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_4NO_3 : N: $2 \times 14.01 = 28.02$

H: $4 \times 1.008 = 4.032$

O: $3 \times 16.00 = 48.00$

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

80.052 g NH_4NO_3 = 1 mol NH_4NO_3

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

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

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

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

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

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

* See SECTIONS 4.7 - 4.10 for more information about MOLARITY and solution calculations (p 154 - 162)

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

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

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

(11,800 mL)

This is too large for a typical lab-scale measurement, so we should probably pick a more concentrated solution of HCl to get 0.657 mol.

What if we used 6.00 M HCl?

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

$$0.657\ \text{mol HCl} \times \frac{1\ \text{L}}{6.00\ \text{mol HCl}} = 0.110\ \text{L}$$

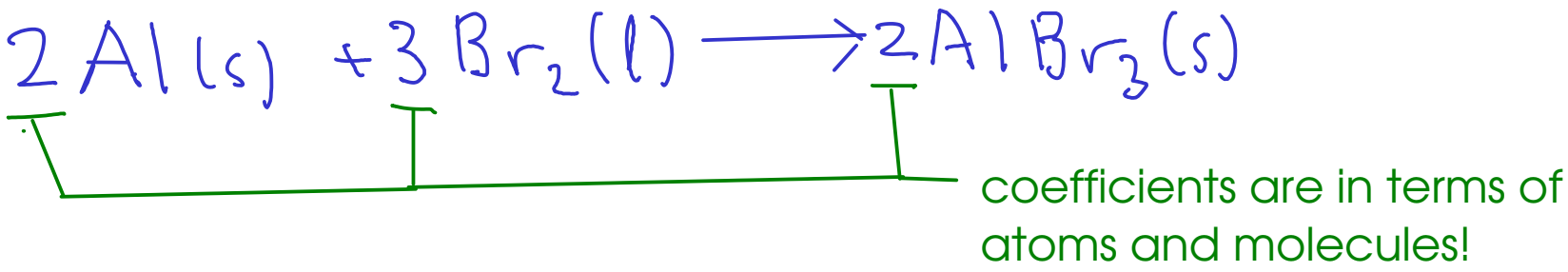
(110. mL)

Use a 250 mL graduated cylinder to measure out this quantity of acid (or use two measurements in a 100 mL cylinder)

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 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

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

* 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!

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

① ② ③

You can solve the second part of the question using CONSERVATION OF MASS - since there's only a single product and you already know the mass of all reactants.

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

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?

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

① convert mass bromine to moles

② convert moles bromine to moles aluminum bromide

③ convert moles aluminum bromide to mass

Example:

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

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

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1 - Convert 25.0 g of sodium carbonate to moles. Use formula weight.
2 - Convert moles of sodium carbonate to moles HCl using chemical equation.
3 - Convert moles HCl to volume using molarity (6.00 M HCl)

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

Formula weight of sodium carbonate

$105.99\ g\ Na_2CO_3 = mol\ Na_2CO_3$

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

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② $2\ mol\ HCl = mol\ Na_2CO_3$

This equality comes from the coefficients in the chemical equation

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

Example:

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

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

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

M = moles solute per liter

$$0.471743\ mol\ HCl \times \frac{L}{6.00\ mol\ HCl} \times \frac{mL}{10^{-3} L} = \boxed{78.6\ mL\ of\ 6.00\ M\ HCl}$$

This step converts from liters to milliliters, since that's what the problem statement requests.