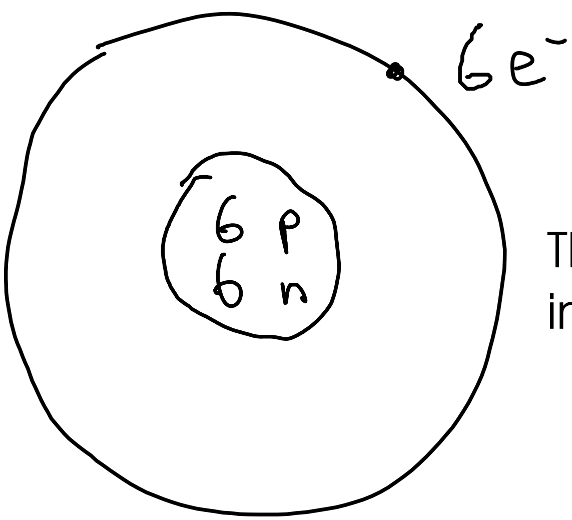
... so how do we relate atoms and molecules with things we routinely measure in lab - like grams and milliliters?

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 fo
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.

$$Mg : 24.31 \quad \Big| \quad 24.31 \text{ g Mg} = 1 \text{ mol Mg}$$

"mol" is the abbreviation for "mole"

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

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

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

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

Fe: 55.85

55.85 g Fe = mol Fe

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

WHAT ABOUT COMPOUNDS? FORMULA WEIGHT

Example: 25.0 g of WATER contain how many MOLES of water molecules?
(H_2O)

H_2O H : 2 x 1.008 = 2.016
O : 1 x 16.00 = 16.00
18.016 — FORMULA WEIGHT of water

Formula weight = mass of one mole of either an element OR a compound!

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

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

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?

First, find the correct formula:

NH_4^+ CO_3^{2-}

NH_4^+

$(NH_4)_2CO_3$

N : 2 x 14.01

H : 8 x 1.008

C : 1 x 12.01

O : 3 x 16.00

96.094 Formula weight of ammonium carbonate

$96.094 \text{ g } (NH_4)_2CO_3 = \text{mol } (NH_4)_2CO_3$

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

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^+ NO_3^-

NH_4NO_3:

N: $2 \times 14.01 = 28.02$

H: $4 \times 1.008 = 4.032$

O: $3 \times 16.00 = 48.00$

80.052 g NH_4NO_3 = mol NH_4NO_3

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

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

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

These percentages SHOULD sum to 100% within roundoff error.

So far, we have

ch8

- 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?

Sec 15.4 p483-488

- 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

solute = dissolved substance

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

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

There are 6.0 moles of hydrochloric acid in each liter of this solution, so you can write this relationship another way:

6.0 mol HCl = 1 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

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

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

0.0555 mol HCl = L   mL = 10^{-3} L

$$0.657 \text{ mol HCl} \times \frac{\text{L}}{0.0555 \text{ mol HCl}} \times \frac{\text{mL}}{10^{-3}\text{ L}} = \boxed{11800 \text{ mL}}$$

This is a very large volume for lab-scale work. We should use a more concentrated solution to get this amount of HCl.

What if we used 6.00 M HCl?

6.00 mol HCl = L   mL = 10^{-3} L

$$0.657 \text{ mol HCl} \times \frac{\text{L}}{6.00 \text{ mol HCl}} \times \frac{\text{mL}}{10^{-3}\text{ L}} = \boxed{110. \text{ mL}}$$

This volume can be measured easily with a 250 mL graduated cylinder ... plus, we're likely to have this much solution available in the first place!

If you're preparing a solution by dissolving a solid in water, you can easily calculate the molarity of the solution. How?

Just find the number of moles of solid you dissolved, then divide by the volume of the solution (expressed in liters!)

What is the molarity of a solution made by dissolving 3.50 g of NaCl in enough water to make 250. mL of solution?

$$M = \frac{\text{mol NaCl}}{\text{L solution}}$$

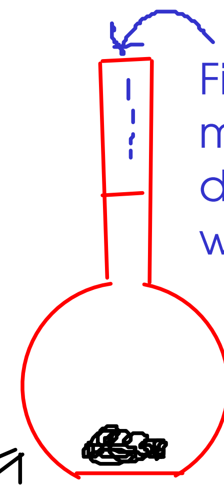
1 - Convert 3.50 grams of NaCl to moles using the formula weight.
2 - Divide moles NaCl / LITERS of solution. (Convert 250 mL to L)

NaCl: Na: 1×22.99
Cl: 1×35.45
$58.44\,\text{g NaCl} = \text{mol NaCl}$

① $3.50\,\text{g NaCl} \times \frac{\text{mol NaCl}}{58.44\,\text{g NaCl}} = 0.05989048\text{6 mol NaCl}$

$\text{mL} = 10^{-3}\,\text{L}$

$250.\,\text{mL} \times \frac{10^{-3}\,\text{L}}{\text{mL}} = 0.250\,\text{L}$



Fill to 250. mL mark with deionized water.

3.50 g NaCl

"volumetric flask" - used to prepare solutions in lab

② $M = \frac{\text{mol NaCl}}{\text{L solution}} = \frac{0.059890486\,\text{mol NaCl}}{0.250\,\text{L}} = \boxed{0.240\,M\ \text{NaCl}}$

A few more examples...

Use FORMULA WEIGHT when relating mass and moles

You have a 250.g bottle of silver(I) chloride (AgCl). How many moles of AgCl do you have?

AgCl: Ag : 1 x 107.9
Cl : 1 x 35.45

143.35 g AgCl = mol AgCl

$$250.\text{ g AgCl} \times \frac{\text{mol AgCl}}{143.35\text{ g AgCl}} = 1.74\text{ mol AgCl}$$

How many moles of NaOH are present in 155 mL of 1.50 M NaOH?

When relating moles and VOLUME, we need to use CONCENTRATION (usually MOLARITY - M)

$\text{mL} = 10^{-3}\text{ L}$ 1.50 mol NaOH = L

$$155\text{ mL} \times \frac{10^{-3}\text{ L}}{\text{mL}} \times \frac{1.50\text{ mol NaOH}}{\text{L}} = 0.233\text{ mol NaOH}$$

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

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

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:

1. - Relate the amount of substance we know (mass or volume) to a number of moles
2. - Relate the moles of one substance to the moles of another using the equation
3. - 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 the 25.0 g of bromine to moles. Use formula weight. $Br_2: \frac{2 \times 79.90}{159.8}$

$159.8\,g\ Br_2 = mol\ Br_2$

$$25.0\,g\ Br_2 \times \frac{mol\ Br_2}{159.8\,g\ Br_2} = 0.156445569\ mol\ Br_2$$

(2) Convert the moles bromine to moles aluminum. Use chemical equation.

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

$$0.156445569\ mol\ Br_2 \times \frac{2\ mol\ Al}{3\ mol\ Br_2} = 0.104297038\ mol\ Al$$

(3) Convert the moles aluminum to mass. Use formula weight. $Al: 26.98$

$26.98\,g\ Al = mol\ Al$

$$0.104297038\ mol\ Al \times \frac{26.98\,g\ Al}{mol\ Al} = \boxed{2.81\,g\ Al}$$

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

$$25.0\,g\,Br_2 \times \frac{mol\,Br_2}{159.8\,g\,Br_2} \times \frac{2\,mol\,Al}{3\,mol\,Br_2} \times \frac{26.98\,g\,Al}{1\,mol\,Al} = \boxed{2.81\,g\,Al}$$

(1) (2) (3)

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

← Conservation of mass!

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?

Calculating the mass of aluminum bromide directly:

$$25.0\,g\,Br_2 \times \frac{1\,mol\,Br_2}{159.8\,g\,Br_2} \times \frac{2\,mol\,AlBr_3}{3\,mol\,Br_2} \times \frac{266.68\,g\,AlBr_3}{1\,mol\,AlBr_3} = 27.8\,g\,AlBr_3$$

$AlBr_3$: Al : 1×26.98

Br : 3×79.90

266.68

Example:

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

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

1 - Convert 25.0 g sodium carbonate to moles using formula weight.
2 - Convert moles sodium carbonate to moles HCl using chemical equation.
3 - Convert moles HCl to volume HCl using concentration (6.00 mol/L)

Na_2CO_3: Na: 2 x 22.49
C: 1 x 12.01
O: 3 x 16.00

105.99 g Na_2CO_3 = mol Na_2CO_3

① $$25.0\,g\,Na_2CO_3 \times \frac{mol\,Na_2CO_3}{105.99\,g\,Na_2CO_3} = 0.235871308\,6\,mol\,Na_2CO_3$$

2 mol HCl = mol Na_2CO_3

②
$$0.2358713086\,mol\,Na_2CO_3 \times \frac{2\,mol\,HCl}{mol\,Na_2CO_3} = 0.4717426172\,mol\,HCl$$

 Example:

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

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

1 - Convert 25.0 g sodium carbonate to moles using formula weight.
2 - Convert moles sodium carbonate to moles HCl using chemical equation.
3 - Convert moles HCl to volume HCl using concentration (6.00 mol/L)

(3) 6.00 mol HCl = L mL = 10^{-3} L

$$0.4717426172 \text{ mol HCl} \times \frac{L}{6.00 \text{ mol HCl}} \times \frac{mL}{10^{-3} L} = 78.6 \text{ mL of } 6.00 \text{ M HCl}$$

You can solve the problem on one line if you want:

105.99 g Na_2CO_3 = mol Na_2CO_3 2 mol HCl = mol Na_2CO_3

6.00 mol HCl = L mL = 10^{-3} L

$$25.0 \text{ g } Na_2CO_3 \times \underbrace{\frac{\text{mol } Na_2CO_3}{105.99 \text{ g } Na_2CO_3}}_{(1)} \times \underbrace{\frac{2 \text{ mol HCl}}{\text{mol } Na_2CO_3}}_{(2)} \times \underbrace{\frac{L}{6.00 \text{ mol HCl}} \times \frac{mL}{10^{-3} L}}_{(3)} =$$

= 78.6 mL