AS Level calculations involving Reacting Gases
(A First Year Blog)

- I am going to do a number of different examples for you shortly, but it is very important that you should start by knowing that Avogadro's principle states that

"Equal volumes of gases will always contain the same number of moles"

- In other words, if I had 'X' sealed jars, each of which had **exactly** the same volume, but each of which contained a different gas, then there would be **exactly the same number of moles** of gas in each jar! **It does not matter what gas there is in each jar, there will be EXACTLY the same number of moles in each jar!**[1]

- To me, Avogadro's discovery was a startling one, because he was saying that it did not matter how big or how small the molecules are, there will always be the same number of molecules in the jar (and if you think about it, this implies that the space between each molecule is so large that the size of the molecules becomes irrelevant)!

- 1kPa= 1 Nm^{-2}, and 1 atmosphere can be defined either as 101.325 kPa or as **100kPa** (cf. your Exam Board), and 0˚C = 273.15K, ∴ **Standard Temperature and Pressure, STP = 0˚C /273.15K** and **100 kPa.** (Room Temp and Pressure, RTP = **25˚C (298.15K)** and **100 kPa**.)

- The volume of a gas increases in line with an increase in temperature therefore
1 mole of ANY gas will occupy approximately **22.4 dm^3** at **0˚C** and 100 kPa (**STP**)
1 mole of ANY gas will occupy approximately **24.0 dm^3** at **25˚C** and 100 kPa (**RTP**).

NB There is a variation of definition between differing bodies as to the exact temperature and pressure to be used.[2] Definitions change from Institute to Institute, and from country to country (and would you believe that the US armed forces have their own specifications for gas pressure and temperature because they need to know the speed at which their bullets leave the muzzles of their weapons!) and the definitions have also changed over time. Follow the definition used by your exam board and the textbook that you are using. The recognised institutes are the International Union of Pure and Applied Chemistry (IUPAC), the National Institute of Standards and Technology (NIST), and International Standard Metric Conditions.

- In essence "gas" calculations are exactly the same as "solid" calculations and "liquid" calculations, except that in "solid" calculations **MOLE** Reaction Ratios are NOT the same as **MASS** Reaction Ratios, and in "liquid" calculations **MOLE** Reaction Ratios are NOT the same as **VOLUME** Reaction Ratios – but in gas calculations, because equal moles of any gas always occupy the same volume,
VOLUME Reaction Ratios work out EXACTLY the same as MOLE Reaction Ratios.

- For example, in the reaction equation **H_2 (g) + Cl_2 (g) —> 2HCl (g)** , if I knew how many cubic metres of Hydrogen or how many cubic metres of Chlorine had reacted, then I would **not** need to convert those volume numbers into moles of the gases! I could work directly from those numbers to obtain the volume of HCl (g) obtained, because **Volume Reaction Ratios ARE exactly the same as the Mole Reaction Ratios** (and this makes gas calculations **very** easy indeed!).

[1] You may not realise how stunning a conclusion this is – but if you go on and read Chemistry at University, and learn about the size of different molecules, then you will see that that this conclusion is almost equivalent to realising that the world is not flat but spherical!
[2] Scientists need to be precise. On one of the US missions to the moon, one lot of engineers were using miles and another lot were working in metric measurements! Luckily nobody was killed on that particular mission (although carelessness did result in deaths on another mission).

- If (for example) 20 cm^3 of H_2 (g) reacted with an unknown volume of Cl_2 (g) to form an unknown volume of HCl (g), then because (a) the reaction equation in the previous paragraph says that the Mole reaction ratio of H to Cl is 1 : 1 and because (b) equal volumes of any gas will always contain the same number of moles, then it follows that 20 cm^3 of Cl_2 (g) reacted with 20 cm^3 of H_2 (g) and 40 cm^3 of HCl (g) were formed!

For gases, the VOLUME Reaction Ratio works out exactly the same as the MOLE Reaction Ratio!

Calculations involving VOLUMES of gases and MOLES

Q What volume of Oxygen is needed for the complete combustion of 2 dm^3 of C_3H_8(g)?

NB Oxygen exists as O_2 molecules therefore the Oxygen has to be in the form of ***molecules****,* and when we get to Organic Chemistry you will see that the reaction equation is

A C_3H_8 (g) + $5O_2$ (g) —> $3CO_2$ (g) + $4H_2O$ (g)

- The Reaction Ratio is 1 mole of C_3H_8 : 5 moles of O_2
- but 1 mole of EVERY GAS/ANY GAS/ALL GASES occupies **exactly the same volume** therefore the VOLUME Reaction Ratio is exactly the same as the MOLE Reaction Ratio,
- therefore 1 dm^3 of C_3H_8 will have reacted with 5 dm^3 of O_2 (cf. footnote [3]),
- ***therefore 2 dm^3 of C_3H_8 will react with 10 dm^3 of O_2 .***

Q) What Volume of Hydrogen is obtained when 3.0g of Zinc react with an excess of dilute H_2SO_4 at STP (Standard Temperature and Pressure[4])?

A The Reaction Equation is Zn (s) + H_2SO_4 (aq) —> H_2 (g) + $ZnSO_4$ (aq)
and we can calculate that 1 mole of solid Zn has a Mass of 1 x RAM of Zn = 65.4g
and we have learnt that 1 mole of ANY gas occupies 22.4 dm^3 of volume at STP

- Therefore we can say that
  1 mole (or 65.4g) of solid Zn generates 1 mole (or 22.4 dm^3) of H_2 (g)
  therefore 3.0g of solid Zn will generate X dm^3 of H_2 (g)
  where $X = \frac{22.4\ dm^3 \times 3.0g}{65.4g} \approx 1.03\ dm^3$ of H_2 (g) .

Q When all 100 cm^3 of a Hydrocarbon, C_xH_y, is burnt in 500cm^3 of Oxygen, 50 cm^3 of Oxygen are unused/300 cm^3 of CO_2 are formed/and 300 cm^3 of Steam are produced. What is the Formula of C_xH_y?

NB If 50 cm^3 of Oxygen are unused, then 450 cm^3 must have been used!

A The **VOLUME** Reaction Ratio is exactly the same as the **MOLE** Reaction Ratio for gases,
∴ 100 cm^3 of C_xH_y + 450 cm^3 of O_2 (g) —> 300 cm^3 of CO_2 (g) + 300 cm^3 of H_2O (g)
∴ the simplest Reaction Equation must be
$1C_xH_y$ (g) + $4.5O_2$ (g) —> $3CO_2$ (g) + $3H_2O$ (g)

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[3] ...to produce 3 dm^3 of CO_2 (g) and 4 dm^3 of H_2O (g). [NB At Room Temperature Water is a liquid, therefore in a reaction equation it would normally be written as H_2O **(l)**, but please note that this reaction is about GASES therefore the Water here has been written as H_2O **(g)**.

[4] STP is where the temperature is 0˚C/273.15K rather than 25˚C/298.15K.

- If we now balance the equation, on the RHS of the equation we get 3 lots of C, and 6 lots of H, and 9 lots of O, therefore there must be the same number of atoms of each of those elements on the LHS of the equation, and the Reaction equation must be
  C_3H_6 (g) + $4.5O_2$ (g) —> $3CO_2$ (g) + $3H_2O$ (g)
  and putting the equation in integers we get
  $2C_3H_6$ (g) + $9O_2$ (g) —> $6CO_2$ (g) + $6H_2O$ (g)

This next one is from Lainchbury Stephens and Thompson (LST).

Q) 10 cm^3 of a gaseous hydrocarbon was mixed at room temperature with 100 cm^3 (an excess) of Oxygen and reacted by a spark and allowed to cool to room temperature. The total volume of gases was now 95 cm^3, and when this was reacted with a concentrated solution of Sodium Hydroxide, the volume of the gases reduced to 75cm^3. What was the formula of the hydrocarbon?

A) Let the formula of the hydrocarbon be C_xH_y , and (assuming complete combustion) the reaction equation will then (ignoring the excess Oxygen) be

$$C_xH_y + (x + \frac{y}{4}).O_2 \longrightarrow xCO_2\,(g) + \frac{y}{2}H_2O\,(l)$$

- The volume of CO_2 (g) produced will be the volume of gas that reacts with the Sodium Hydroxide, and this is given by (95 – 75) cm^3 = 20 cm^3 .

- At room temperature, liquid Water, H_2O (l), will occupy almost no volume, therefore the 75 cm^3 of gas must be the excess Oxygen, therefore the volume of Oxygen that was used up was (100 – 75 =) 25 cm^3 .

Reaction Equation $C_xH_y + \frac{4x+y}{4}O_2 \longrightarrow x.CO_2\,(g) + \frac{y}{2}H_2O\,(l)$

Multiplying across by "4" $4C_xH_y + (4x + y)\,O_2 \longrightarrow 4x.CO_2\,(g) + 2yH_2O\,(l)$

Volume Reaction Ratio	10	25	20	10
which is the same as	2	5	4	2

- $4C_xH_y$: $4xCO_2$ has a ratio of 1 : 2 , therefore x = 2 , and by substituting x = 2 we get

- From $4C_2H_y$: $2yH_2O$ we get y = 2.

- Therefore the substance has the formula C_2H_2.

- As a check we can see that there are [(4x2) + 2] = 20 Oxygen atoms on the left, and [(8 x 2) + 4] = 20 O atoms on the right.

- **The secret of working with Gases is to recognise that**

    - **The MOLAR Reaction Ratio and the VOLUME Reaction Ratio are EXACTLY the same, and**

    - **where it is relevant, it is necessary to convert one mole of a substance into its Mass or Volume equivalent (and vice versa).**[5]

- **After doing a lot of worked examples, you will get the hang of doing it without thinking about it. [It is just like learning to change gear when you are learning to drive.]**

- In the next Chapter, I am going to do three examples for each of SOLIDS / LIQUIDS /and GASES, but there are *many* calculations that can be done with regard to Gases (and in principle most of them are very simple), and I would strongly urge you to work through as many calculations involving Solids/Liquids/and Gases as you can from "Advanced Chemistry Calculations" by Lainchbury, Stephens and Thompson (I.L.P.A.C.), and Jim Clark's book.

[5] You will remember that "vice versa" is the Latin for "the other way round".