6.1 – Rates of Reaction

6.1.1 – Define the term rate of reaction

The change in concentration of reactants or products with time.

In other words, how quickly the reactants are converted into products. These are expressed in **mol dm^{-3} s^{-1}**.

$$Rate = -\frac{concentration\ of\ R\ at\ time\ t_2 - concentration\ of\ R\ at\ time\ t_1}{t_2 - t_1}$$

$$= -\frac{\Delta[R]}{\Delta T}$$

If you substitute products in here, then the negative sign is removed to keep it a positive number.

6.1.2 - Describe suitable experimental procedures for measuring rates of reactions

When you are asked questions on this, these may be for average rate of reaction over a period of time, initial rate of reaction (t=0) or instantaneous rate of reaction (t=x). There are a number of experiment that can be performed:

Change in Volume or Mass

For reactions that produce gaseous products, this may be collected in a syringe, which will indicate the volume. This should be measured at time intervals to track the progression of the reaction.

Another option is to leave the container open and place is on a balance, recording the mass over time. Since gases will escape the environment, the lost mass will indicate how much was produced.

Change in Gas Pressure

Using the appropriate sensors, the gas pressure can be measured over time, keeping the temperature and volume constant.

Titrimetric Analysis

This is when a sample of the mixture is taken at time intervals and then quenched – that is to say, the reaction is stopped. The concentration of a particular product or reactant in the sample can then be measured by titration. This is continued and the change in concentration over time can be used to determine the reaction rate.

Colorimetry

If one of the reactants or products in coloured, then a colorimeter can be used to measure the change in colour over time. This is done using the wavelengths of light. The results can then be converted to give the concentration of the coloured substance.

When the reactants and products are different colours, the time taken for the mixture to completely change colour may also be recorded and used as a measure of rate of reaction.

Appearance of a Precipitate

The colorimetry technique can also be used when a precipitate is formed in the reaction, measuring the light wavelengths using a colorimeter.

Also, by placing the mixture over a cross, the reaction can be timed until the cross disappears.

Electrical Conductivity

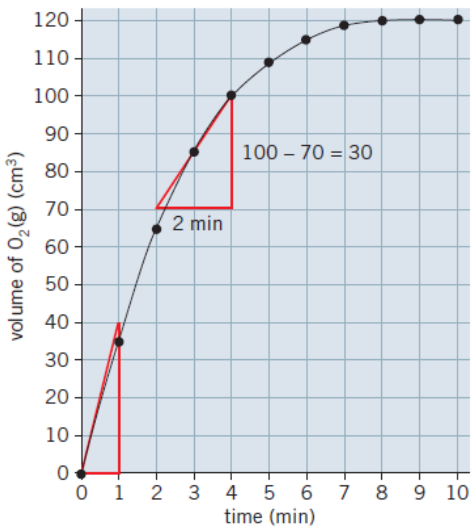
The formation of ions in the reaction will lead to a change in the electrical conductivity of the mixture. A probe can measure the conductivity, and the change over time will show the rate of reaction. The proportion of electrical conductivity to concentration of ions is used to determine this.

6.1.3 - Analyse data from rate experiments

In the reaction below, a gas is formed. Its volume can be measured to find the rate of reaction.

$$2H_2O_{2(aq)} \rightarrow 2H_2O_{(l)} + O_{2(g)}$$

Time (min)	Volume of Oxygen (cm^3)
0	0
1	35
2	65
3	85
4	100
5	108
6	114
7	118
8	120
9	120
10	120



As is to be expected, the volume of oxygen being produced steadily decreases over time, until it stops altogether. The rate of reaction is therefore decreasing as well.

The rate of reaction can be measured form the graph by drawing a tangent to the curve, and determining the gradient of the tangent. In this example, the initial rate is 40 cm^3 min^{-1}

The instantaneous rate of reaction is again calculated at three minutes, when it is equal to 15 cm^3 min^{-1}. The shows us that the rate of reaction has indeed decreased.

It is also useful to be able to find the average rate of reaction in a given time period. This can be done using:

$$Average\ Rate\ of\ Reaction = \frac{Volume\ of\ Oxygen\ produced\ in\ time\ period}{Time\ Period}$$

This too can be compared to show that the rate of reaction decreases over time.

The data and graph above were taken from:

Derry, Lanna, et al. Chemistry for Use with the IB Diploma Program – Standard Level. (2008) Pearson Education Australia, Melbourne. – p. 222

6.2 – Collision Theory

6.2.1 - Describe the kinetic theory in terms of the movement of particles whose average energy is proportional to temperature in Kelvin

All particles – whether they are in a liquid, gaseous or solid state – move in some way. These types include **vibration**, **rotation** and **translation**. The amount of energy the particle possesses determines the velocity is travels at.

However, we do not measure the energy of each individual particle, but instead find the average energy. The measurement for this is **temperature**, conventionally expressed in Kelvin. Particles at a higher temperature possess more energy, and therefore move faster.

We look at this kinetic theory in terms of gaseous particles. According to this theory, the properties of gases include:

- They are continuously moving
- Do not have any intermolecular forces
- Transfer, but do not lose, energy when the collide
- Their energy depends entirely on the absolute temperature they are at.

6.2.2 - Define the term activation energy, E_a

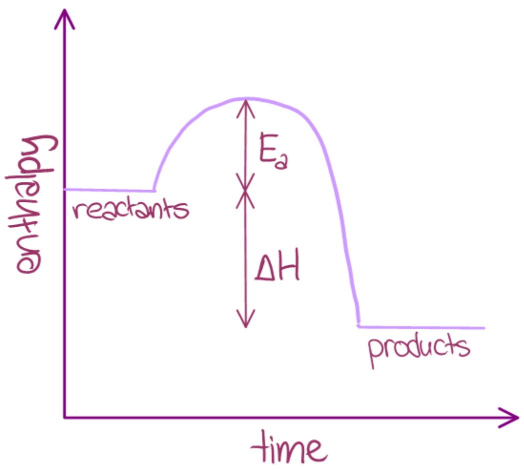
The kinetic energy required to break the bonds of the reactant particles, initiating a chemical reaction and hence allowing it to progress.

6.2.3 - Describe the collision theory

For a reaction to occur, there are three conditions that must be met

- The reactant particles must collide

- They must collide at the correct orientation so that the reactive parts come into contact
- They must collide with sufficient energy to break their bonds



This minimum kinetic energy is the **activation energy**. Other factors may be changed that will allow for more collisions or greater kinetic energy, which speeds up the reaction. This is because there are more frequent collisions and more particles with sufficient kinetic energy.

6.2.4 - Predict and explain, using the collision theory, the qualitative effects of particle size, temperature, concentration and pressure on the rate of a reaction

Particle Size

Increasing the surface area of the reactant particles in a reaction will **increase the reaction rate**. This is because more particles are able to come into contact with other particles and increase the frequency of collisions.

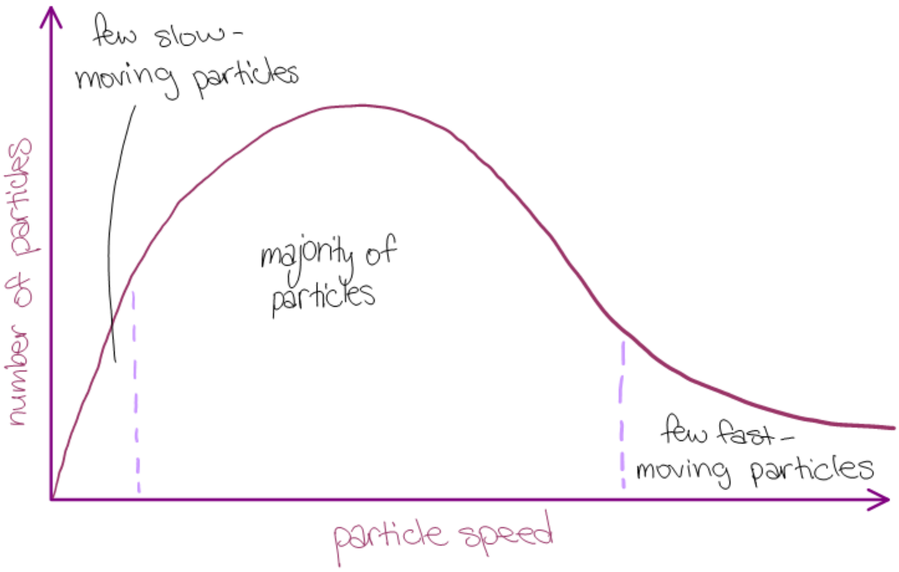
Temperature

Increasing the temperature will **increase the rate of reaction**. This is because the aver particle speed increases, giving each particle more kinetic energy when it collides. As a result, the colliding particles are more likely to overcome the activation energy and be able to react. Also, at higher speeds, the **frequency of collisions will increase**, giving the particles more chance to react.

Concentration and Pressure

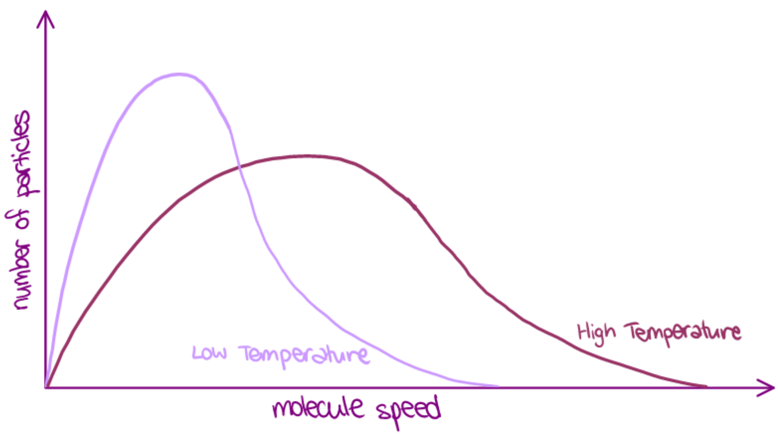
Increasing the concentration also increases the number of particles that are available to react per unit area, increasing the frequency of collisions. Increasing the pressure has the same effect. As a result, the **rate of reaction increases**.

The Maxwell-Boltzmann Diagram:



6.2.5 - Sketch and explain qualitatively the Maxwell-Boltzmann energy distribution curve for a fixed amount of gas at different temperatures and its consequences for changes in reaction rate

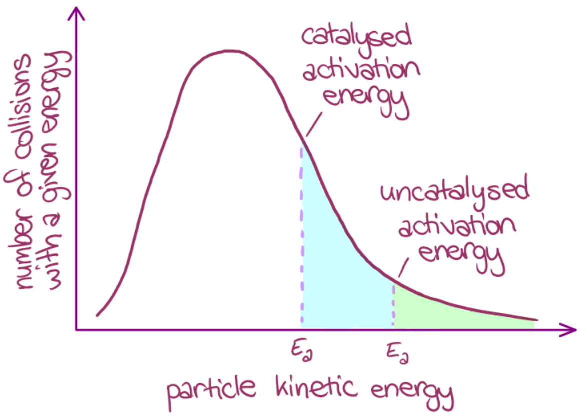
The area under the curve is constant and does not change with temperature. Not all of the particles have the same kinetic energy, hence a measurement of the temperature gives the **average kinetic energy**. In any state, the particles will still be distributed according to the curve.



The curve flattens out with increasing temperature

6.2.6 - Describe the effect of a catalyst in a reaction

A catalyst is a substance that increases the rate of reaction by providing an alternative reaction pathway with a **lower activation energy**. This means that the number of particles that are at or above the activation energy will increase, allowing more of them to react.



6.2.7 - Sketch and explain Maxwell-Boltzmann curves for reactions with and without catalysts