A First Year blog on Calculations in Chemistry: Part 3, 9th March 2019

(This is a **revision** blog. It is merely a *summary* of some of the things that you need to know. *Everything in this blog can be found in Chapters 38-41 of the First Year, Foundation Chemistry Book*.)

In Part 1 of this blog I told you about	Moles, and
in Part 2 I told you about	Relative Atomic Mass (RAM), and
in Part 3 I will tell you about	Relative Molecular Mass and Relative Formula Mass, and
in Part 4 I will tie everything up.	

Let us now consider
A) Relative **Molecular** Mass (RMM or M_r), and
B) Relative **Formula** Mass (RFM or M_r).

We talk about the **Atomic Mass** of atoms of all the different elements, but we do not talk about the "*Atomic* Mass*"* of a ***molecule***. Instead we talk about its "**MOLECULAR** Mass".

We also do not talk about the *Atomic Mass* of an ***ionic unit*** but instead we talk about its "**FORMULA** Mass".

However, we DO talk about the *Atomic* mass of a metallic substance even though technically speaking a piece of metal actually consists of metal *ions* and not metal *atoms*, and the reason that we do so is because, numerically speaking, one metal ion together with its delocalised electron (or electrons) is equivalent to one atom of the metal.

If therefore a substance under consideration is a "*molecule*" then we talk about its "***MOLECULAR mass***", and if the substance in question is an *ionic substance*, then we talk about its "***FORMULA mass***". I'll say that again in a different way. We talk about

• **ATOMIC Mass**	if it is an	**atom of an element**
• **MOLECULAR mass**	if it is a	**molecule**
• **FORMULA mass**	if it is an	**ionic unit.**

A) Relative MOLECULAR Mass (RMM or M_r)

Just as the RAM of an element is the mass of 1 atom of an element compared to one-twelfth of the mass of 1 atom of Carbon *(or the mass of 1 mole of atoms of the element compared to one-twelfth the mass of 1 mole of Carbon atoms i.e. 1g)*, so also the **Relative Molecular Mass (RMM** or **M_r)** of a substance is
a) the mass of 1 molecule of the substance compared to one-twelfth of the mass of 1 atom of Carbon, or
b) the mass of 1 mole of molecules of that substance compared to one-twelfth the mass of 1 mole of Carbon atoms i.e. 1g)
and, all that we need to know is how many atoms there are in the molecule, and what sort of atoms they are (i.e. which element the atoms belong to), and we can then easily calculate the Mass of the molecule.

Please note that RMM or M_r has NO UNITS! RMM (just like RAM or A_r) is a relative unit of measurement, therefore **it has no units**.

It is in fact very easy to calculate the RMM of a molecular substance. A molecular substance can exist (i) as molecules of an **element**, or (ii) as molecules of a **compound**, and the calculation of the RMM of either (a) the molecules of an element or (b) the molecules of a compound is very easy.

a) Calculating the RMM (or M_r) of the molecules of an ELEMENT

When looking at a Periodic Table, the RAM of an element is the larger of the two numbers in the box that contains the chemical symbol of the element, and **that number represents the absolute mass (in grams) of 1 MOLE of the atoms of that element**.

- The absolute mass of 1 mole of ^{16}O ***atoms*** is thus 16g, and

since there are two atoms of Oxygen in every molecule of Oxygen

- the mass of 1 mole of Oxygen (O_2) **molecules** is therefore (2 x 16g =) 32g, and
- the mass of 1 mole of Nitrogen (N_2) molecules will be (2 x 14g =) 28g

and, (just as we did for RAM) we can therefore write the RMM of O_2 = 32, and the RMM of N_2 = 28, *with no units after the numbers*.

However, (just as we did for the RAM) we can also write
RMM of 1 mole of Oxygen molecules = 32 g mol^{-1}, and
RMM of 1 mole of Nitrogen molecules = 28 g mol^{-1}, ... and so on, and
I would advise you ALWAYS to put RAM and RMM and RFM figures in the "g mol^{-1}" form in your calculations – otherwise the units in your answer could go awry when you start cancelling![1]

When you start to do Second Year Chemistry calculations they could look like this

Question

- The following concentrations in the production process for Ammonia were obtained at equilibrium at 400K: $[NH_3]$ = 31 x 10^{-2} mol dm^{-3}, $[N_2]$ = 8.5 x 10^{-1} mol dm^{-3}, $[H_2]$ = 3.1 x 10^{-3} mol dm^{-3} and you were asked to calculate K_c .

Answer

$$N_2\,(g) \;+\; 3\,H_2\,(g) \;\rightleftharpoons\; 2\,NH_3\,(g)$$

and since $$K_c = \frac{[NH_3]^2}{[N_2]^1\,[H_2]^3} \quad \text{at equilibrium at 400K}$$

$$= \frac{(31 \times 10^{-2})^2}{(8.5 \times 10^{-1}) \times (3.1 \times 10^{-3})^3} \quad \frac{(\text{mol dm}^{-3})^2}{(\text{mol dm}^{-3}) \times (\text{mol dm}^{-3})^3}$$

$$\approx 3.795 \times \frac{10^{-4}}{10^{-1} \times 10^{-9}} \quad \frac{\text{mol}^2\,\text{dm}^{-6}}{\text{mol}^4\,\text{dm}^{-12}}$$

$$\approx 3.8 \times 10^6\ \text{mol}^{-2}\,\text{dm}^6$$

- **Please notice how strange the units are! Whether K_c has units and what the units are will vary from reaction equation to reaction equation depending on the stoichiometry of the equation, and you do need to state the units in your answer**! **If therefore you did not state your units correctly, then they would not have cancelled out correctly and you could have lost one mark for getting your units wrong.** (When you are striving to get an A or an A* grade, then every single mark that you score is important – and every mark that you do **not** score is equally important.)

OK, let us leave the complicated stuff for a Second Year blog, and get back to the elementary stuff that we were doing.

---

[1] The word "awry" here signifies that you will be in grave danger of putting the wrong units to the final answer to your calculation.

b) Calculating the RMM (or M_r) of the molecules of a COMPOUND

Let us say that we want to calculate the RMM of a molecule of Sulphuric Acid (H_2SO_4). Well, we can easily do so because we know that there are

2 atoms of Hydrogen + 1 atom of Sulphur + 4 atoms of Oxygen in the molecule, therefore

the Mass of 1 molecule of H_2SO_4 = (2 x RAM of H) + (1 x RAM of S) + (4 x RAM of O)

= [(2 x 1.0) + (1 x 32.1) + (4 x 16.0)] g mol^{-1} = **98.1 g mol^{-1}**.

Equally, the RMM of a molecule of CH_3CH_2COOH (Propanoic Acid) would be given by

[(1x12) + (3x1) + (1x12) + (2x1) + (1x12) + (1x16)+ (1x16) + (1x1)] g mol^{-1} = **74 g mol^{-1}**,

or you could add up all the Cs/all the Hs/and all the Os and multiply each number by its RAM and you would get [(3x12) + (6x1) + (2x16)] g mol^{-1} = 74 g mol^{-1},

and similarly the RMM of Ethanedioic Acid (COOHCOOH or $C_2H_2O_4$) would be given by

[(2x12) + (4x16) + (2x1)] g mol^{-1} = 90 g mol^{-1}.

NB A general rule/tip for a Science 'A' Level exam

In an exam you may be asked to define something, and if you are asked to do so, then do NOT try to define it by writing an essay in English. You will **not** have enough time in an exam to do so! Instead **just write out the definition in the form of a mathematical calculation**.

Thus, for example if you are asked to define RMM, then just write

$$\textbf{RMM or } M_r = \frac{\text{Mass of 1 molecule of the molecular substance in g}}{\text{One-twelfth the mass of one ATOM of C-12 in g}}$$

or

$$\textbf{RMM or } M_r = \frac{\text{Mass of 1 MOLE of molecules of the molecular substance in g}}{\text{One-twelfth the mass of 1 mole of C-12 ATOMS in g (i.e. 1g)}}$$

NB Write out just one of the above in the exam. *You do not need to write both.*

Relative Formula Mass (RFM or M_r)

An Ionic substance is not the same as a Molecular substance – therefore while a molecular substance has a Relative MOLECULAR Mass, an Ionic substance is said to have a Relative ***FORMULA*** Mass (RFM).

[NB The symbol for RFM is still M_r! **"M_r"** ***is used for both RMM and RFM!****]*

The value for RFM is calculated in exactly the same way that the value for RMM is calculated e.g. if we wanted to calculate the RFM for $CaCO_3$, we would look up the RAM for 1 atom of Ca/the RAM for 1 atom of C/and three times the RAM for 1 atom of O – and then we would add up all the RAMs involved viz.

[(1x40.1) + (1x12.0) + (3x16.0)] = 100.1 ≈ 100 (to 3 significant figs.) = RFM of $CaCO_3$.

The Relative Formula Mass, RFM or M_r, of an Ionic substance is defined as

$$\textbf{RFM or } M_r = \frac{\text{Mass of 1 ionic unit of the ionic substance in g}}{\text{One-twelfth the mass of one ATOM of C-12 in g}}$$

or

$$\textbf{RMM or } M_r = \frac{\text{Mass of 1 MOLE of ionic units of the ionic substance in g}}{\text{One-twelfth the mass of 1 mole of C-12 ATOMS in g (i.e. 1g)}}$$

<u>The Calculation of Mass i.e. M = N x RAM, or M = N x RMM, or M = N x RFM</u> (whichever is appropriate)

Let us say that we wanted to calculate the combined Mass of 579 marbles, each of which (on earth) has a mass of 1.75g. The calculation would be very simple

Total Mass = Number of objects x Mass of 1 object

Mass of 579 marbles = 579 x 1.75g = 1,013.25g = 1.01325 kg

and we can make use of this methodology when we want to calculate the Mass of any group of objects in Chemistry.

Let us say that we did not have a weighing machine – but that we wanted to calculate the Mass of a bucketful of Calcium Carbonate ($CaCO_3$). Well, if we knew the Mass of 1 mole of $CaCO_3$, and we knew how many moles of $CaCO_3$ there were in the bucket, then we could easily calculate the Mass of the bucketful of $CaCO_3$ because we could use the equation above to say

Mass of the $CaCO_3$ = Number of moles of $CaCO_3$ x Mass of 1 mole of $CaCO_3$

or, if we use the accepted nomenclature, then

Mass of $CaCO_3$ = N x RFM of $CaCO_3$ (because M = N x RFM).

Or, if we wanted to know the Mass of a bucketful of dry Sulphuric Acid (H_2SO_4), i.e. with no water in it, then

Mass of the H_2SO_4 = Number of moles of H_2SO_4 x Mass of 1 mole of H_2SO_4 ,

or Mass of H_2SO_4 = N x RMM of H_2SO_4 (because M = N x RMM).

We can now formulate a general rule viz.

Mass = N x RAM for Elements
= N x RMM for Molecular substances, and
= N x RFM for Ionic substances

and could you please note that in *theoretical* Chemistry, Mass is normally measured in grams (g) **although in Industry itself it is normally measured in kilograms or in tonnes**.

Using the above three equations and the rule of cross-multiplication, we can say that

for **<u>Elements</u>**

if **M = N x RAM**, then $\mathbf{N = \frac{M}{RAM}}$, and $\mathbf{RAM = \frac{M}{N}}$

and for **<u>Molecular substances</u>**

if **M = N x RMM**, then $\mathbf{N = \frac{M}{RMM}}$, and $\mathbf{RMM = \frac{M}{N}}$

and for **<u>Ionic substances</u>**

if **M = N x RFM**, then $\mathbf{N = \frac{M}{RFM}}$, and $\mathbf{RFM = \frac{M}{N}}$

Molar Mass

The term "Molar Mass" is self-explanatory, because

"Molar Mass" = the mass of 1 mole of the atoms/or of the molecules/or of the ionic units of the substance under consideration.

Relative Mass and ABSOLUTE MASS

In atomic and molecular Chemistry, **Absolute** Mass is designated in grams, and the

Molar Mass of the **atoms** of an element = (1 x RAM) in grams

Molar Mass of the **molecules** of an element = (1 x RMM) in grams

Molar Mass of the **molecules** of a molecular substance = (1 x RMM) in grams

Molar Mass of the **ionic units** of an ionic substance = (1 x RFM) in grams

where the relevant RAM can be found in a Periodic Table, and RMM and RFM consist of all the RAMs of the elements in the substance added together.

The Mass of a molecule and the Mass of an ionic unit are both THE SUM OF THE MASSES OF THEIR COMPONENTS.

The relationship between the Mass of a **molecule** and the Mass of its constituents is exactly the same as the Mass of an **ionic unit** and the Mass of its constituents.

At this point in this Chapter, you might want to say to me "I understand that I have to look at a Periodic Table to ascertain the *RAM* of an element, but I am not all that confident about the calculations involved in finding out the *RMM* of a molecular substance or the *RFM* of an ionic substance", and I would then say to you, *"That's all right. That is exactly how most people feel when they come to this point in 'A' Level Chemistry"*. However, all this stuff is just like learning to drive a car. If you watch your parents when they are driving, they do not stop to think (not even for a nano-second) about what they are doing – they just get in the car and drive it automatically; and yet, if *you* are learning to drive, you will find it very difficult to master clutch control/hill starts/reversing/three point turns/lane discipline/etc. I promise you that, with practice, the mathematical calculations involved in Chemistry will become just as easy to do as it is to drive a car. **All that you need is practice.**

.