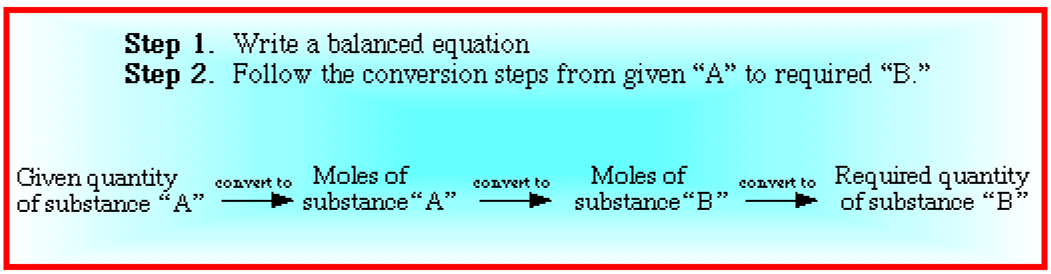
Stoichiometry

There are four basic types of stoichiometry problems:

1. **Given moles** of substance "A", **find moles** of substance "B." (Called mole to mole stoichiometry) which we covered in the last lesson
2. **Given moles** of substance "A", **find the quantity** (mass, volume, concentration, etc) of substance "B".
3. **Given a quantity** (mass, volume, concentration, etc) of substance "A", **find moles** of substance "B".
4. **Given a quantity** (mass, volume, concentration, etc) of substance "A", **find a quantity** of substance "B".

All of these types can be solved by using all or part of a single pattern or "roadmap."



Let's look at them one at a time skipping the first since we've already looked at it:

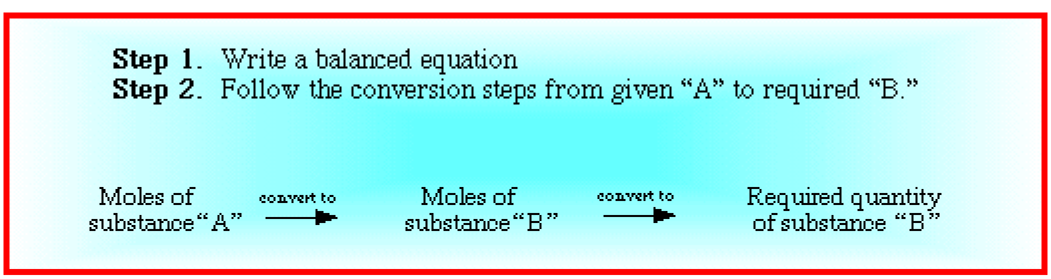
2. Mole-to-Quantity Stoichiometry

This type of stoichiometry question involves using the mole ratio of a balanced equation to determine the required quantity (mass, volume, concentration, etc.) of a substance, given a number of moles of another substance.

The steps required for complete solution are:

1. Write a balanced equation
2. Use dimensional analysis to convert moles of given (A) to moles of (B) to "quantity" of (B).

The "roadmap changes slightly to look like this:



Example 1:

What mass of sodium chloride can be produced by reacting 0.750 mol of chlorine gas with sufficient sodium metal?

Given: 0.750 mol of $Cl_{2(g)}$ (A)
Find: _?_ **grams** of $NaCl_{(s)}$ (B)

The Balanced Equation is:

$$2Na_{(s)} + Cl_{2(g)} \text{ -------> } 2NaCl_{(s)}$$

mass of NaCl produced = $0.750 \text{ mol } Cl_{2(g)} \times \frac{2 \text{ mol } NaCl_{(s)}}{1 \text{ mol } Cl_{2(g)}} \times \frac{58.44 \text{ g } NaCl_{(s)}}{1 \text{ mol } NaCl_{(s)}}$

(Note: Units that cancel are shown in the same color.)

mass of NaCl produced = 87.7 g of NaCl

Example 2:

What volume of oxygen gas at 25.0°C and 90.0 kPa can be produced by decomposing 2.75 mol of potassium chlorate?

Given: 2.75 moles of $KClO_{3(s)}$ (A)
Find: _?_ liters of $O_{2(g)}$ at 25.0°C and 90.0 kPa (B)

The balanced equation is:

$$2KClO_{3(s)} \text{ -------> } 2KCl_{(s)} + 3O_{2(g)}$$

Moles (n) of $O_{2(g)}$ produced = $2.75 \text{ mol } KClO_{3(s)} \times \frac{3 \text{ mol } O_{2(g)}}{2 \text{ mol } KClO_{3(s)}} = 4.125 \text{ mol } O_{2(g)}$

Remembering that **PV = nRT**

Transposing in terms of V produces:

$$V = \frac{nRT}{P}$$

Therefore

$$V = \frac{4.125 \text{ mol } O_{2(g)} \times 8.314 \text{ kPa/L /mol/K} \times 298K}{90.0 \text{ kPa}}$$

= 114 L of oxygen gas

Example 3:

What volume of 1.25 mol/L $H_2SO_{4(aq)}$ is needed to neutralize 3.50 mol of potassium hydroxide?

Given: 3.50 mol $KOH_{(aq)}$ (A)
Find: _?_ L of 1.25 mol/L $H_2SO_{4(aq)}$ (B)

The balanced equation is:

$$\mathbf{H_2SO_{4(aq)} + 2KOH_{(aq)} \text{-------}> K_2SO_{4(aq)} + 2H_2O_{(l)}}$$

$$\textbf{Moles of } \mathbf{H_2SO_{4(aq)}} = 3.50\ \cancel{\text{mol KOH}}_{(aq)} \times \frac{1\ \text{mol } H_2SO_{4(aq)}}{2\ \cancel{\text{mol KOH}}_{(aq)}} = 1.75\ \text{mol } H_2SO_{4(aq)}$$

Recalling that Concentration (C) $= \dfrac{\text{moles (n)}}{\text{Volume (L)}}$

Transposing in terms of V produces...

$$\text{Volume in Liters} = \frac{\text{moles (n)}}{\text{Concentration (C)}}$$

Substituting:

$$\mathbf{V} = \frac{1.75\ \text{mol } H_2SO_{4(aq)}}{\frac{1.25\ \text{mol}}{\text{L}}}$$

$$= 1.75\ \cancel{\text{mol } H_2SO_{4}}_{(aq)} \times \frac{1\ \text{L}}{1.25\ \cancel{\text{mol } H_2SO_{4}}_{(aq)}}$$

$$= 1.40\ \text{L}$$

It requires 1.40 L of 1.25 mol/L $H_2SO_{4(aq)}$ to neutralize 3.50 mol of $KOH_{(aq)}$.

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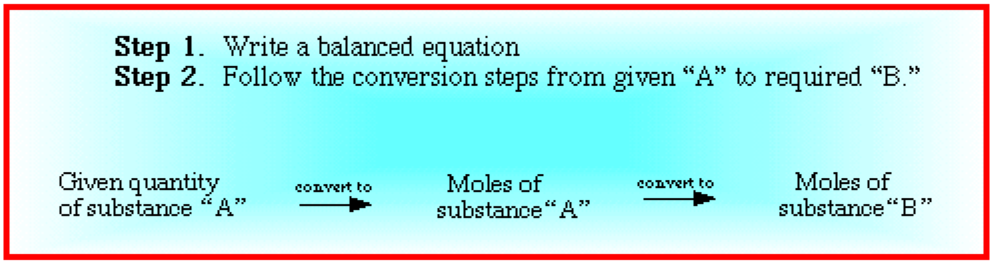
3. Quantity-to-Mole Stoichiometry

This type of question involves converting the given quantity of one substance (A) to a number of moles of A and then using the mole ratio from a balanced equation to determine the required number of moles of another substance (B).

The "roadmap" changes again to look like this.



Example 1:

How many moles of water vapor can be produced by completely burning 50.0 g of methane gas?

Given: 50.0 g of $CH_{4(g)}$ (A)
Find: __?__ mol of $H_2O_{(g)}$ (B)

The balanced equation is

$$\mathbf{CH_{4(g)} + 2O_{2(g)} \text{ -------> } CO_{2(g)} + 2H_2O_{(g)}}$$

$$\text{Moles of } H_2O_{(g)} = 50.0 \cancel{\text{g CH}_{4(g)}} \times \frac{1 \cancel{\text{mol CH}_{4(g)}}}{16.05 \cancel{\text{g CH}_{4(g)}}} \times \frac{2 \text{ mol } H_2O_{(g)}}{1 \cancel{\text{mol CH}_{4(g)}}} = \mathbf{3.12 \text{ mol } H_2O_{(g)}}$$

Completely burning 50.0 g of methane gas will produce 6.23 mol of water vapor.

Example 2:

How many moles of calcium hydroxide are needed to completely react with 25.0 mL of 1.25 mol/L $HCl_{(aq)}$?

Given: 25.0 mL of 1.25 mol/L $HCl_{(aq)}$ (A)
Find: __?__ mol of $Ca(OH)_{2(aq)}$ (B)

The balanced equation is: $\mathbf{2HCl_{(aq)} + Ca(OH)_{2(aq)} \text{ -------> } CaCl_{2(aq)} + 2H_2O_{(l)}}$

Since $HCl_{(aq)}$ is in solution, the "given quantity" is a concentration and a volume. The number of moles of solute present is calculated using n = C x V. The path will look like this:

Concentration of $HCl_{(aq)}$ x Volume $HCl_{(aq)}$ ---gives---> mol $HCl_{(aq)}$ ---convert to ---> mol $Ca(OH)_2$

mol of $Ca(OH)_{2(aq)}$ = $\frac{1.25\ \cancel{mol\ HCl_{(aq)}}}{\cancel{L}} \times 0.0250\ \cancel{L} \times \frac{1\ mol\ Ca(OH)_{2(aq)}}{2\ \cancel{mol\ HCl_{(aq)}}}$

= **0.0156 mol $Ca(OH)_{2(aq)}$**

Example 3:

How many moles of carbon dioxide gas are produced by burning 50.0 L of $C_2H_{6(g)}$ at standard temperature and pressure (STP)?

Given: 50.0 L of $C_2H_{6(g)}$ (A)
Find: _?_ moles of $CO_{2(g)}$ (B)

The balanced equation:

$2C_2H_{6(g)}$ + $7O_{2(g)}$ -------> $4CO_{2(g)}$ + $6H_2O_{(g)}$

Recall that one mole of any gas at STP occupies 22.4 L.

moles of $CO_{2(g)}$ = $50.0\ \cancel{L} \times \frac{1\ \cancel{mol\ C_2H_{6(g)}}}{22.4\ \cancel{L}} \times \frac{4\ mol\ CO_{2(g)}}{2\ \cancel{mol\ C_2H_{6(g)}}}$ = **4.46 mol $CO_{2(g)}$**.

(Note: Units that cancel are shown in the same color.)

Burning 50.0 L of ethane gas at STP will produce 4.46 mol of carbon dioxide.

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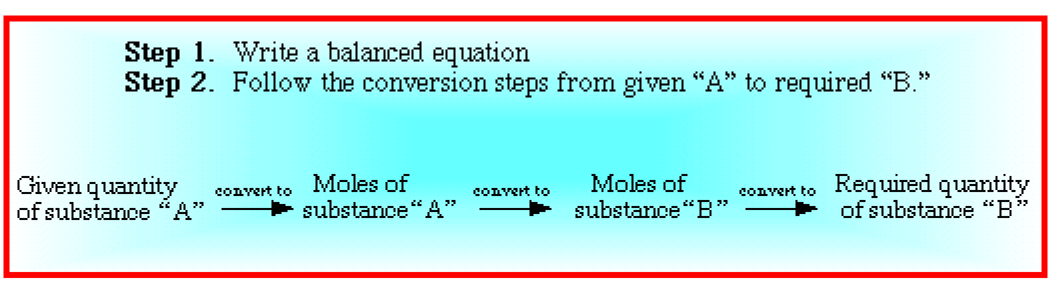
4. Quantity-to-Quantity Stoichiometry

This type of question involves:

1. converting the given quantity of one substance to a number of moles of that same substance, and then
2. using the mole ratio of a balanced equation to convert the number of moles of the "given" substance to the number of moles of the "required " substance, and finally
3. converting that number of moles to the required quantity asked for by the problem.

The "roadmap" now looks like this:



You can see clearly that there are three conversions to be made to get from the given information to the required information. Once again, dimensional analysis is the mathematical method used to convert from one unit to the next during the solution of the problem.

Example 1:

What volume of 0.250 mol/L $H_3PO_{4(aq)}$ can be neutralized by 16.8 g of $KOH_{(s)}$?

Given: 16.8 g of $KOH_{(s)}$ (A)
Find: _?_ mL of 0.250 mol/L $H_3PO_{4(aq)}$ (B)

The balanced equation:

$H_3PO_{4(aq)}$ + $3KOH_{(s)}$ -------> $K_3PO_{4(aq)}$ + $3H_2O_{(l)}$

$$\text{Volume of } H_3PO_{4(aq)} = 16.8\text{ g } \cancel{KOH_{(s)}} \; \frac{1\; \cancel{\text{mol } KOH_{(aq)}}}{56.11\; \cancel{\text{g } KOH_{(s)}}} \times \frac{1\; \cancel{\text{mol } H_3PO_{4(aq)}}}{3\; \cancel{\text{mol } KOH_{(aq)}}} \times \frac{\text{L}}{0.250\; \cancel{\text{mol } H_3PO_{4(aq)}}}$$

= **0.399 L or 399 mL**

399 mL of 0.250 mol/L $H_3PO_{4(aq)}$ will be neutralized by 16.8 g of $KOH_{(s)}$.

Example 2:

If 200.0 mL of 0.100 mol/L $AgNO_{3(aq)}$ reacts completely with solid copper, what mass of silver will be produced?

Given: 200 mL of 0.100 mol/L $AgNO_{3(aq)}$ (A)
Find: _?_ g of $Ag_{(s)}$ (B)

The balanced equation:

$2AgNO_{3(aq)}$ + $Cu_{(s)}$ -------> $Cu(NO_3)_{2(aq)}$ + $2Ag_{(s)}$

$$\text{Mass of } Ag_{(s)} = \frac{0.100\; \cancel{\text{mol } AgNO_{3(aq)}}}{\cancel{\text{L}}} \times 0.200\; \cancel{\text{L}} \times \frac{2\; \cancel{\text{mol } Ag_{(s)}}}{2\; \cancel{\text{mol } AgNO_{3(aq)}}} \times \frac{107.87\text{ g } Ag_{(s)}}{\cancel{\text{mol } Ag_{(s)}}}$$

= **2.16 g $Ag_{(s)}$**

200.0 mL of 0.100 mol/L $AgNO_{3(aq)}$ reacts completely to produce 2.16 g of $Ag_{(s)}$

Example 3:

What volume of 0.540 mol/L $H_2SO_{4(aq)}$ is necessary to react completely with 50.0 mL of 0.650 mol/L $KOH_{(aq)}$?

Given: 50.0 mL of 0.650 mol/L $KOH_{(aq)}$ (A)
Find: _?_ mL of 0.540 mol/L $H_2SO_{4(aq)}$ (B)

The balanced equation:

$$\mathbf{2KOH_{(aq)} + H_2SO_{4(aq)} \text{ -------> } K_2SO_{4(aq)} + 2H_2O_{(l)}}$$

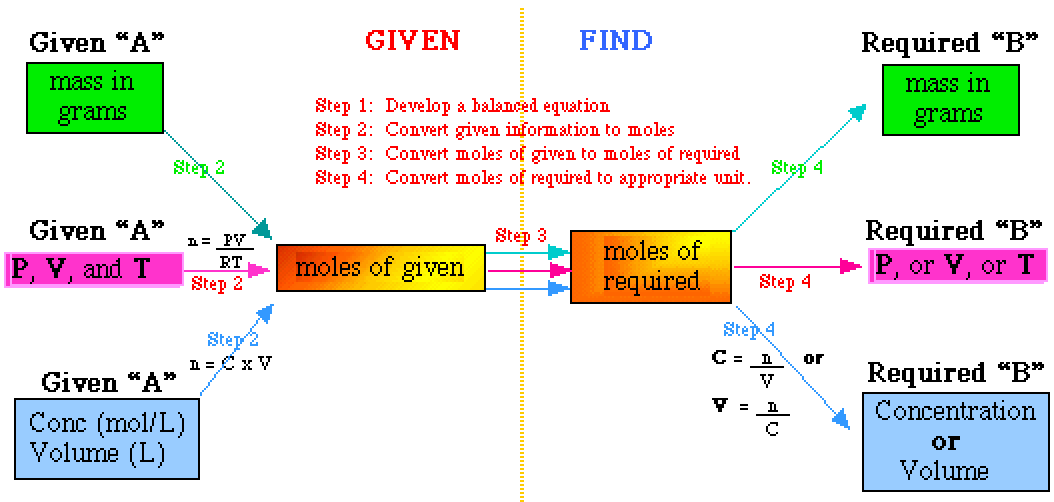
$$\text{Volume of } H_2SO_{4(aq)} = \frac{0.650\ \cancel{mol\ KOH_{(aq)}}}{\cancel{L}} \times 0.050\ \cancel{L} \times \frac{1\ \cancel{mol\ H_2SO_{4(aq)}}}{2\ \cancel{mol\ KOH_{(aq)}}} \times \frac{L}{0.540\ \cancel{mol\ H_2SO_{4(aq)}}}$$

= **0.0301 L or 30.1 mL**

50.0 mL of 0.650 mol/L $KOH_{(aq)}$ reacts completely with 30.1 mL of 0.540 mol/L $H_2SO_{4(aq)}$.

Here is a summary "roadmap" that attempts to include all the possible combinations of stoichiometry questions into one diagram:

A Stoichiometry Roadmap



A Stoichiometry problem can ask you to start at any box on the "given" side, and convert your way to any box on the "find" side. However,

- The moles of given to moles of required path is referred to a **mole-to-mole** Stoichiometry
- The green path is often referred to as **Gravimetric stoichiometry**
- The red path is often referred to as **Gas stoichiometry**
- The blue path is often referred to as **Solution stoichiometry**