# Rates of Reactions (RoR), and Equilibria

There used to be a time when "Thermodynamics" in Chemistry (in schools) was known as "How Far, How Fast?" – and that is precisely what this Section is all about. The Rate of a Reaction is the speed at which the reaction takes place. *In other words it tells you haw fast the reaction has occurred.*

The rate at which a reaction takes place is the **speed** at which it happens.

A **tangent** is a straight line that just touches a curve, and please keep in mind the following when reading this Section: in a reaction, a reactant **is used up** therefore the tangent of the angle for the gradient of the decomposition of a reactant will be **NEGATIVE**, whereas a product **builds up** therefore the tangent of the angle for the gradient of a product will be **POSITIVE**.

To draw a tangent to a curve, place a ruler against the curve until it is **just** touching the curve and then draw a straight that just touches the curve   –   and that will be the *tangent* to the curve.
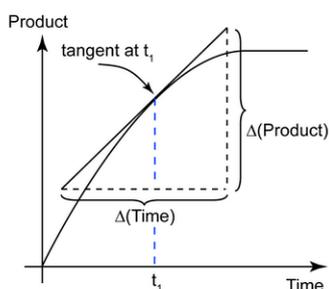
RoR for the formation of a PRODUCT
(The curve **starts** at "0".)
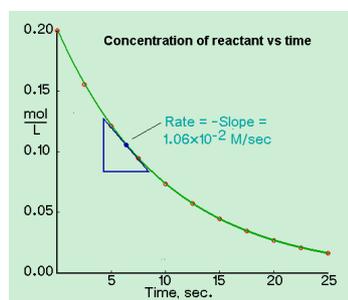
RoR for the decomposition of a REACTANT
(The curve **finishes** at "0" or something approaching "0".)

Average Speed vs Instantaneous Speed

If I travelled from Gerrards Cross to Hillingdon and it took me 12 minutes to drive the 6 miles, then the speed at which I travelled would be given by the formula

$$\textbf{Speed} \; = \; \frac{6 \text{ miles}}{12 \text{ minutes}} \; = \; \frac{6 \text{ miles}}{0.2 \text{ hours}} \; = \; \textbf{30 miles per hour}$$

My **overall speed** would have been 30 mph, but when I got to the A40 I had to stop and wait for a gap in the traffic before I drove onto the A40, and then when I got to the big roundabout at Denham I had to stop and wait for a gap in the traffic, but when I got onto the M40 I was able to drive at 70 mph. Even though my overall speed was 30 mph, my **speed at any one moment in time** therefore varied quite a lot during the journey.

It is easy to calculate overall speed by using the formula

$$\text{Speed} \quad = \quad \frac{\text{Distance Travelled}}{\text{Time Taken}}$$

but **how would I calculate my speed at any particular point on my journey** (?), and that is where Trigonometry comes in viz.

Instantaneous speed = Speed at any particular point on a journey = **tan θ**

where   **tan θ** = the gradient of the tangent to the curve at that particular point in the journey.
Let us spend a few minutes refreshing our memories about   **SOH CAH TOA**

where   **S = SINE** (sin)   ;   **C = COSINE** (cos)   ;   **T = TANGENT** (tan) ,

and   **O = Opposite side**   ;   **A = Adjacent side**   ;   **H = Hypothenuse**   .

$$\textbf{S}\;=\;\dfrac{\textbf{O}}{\textbf{H}} \qquad\qquad \textbf{C}\;=\;\dfrac{\textbf{A}}{\textbf{H}} \qquad\qquad \textbf{T}\;=\;\dfrac{\textbf{O}}{\textbf{A}}$$

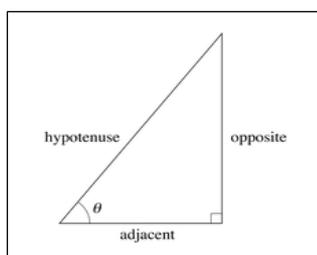**The Hypotenuse, H is always the side that is located opposite the right-angle.**
The Opposite, O is the side opposite to the angle chosen (and that angle is often given the name θ)
The Adjacent, A is the side next to the angle θ.

sin θ **=**   **opposite**   ,   **SOH**
              hypotenuse

cos θ **=**   **adjacent**   ,   **CAH**
              hypotenuse

tan θ **=**   **opposite**   ,   **TOA**
              adjacent

The right-angle in a right-angled triangle could be anywhere (at the top/at the bottom/on the right/on the left/etc) and there are two particular situations that are important viz. where θ is less than 90˚ (and thus were tan θ has a positive value) and where θ is greater than 90˚ but less than 180˚ (and where tan θ then has a negative value). In the graph on the **right** below, θ = 180˚ – angle C.

Here tan θ has a positive value because (90˚ > θ > 0˚). The use of the symbols "<" and ">" above indicates that θ lies between 0˚ and 90˚.
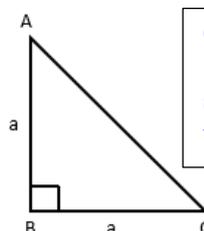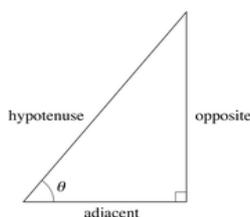
θ has a negative value here because 180˚ > θ > 90˚). The use of the symbols "<" and ">" above indicates that θ lies between 90˚ and 180˚.

I have drawn your attention to the two different situations above because, in Chemistry, one could measure
-   the rate of **formation of a product** (graph on the left on page 1 where tan θ is "+ve"),
    or one could measure
-   the rate of **decomposition of a reactant** (graph on the right on page 1 where tan θ is "–ve").

Please note carefully that in the formation of a Product
-   at the start of the reaction there is **no Product at all**, and that
    when the reaction is finished **no more Product is formed**,
whereas in the decomposition of a Reactant
-   you start with a given concentration (or else a given amount) of the Reactant and
-   the concentration (or the amount) of the Reactant keeps declining until at the end of the reaction there may be nothing of the Reactant left.

NB "**Amount**", N = the **number of moles** of the substance.
Please note that in both of the graphs on page 1, the Rate of the Reaction at any particular point in time can be ascertained/can be found by drawing the tangent to the curve at that point in time and then calculating the gradient of the tangent.

Gradient of a tangent

Can you remember how the speed of my journey from Gerrards Cross to Hillingdon (page 1) varied? Well, the rate of a reaction also changes (continuously) and therefore the gradient of the tangent to the curve will change continuously (cf. graphs on page 1). When measuring the rate of formation of a product (the left hand graph on page 1), the gradient of the tangent can be calculated by using the formula

The gradient = tan (angle at A) = <u>Opposite</u> = <u>Rise</u> = <u>CB</u> = <u>3.0</u> = 0.5
**Adjacent   Run   AC   6.0**
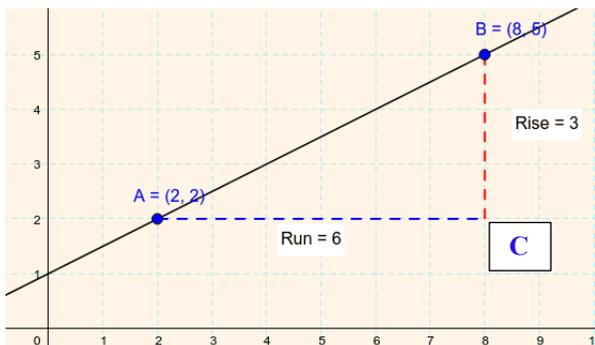
θ = angle at "A", and here tan θ = 0.5, therefore $\theta \approx 26.6°$.

To find the value of θ, you must use the **"inverse tan"** function on a calculator.

(NB "Inverse tan" = **SHIFT TAN**.)

Source: https://www.geogebra.org/m/md8VGj8J

When measuring the gradient of the tangent to a rate of decomposition of a reactant curve (the right hand curve on page 1, the angle θ (= 180° – angle C in the diagramme below) will be greater than 90° but less than 180° therefore tan θ will have a **NEGATIVE** value. Do use a calculator to calculate tan θ for values of θ between 90° and 180° and you will see what I mean.

Tan θ = <u>Rise</u> = <u>BA</u> = <u>5</u> = –0.8$\dot{3}$.
Run   CB   -6
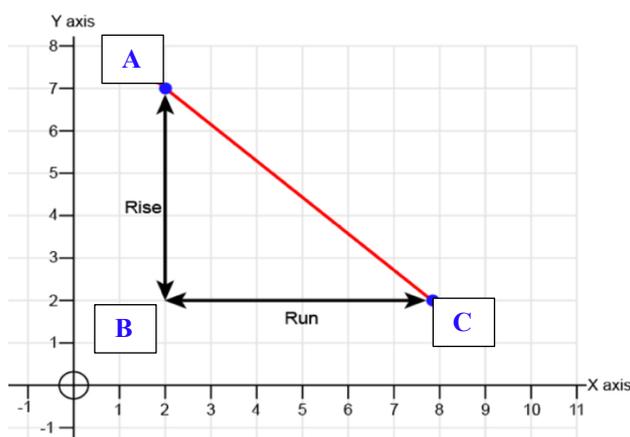
Here CB has a negative value (because it is measured leftwards on a number line), therefore tan (θ) = – tan (180° - θ) and the use of the *inverse tan* function gives tan^{-1} (39.806) = 0.8$\dot{3}$, therefore $\theta \approx 180° - 39.8° = \mathbf{140.2°.}$

If you enter tan 140.2° into a calculator, the answer will be **–0.8$\dot{3}$**.

Source (graph): https://mammothmemory.net/maths/graphs/finding-the-gradient/gradient-rise-and-run.html

For the decomposition of a REACTANT, 180° > θ > 90°, and for the formation of a PRODUCT, 90° > θ > 0° .

Helpful piece of advice

When calculating the gradient of the tangent do **<u>not</u>** draw a small triangle on the tangent as has been done in the diagramme below. Instead draw the triangle as LARGE AS POSSIBLE (extending all the way to the x-axis and to the y-axis) and *then* measure the RISE and the RUN.
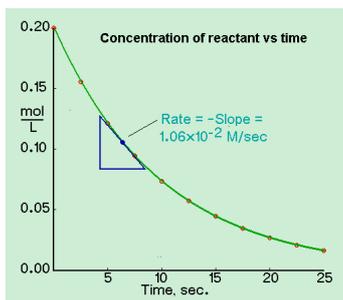
Here "M" stands for "Molarity" = mol dm^{-3}. In Europe we have stopped using the term "Molarity" because of the confusion that it caused with the symbol "M" for Mass.

The larger that you draw your triangle, the more accurate will your calculations be for the angle θ.

OK, I believe that you need all the above Maths in order to start any understanding of the Rate of a Reaction. In fact, there will be more Maths involved in 'A' Level Rates of Reaction, but let us now see what the AQA textbook has to say (but please keep in mind the distinction that I have made for you between monitoring
  A) the Rate of decomposition of a **REACTANT**, and
  B) the Rate of formation of a **PRODUCT**.

(A) gives a value **180° > θ > 90°** whereas (B) gives a value **90° > θ > 0°**.
tan θ is negative   tan θ is positive

I will tell you one more thing, and then we can look at what the AQA textbook says.

For a reaction to take place if more than one species is involved then
i) the Reactant species must collide
ii) with the qualifying amount of Activation Energy (E_a), whereupon
iii) existing bonds must be broken, and
*iv) new bonds must be formed – and unless all **four** things happen then **no reaction will take place**.*
(When we get to 'A' Level, I will tell you that the reactants must also collide in the correct *spatial configurations* – but let us not worry about that for the moment.)

You may want to read the whole of the above again before you read what the AQA textbook has to say.

<u>**Section C 8.1: The Rate of a Reaction (viz. "How quickly is it proceeding?")**</u>

- You can find the rate of a chemical reaction by monitoring the amount of **reactants** that are used up over a period of time.
- Alternatively you can find out the rate of a reaction by measuring the amount of **products** that are formed over a period of time.
- The gradient of the line drawn at any given moment in time on the graph drawn from such an experiment tells you the rate of the reaction at that moment in time. The steeper the gradient of the line, the faster that the reaction is taking place.
- To calculate the rate of the reaction at any given moment of time, draw the tangent to the curve and then calculate its gradient (where gradient = tan θ = <u>Rise</u> = <u>Opposite Side</u>).
                                                                  Run   Adjacent Side

<u>**Section C 8.2 Collision Theory and surface area**</u>

- Particles must collide with a certain minimum amount of energy before they can react.
- The minimum amount of energy that particles must have in order to react is called the Activation Energy of a reaction.
- The rate of a chemical reaction increases if the surface area to volume ratio of any solid reactants immersed in a liquid solution is increased. This increases the frequency of collisions between the reacting particles.

The example given in the textbook is the difference in the rate of the reaction between calcium carbonate ($CaCO_3$) immersed in an acid where the $CaCO_3$ is in the form of big chips/medium sized chips/and very fine powder (and the RoR increases the smaller the size of the particles of the $CaCO_3$).

Before telling you what the textbook says next, let me tell you that **ANY** reaction/**EVERY** reaction will take place at a faster rate the higher the temperature of the reactants. The reason for this is that the more energy that a particle has the faster will it move around, and the faster that it moves the more often will it collide with its neighbouring particles. The higher the temperature **the more collisions will there be per second**, and the more collisions per second the greater will be the RoR.

Section 8.3 The effect of temperature on the RoR

- **The higher the temperature of the reactants, the quicker a reaction will take place.** (A spoonful of sugar will take longer to dissolve in cold water than the same size spoonful of sugar in hot water.)
- Increasing the temperature of a reaction increases the rate of a reaction because the particles collide more frequently and more energetically. More of the collisions occurring in a given time results in a faster reaction.

Let me remind you that for a reaction to take place, if more than one reactant is involved then
i) *the Reactant species must* <u>*collide*</u>
ii) *with the qualifying amount of Activation Energy (E_a), whereupon*
iii) *existing bonds must be broken, and*
iv) *new bonds must be formed – and unless all **four** things happen then **no reaction will take place**.*

It is therefore clear from condition (i) that <u>**collisions**</u> **are an essential feature of reactions**, and therefore, the rate of a reaction (RoR) will be influenced by both
a) the number of reactant species in a given volume of the reactant container (i.e. the concentrations involved), and (from what we said earlier)
b) the temperature of the reactant species.

The greater the concentration of reactant species in the reactant container, the more collisions will there be per second therefore **the rate of the reaction will be greater**, and the higher the temperature of the reactants the faster will they be moving around and therefore the more collisions will there be per second and therefor the rate of the reaction will be greater.

The RoR is directly proportional to <u>CONCENTRATION</u>, and the RoR is directly proportional to <u>TEMPERATURE</u>

and this can easily be confirmed by experimentation.

Section 8.4 The effect of Concentration and Pressure

- **Dissolved reactants**: Increasing the *concentration* of the dissolved reactants in a solution increases the frequency of the collisions between the reactant species, and the RoR therefore rises.
- **Gases**: Increasing the *pressure* of reacting gases brings the reacting particles closer together and this increases the frequency of collisions amongst the reactant species, and the RoR thus rises.

What is a catalyst?

A "catalyst" is any substance that speeds up a reaction but which does not undergo any **permanent** change during the reaction. A catalyst will undergo some sort of change during a reaction *(otherwise it could not catalyse the reaction in any way)*, but if the substance is **permanently** altered during a reaction then it would cease to be a "catalyst" and instead it would be a **<u>reactant</u>**.

Porous iron as the catalyst in the production of Ammonia: The classic 'catalyst' in Chemistry is porous iron (i.e. a piece of iron with a large number of miniscule holes in it (and which therefore has a large surface area to volume ratio) in the reaction of Nitrogen gas and Hydrogen gas being converted into Ammonia. The great Polish-German scientist Fritz Haber invented the process whereby Nitrogen (N_2) and Hydrogen (H_2) could be converted into Ammonia (NH_3), and he received the Nobel Prize in 1918 for his invention. The catalyst in the process was 'porous iron'. The process is known as the Haber-Bosch process because the great German chemical engineer Carl Bosch (who founded the giant engineering firm IG Farben) developed the theoretical concept into an industrial manufacturing process.

Vanadium(V) Oxide as the catalyst in the Contact process for the production of Sulphuric Acid: V_2O_5 is used as the catalyst in this process (and I will tell you more about it when we get to 'A' Level).

"Enzymes" are biological catalysts and many of them have names that end in "–ase": Enzymes use something called a 'lock-and-key' mechanism.

In the olden days **oxides** such as Silica/Silicon Dioxide (SiO_2), and Aluminium Oxide (Al_2O_3) were often used as catalysts (especially in the Petroleum Industry) but nowadays specially formulated catalysts such as "zeolite" are used instead.

Transition metals (such as Titanium/Rhodium/Vanadium/etc) make very good catalysts because they have many different Oxidisation states, but I will leave that until we get to 'A' level Chemistry.

Now back to the AQA textbook.

Section C 8.5 The effect of a catalyst

- A catalyst speeds up the rate of a chemical reaction, but it is not used up during the reaction. (This is not a good definition and I have given you a better one above.)
- Different catalysts are needed for different reactions.
- In Industry, catalysts are used whenever possible, because they speed up a reaction and thus reduce the cost of production.
- A catalyst will allow a reversible reaction to reach dynamic equilibrium faster, but it will **<u>not</u>** change the yield of the reaction.

Reversible Reactions

A reaction that proceeds in only one direction is often called a "reaction to completion". For instance, if HCl (g) is bubbled through water, the HCl (g) will dissolve in the water and become HCl (aq). This is **<u>not</u>** a reversible reaction. **It proceeds in only one direction.**

$$HCl\ (g)\ +\ H_2O\ (l)\ \longrightarrow\ HCl\ (aq)$$

There are many reversible reactions, and in Chemistry the most important one of all is the breakdown of Water into H^+ ions (Protons) and OH^- ions (Hydroxy or Hydroxyl ions). However, while molecules of Water are breaking down into their ionic components, at exactly same time H^+ ions and OH^- ions are re-combining to form molecules of Water. You can see therefore that this is a **reversible** reaction and it is written thus.

$$H_2O\ (l)\ \rightleftharpoons\ H^+\ (aq)\ +\ OH^-\ (aq)$$ Please note the symbol for a reversible reaction.

The substances on the left of the reaction equation sign are always called the **Reactants** while those on the left are always called the **Products**; and, the direction from left to right in a reversible reaction is called the forward reaction and the direction from right to left is called the backward reaction. Had I written the reaction the other way round (and indeed I could have written it the other way round because the reaction is a *reversible* one), then I would have written

$$H^+\ (aq)\ +\ OH^-\ (aq)\ \rightleftharpoons\ H_2O\ (l)$$

and now the formation of Water molecules from its ionic components has become the "forward" reaction. It all depends on how the equation has been written as to which is considered to be the forward and which is considered to be the backward reaction.

The AQA textbook says.

Section C 8.6 Reversible Reactions

- In a reversible reaction the products of the reaction can react to reform the original reactants.
- You can show a reversible reaction by using the sign "$\rightleftharpoons$".
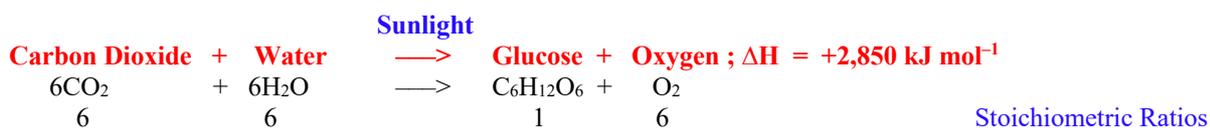
Section C 8.7 Energy and Reversible Reactions

- If a reaction generates heat (i.e. the reaction is an Exhothermic one) when the reaction is proceeding in one direction, then when the reaction is proceeding in the opposite reaction it will absorb heat (i.e. it will be an Endothermic reaction.
- The amount of energy involved in a forward reaction is exactly the same as the amount of energy involved in a backward reaction. One reaction will be Exhothermic and the other will be Endothermic.
- The most important example of this is that of Cellular Respiration and Photosynthesis in Biology.

Photosynthesis and **Cellular Respiration** are essentially the same reaction except that they are the reverse of each other. In Photosynthesis (an Endothermic Reaction), energy from sunlight is used to convert Carbon Dioxide and Water into Oxygen and a Carbohydrate (usually Glucose), whereas in Cellular Respiration (an Exhothermic Reaction), Oxygen and Glucose are reacted together to produce energy (that is then stored, usually in the bonds of ATP, until the energy is needed by the cell).

If you have never appreciated this fact before, then I imagine that you will go round hugging yourself in delight at having made such an important (and beautiful) intellectual discovery. Let me write in chemical symbols what I have told you in words. *(NB I have seen the ΔH value for this equation vary from 2,810-2,870 kJ mol^{-1}. It seems quite a large range, but perhaps ΔH values in Biology can vary more than they do in Chemistry.)*

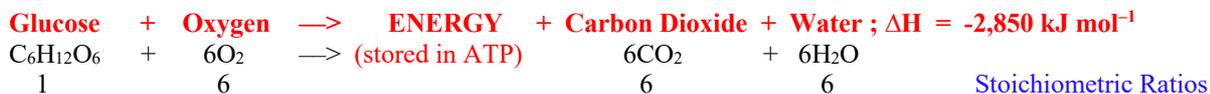## Photosynthesis (an ENDOTHERMIC reaction)
(Photosynthesis uses the energy in sunlight to convert Carbon Dioxide and Water into Glucose and Oxygen.)

<div align="center">**Sunlight**</div>

Carbon Dioxide + Water   —>   Glucose + Oxygen ; ΔH = +2,850 kJ mol⁻¹

Carbon Dioxide + Water   —>   Glucose + Oxygen ; $\Delta H = +2{,}850$ kJ mol^{-1}

$6CO_2$ + $6H_2O$ —> $C_6H_{12}O_6$ + O_2

  6   6   1   6   Stoichiometric Ratios

Cellular Respiration (an EXHOTHERMIC reaction)

(It reacts Glucose and Oxygen to convert them into ENERGY with Carbon Dioxide and Water being the by-products.)

Glucose   +   Oxygen   —>   ENERGY   + Carbon Dioxide + Water ; $\Delta H = -2{,}850$ kJ mol^{-1}

$C_6H_{12}O_6$ + $6O_2$ —> (stored in ATP) $6CO_2$ + $6H_2O$

  1   6   6   6   Stoichiometric Ratios

Cells need energy and the mitochondria in cells react Glucose and Oxygen together to produce the energy that is needed (and it is used either immediately or else it is stored in the bonds of ATP). In contrast, plants use the energy in sunlight to convert Carbon Dioxide and Water into energy which is then stored in sugar molecules [1] and then distributed all over the plant via the Phloem System.

Can you see how Photosynthesis and Cellular Respiration are the reverse of each other, and that is why one is Endothermic and the other is Exhothermic.

Dynamic equilibrium

In a reversible reaction, both reactions (the forward and the backward reaction) proceed simultaneously, and when the reaction settles down to a steady state where the rate of the forward reaction exactly equals the rate of the backward reaction, then the reaction is said to be in a position of "**dynamic equilibrium**".

There is a nice easy way of visualising the difference between static equilibrium and dynamic equilibrium.

Imagine that you are standing still on your staircase at home, then you are at **static equilibrium** in relation to the staircase – but if you were running up a "down" escalator at the same speed as the escalator is moving, then you would be in dynamic equilibrium in relation to the escalator because you would be running to keep yourself in a static position. (The same effect is seen on an electrically-driven indoor running machine.)

Please be careful when thinking about what is and what is not a reversible reaction. One of the experiments that you will do at GCSE Level is the decomposition of Calcium Carbonate by heat into Calcium Oxide (CaO) and Carbon Dioxide (CO_2) gas. Calcium Oxide is noxious (nasty and very harmful) therefore in a classroom you will always see the reaction carried out in a fume cupboard so that you do not get anywhere near the CaO. As a result you might think that the reaction is a one-way reaction

<div align="center">$CaCO_3$ (s)   —>   CaO (s) + CO_2 (g)</div>

that goes to completion and you would be completely and utterly **WRONG**!

In fact, the reaction is a reversible reaction as you would find out were you to thermally decompose $CaCO_3$ (s) in a sealed container. Please be careful therefore because appearances can be deceptive. You might think of a reaction as being something (because you always see it from that point of view) and it never even occurs to you that in fact the reaction could be something else. However, the more Chemistry that you do, the more that you will learn about the subject.

Section 8.8 Dynamic Equilibrium

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[1] NB Plants can manufacture Glucose (and other sugars), but animals **cannot** manufacture Glucose as plants do therefore they have to eat vegetable matter or meat to obtain their glucose (and breathe in, from the air, the Oxygen that they need).
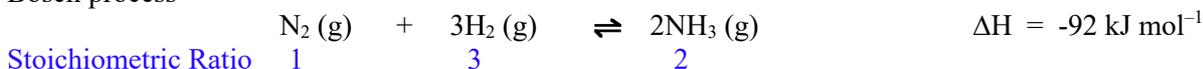
- In a reversible reaction, the products of the reaction can react to re-form the original reactants.
- In a closed system, the rate of the forward and the reverse reactions is equal when the system is in dynamic equilibrium.
- Changing the reaction conditions can change the amounts of products and the amounts of reactants in a reaction that is in dynamic equilibrium.

Le Chatelier's Principle (Henri Louis Le Chatelier, 1850-1936)

According to Le Chatelier's Principle, a reversible reaction that is in dynamic equilibrium will seek to oppose any changes that are made to it.

This does not sound very important when stated as above, and yet it is one of the most important principles in Chemical Engineering!
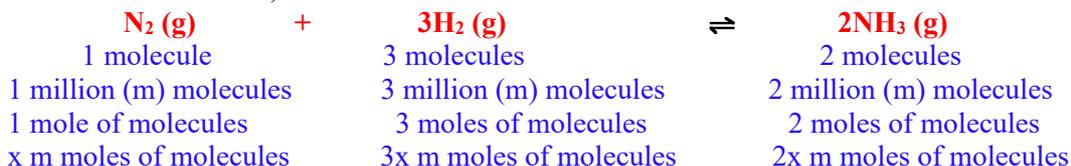
Earlier on I told you that the conversion of Nitrogen gas and Hydrogen gas into Ammonia by the Haber-Bosch process

$$N_2 \text{ (g)} \quad + \quad 3H_2 \text{ (g)} \quad \rightleftharpoons \quad 2NH_3 \text{ (g)} \qquad \Delta H = -92 \text{ kJ mol}^{-1}$$

Stoichiometric Ratio   1   3   2

was a massively important discovery (for which Fritz Haber was awarded the Nobel Prize).

When the above process settles down and is in dynamic equilibrium (i.e. when the rate of the forward reaction is exactly the same as the rate of the backward reaction), then (depending on the reaction conditions) a small amount of Ammonia may be being produced or a large amount of Ammonia may be being produced.

The stoichiometric ratio is 1:3 —> 2, therefore *all* the statements below are true

N_2 (g)	+	$3H_2$ (g)	$\rightleftharpoons$	$2NH_3$ (g)
1 molecule		3 molecules		2 molecules
1 million (m) molecules		3 million (m) molecules		2 million (m) molecules
1 mole of molecules		3 moles of molecules		2 moles of molecules
x m moles of molecules		3x m moles of molecules		2x m moles of molecules

It is the ratios that are important and **not** the absolute number of molecules/moles of molecules.

Let us assume that I put 1 million moles of Nitrogen gas molecules and 3 million moles of Hydrogen gas molecules into a reaction container, and I then produced 2 million moles of Ammonia molecules. As a chemical engineer I would be thrilled because I had obtained the theoretical maximum yield of 100% conversion of reactants into products – but if I had produced only ONE MOLECULE of Ammonia, then I would walk around with tears in my eyes because it would not have been worth all my hard work building my plant and carrying out the conversion.

1 m moles of N_2 (g) + 3 m moles of H_2 (g) $\rightleftharpoons$ 2 m moles of Ammonia   FANTASTIC
1 m moles of N_2 (g) + 3 m moles of H_2 (g) $\rightleftharpoons$ 1 mole of Ammonia   Waste of time and money

I would then have to investigate why it was that I had produced so little Ammonia, and that is where Chemistry and Henri Louis Le Chatelier's Principle would come in useful.

We have already learnt that increasing the temperature of a reaction increases the RATE of the reaction, and it will also alter the Yield. However, Henri Le Chatelier found out that a reversible reaction that is in dynamic equilibrium will seek to oppose any changes that are made to it, therefore increasing the Pressure of the above reaction would move the position of dynamic equilibrium to the RIGHT because that would reduce the pressure in the reaction container because that would mean that (because the stoichiometric ratio is 1:3 –> 2) there would be fewer molecules on the right of the reaction, and that would reduce the Pressure in the reaction container.

To improve the yield of Ammonia we would increase the Pressure in the reaction container (but we would not want to increase the Pressure too much in case that fracted a pipe and caused an explosion).

As it happens we would also increase the Temperature because that would speed up the reaction, and the faster the reaction the more Ammonia that we would be able to make and sell each day.

However, increasing the temperature would **<u>reduce</u>** the yield in this particular reaction (reduce the amount of Ammonia that was being produced) because the forward reaction is an Exhothermic Reaction therefore the forward reaction releases heat whereas the backward reaction consumes heat – and Le Chatelier's Principle says that if we increase the heat in the system, then the position of dynamic equilibrium will move so as to reduce the heat in the system.

Let us now see what the textbook has to say.

Section C 8.8 Dynamic Equilibrium

- In a reversible reaction, the products of a reaction can react to reform the original reactants.
- In a closed system, at dynamic equilibrium the rate of the forward and the backward reactions are exactly equal to each other.
- Changing the reaction conditions can change the position of dynamic equilibrium to the left or to the right.

Section C 8.9 Altering the conditions

- Where **<u>gases</u>** are involved in a reaction, changing the Pressure can affect the position of dynamic equilibrium (moving it to either the left or to the right). An increase in Pressure will drive the reaction towards the side of the reaction that has fewer moles of gas because that reduces the pressure in the containment vessel (and remember that M. Le Chatelier found that a reversible reaction that is in dynamic equilibrium will seek to oppose any changes that are made to it. In contrast, decreasing the Pressure will drive the reaction towards the side of the reaction that has a larger number of moles of gas molecules.
- A reversible reaction will be endothermic in one direction (i.e. it will use up heat) and exhothermic in the other direction (i.e. it will generate heat). Changing the temperature of a reaction that is in dynamic equilibrium will change the position of dynamic equilibrium.
    - Increasing the temperature will cause the reaction to try to reduce the temperature by using up heat i.e. it will increase the yield of the endothermic reaction, while
    - reducing the temperature of the reaction will cause the reaction to try to warm up the reaction by moving in the exhothermic direction.

There is a large amount of Maths and Chemistry in this Section, therefore let us summarise what we have learnt.

Summary of Section C8

- The **overall speed** of a reaction is given by <u>Change in Concentration</u> (in mol m^{-3} s^{-1})
    Time Taken
    and the **instantaneous speed** of a reaction at any point in time is given by the gradient of the tangent to the curve of the change in concentration (of either the reactants or the products) at that point in time.

Reaction to Completion vs. Reversible Reactions

- In a reaction, the **reactants** react with each other to produce the **products** of the reaction.
- In a reaction that **goes to completion**, the products never recombine to reform the products viz.
        aA + bB   —>   cC + dD
    where the Capital letters indicate the substances involved and the small letters give the stoichiometric ratios that are involved.
- However in a reversible reaction, the products **do recombine** to reform the original products
        aA + bB   ⇌   cC + dD
    and when the rate of the forward reaction exactly equals the rate of the backward reaction, then the reaction is said to be in **dynamic equilibrium**.
- The position of dynamic equilibrium can be very far t**o the left** (where hardly any product is produced), or the position of dynamic equilibrium can lie very far **to the right** (where almost all the reactants have reacted to form the products).

Reaction Conditions

- The introduction of a **CATALYST** into a reaction will speed up the rate of the reaction but it will **<u>not</u>** increase the yield of the reaction. (The amount of product formed will **not** alter.)

- For reacting **gases,** an increase in **PRESSURE** will cause the RoR to rise (because the gas particles are closer to each other therefore they will collide more frequently), and in a reversible reaction an increase in pressure will cause the reaction to move to the side that has fewer molecules/moles of molecules (because that will reduce the pressure); and, when the pressure of the reaction is reduced, then the reaction will move to the side where there are more molecules of gas because that will increase the pressure.

- For substances in **solution**, an increase in concentration will cause more collisions per second and this increases the RoR. In a reversible reaction, an alteration in the concentrations of the reacting substances can cause an alteration in the concentration of the products, and an alteration in the concentration of the products can cause an alteration in the concentration of the reactants.

- An increase in T**EMPERATURE** will increase the **<u>rate</u>** of **every** reaction, but in a reversible reaction the temperature will affect the **<u>yield</u>** of the reaction (i.e. the amount of product that is formed). It must be remembered that in a reversible reaction, one reaction will always be exothermic while the other reaction will always be endothermic, and Le Chatelier's Principle states that in a reversible reaction that is in dynamic equilibrium, the reaction will always seek *to oppose/to reverse* any changes that are made to it, therefore
    - an increase in temperature will cause the reaction to try to reduce the temperature of the reaction by using up energy i.e. the reaction will move endothermically, while
    - a reduction in temperature will cause the reaction to move exothermically by generating energy/heat (to try to heat up the reaction).

That is enough for now. We will learn a lot more about Rates of Reaction/Reactions to Completion/ Reversible Reactions/Le Chatelier's Principle/etc when we get to 'A' Level.