Kinetics SL (answers)

IB CHEMISTRY SL

25 Mn Manganese 54.938045 | 16 S Sulfur 32.065 | J | 6 C Carbon 12.0107 | 2 He Helium 4.002602 | 25 Mn Manganese 54.938045

Understandings:

- Species react as a result of collisions of sufficient energy and proper orientation.
- The rate of reaction is expressed as the change in concentration of a particular reactant/product per unit time.
- Concentration changes in a reaction can be followed indirectly by monitoring changes in mass, volume and colour.
- Activation energy (E_a) is the minimum energy that colliding molecules need in order to have successful collisions leading to a reaction.
- By decreasing E_a, a catalyst increases the rate of a chemical reaction, without itself being permanently chemically changed.

Applications and skills:

- Description of the kinetic theory in terms of the movement of particles whose average kinetic energy is proportional to temperature in Kelvin.
- Analysis of graphical and numerical data from rate experiments.
- Explanation of the effects of temperature, pressure/concentration and particle size on rate of reaction.
- Construction of Maxwell–Boltzmann energy distribution curves to account for the probability of successful collisions and factors affecting these, including the effect of a catalyst.
- Investigation of rates of reaction experimentally and evaluation of the results.
- Sketching and explanation of energy profiles with and without catalysts.

Guidance:

- Calculation of reaction rates from tangents of graphs of concentration, volume or mass vs time should be covered.
- Students should be familiar with the interpretation of graphs of changes in concentration, volume or mass against time.

Syllabus checklist

Objective	I am confident with this	I need to review this	I need help with this
Outline the meaning of the term *rate of reaction*			
Calculate the initial (and instantaneous) rate of reaction from a graph			
Describe the two factors that determine whether or not a chemical reaction takes place between reactant particles (energy and geometry of collisions).			

Outline the meaning of the term *activation energy*			
Sketch energy level profile for exothermic and endothermic reaction showing the activation energy of the reaction.			
State and explain the factors that affect the rate of a chemical reaction (changes in temperature, pressure and surface area).			
Explain how a catalyst increases the rate of reaction			
Construct Maxwell–Boltzmann energy distribution curves to explain the effects of temperature and catalysts on the rate of reaction.			

Rate of reaction

- Rate of reaction is defined as the following:

Rate of reaction is the change in concentration of reactants or products per unit time.

- The units for rate of reaction are mol dm^{-3} s^{-1}

The rate of reaction can also be defined as:

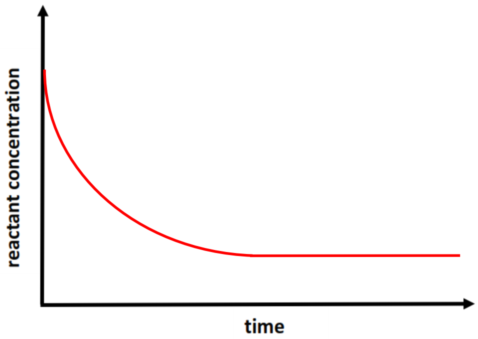
$$\textbf{rate of reaction} = \frac{\textbf{increase in product concentration}}{\textbf{change in time}}$$

$$\textbf{rate of reaction} = \frac{\textbf{decrease in reactant concentration}}{\textbf{change in time}}$$

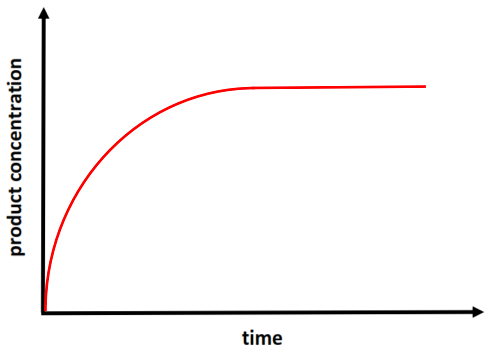
$$\text{rate of reaction} = \frac{\Delta[\text{P}]}{\Delta \text{t}} \text{ or } -\frac{\Delta[\text{R}]}{\Delta \text{t}}$$

Exercise: On the axis below sketch the following graphs:

1) The change of concentration of reactants against time

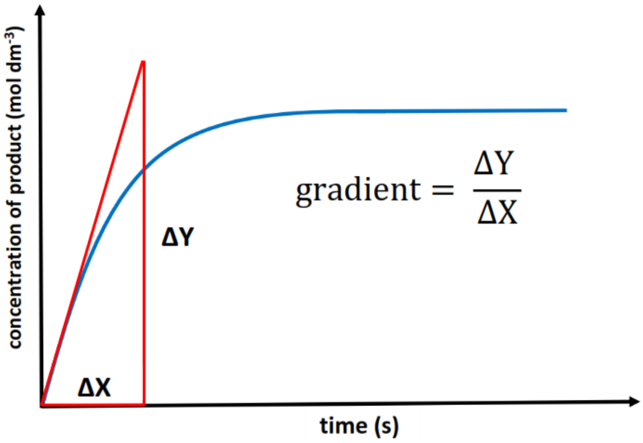


2) The change of concentration of products against time



Rates of reaction graphs

- The instantaneous rate of reaction can be determined graphically as shown below.
- The rate of reaction decreases with time as the concentration of reactant particles decrease which results in a lower frequency of collisions between the reactant particles.
- This can be seen in the graph below, where the initial rate is fastest (the line is the steepest) but the line becomes less steep (rate of reaction is decreasing). Once the limiting reactant is consumed, no more product is produced and the line becomes flat.

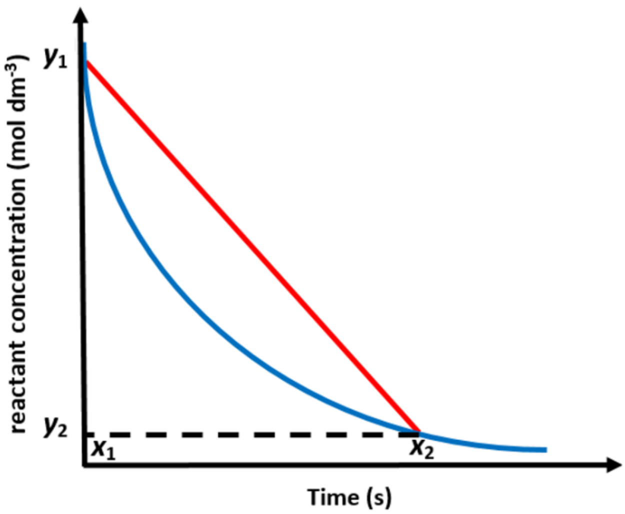


How to measure the rate of reaction from a graph

- Draw a tangent to the curve at a specific time (at time = 0s for the initial rate of reaction).
- Measure the gradient of the line (change in y / change in x)
- The gradient of the line = the rate of reaction.

Average rate of reaction

- The average rate of reaction is the rate of reaction averaged over a certain time period.



$$\text{Average rate of reaction} = \frac{y_2 - y_1}{x_2 - x_1}$$

Exercises:

1) Define the term 'rate of reaction'.

Change in concentration of reactant or product per unit time.

2) Outline how the initial rate of reaction can be determined from a graph.

Draw tangent at curve at time = 0 s

Determine gradient of line (ΔY / ΔX); the gradient is the rate of reaction.

3) Explain how the rate of reaction changes with time.

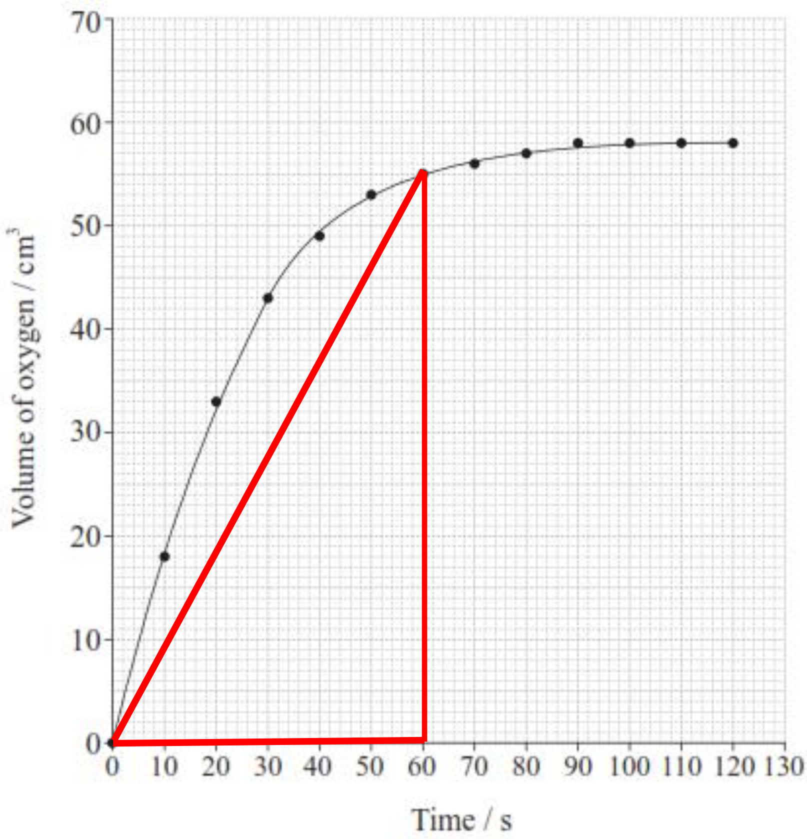
Initial rate of reaction is faster due to higher concentration of reactant particles which results in a higher frequency of collisions between reactant particles.

Rate of reaction decreases over time as the concentration reactant particles decreases and less frequent collisions between reactant particles.

4) Use the graph below to determine:

a. the rate of formation of $O_{2(g)}$ at 40 seconds.
b. the average rate of reaction between 0 and 60 seconds.

$$\text{Average rate of reaction} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{55-0}{60-0} = 0.92\ \text{cm}^3\ \text{s}^{-1}$$



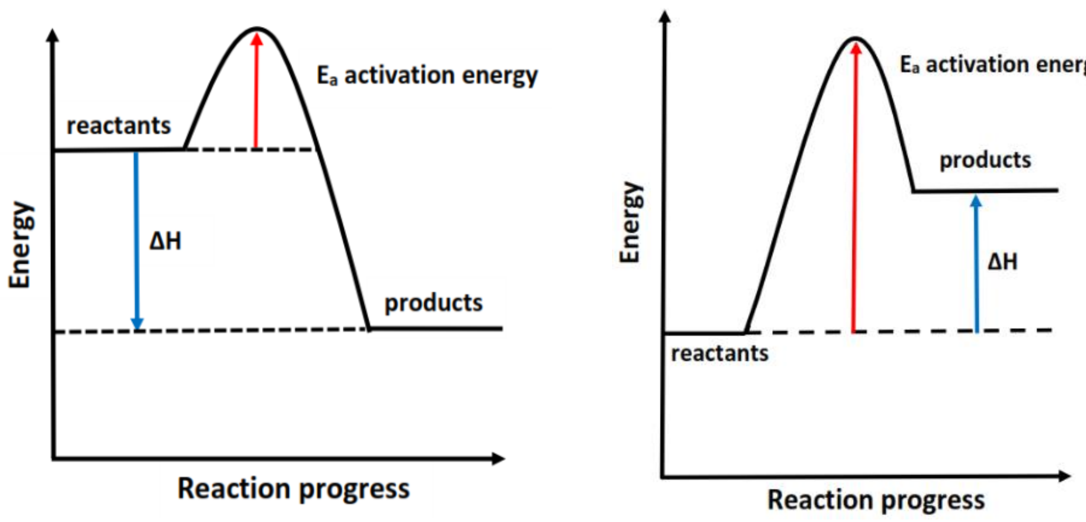
Collision theory

- Collision theory states that to react:
  1. reactant particles must collide with energy equal to, or greater than, the activation energy
  2. reactant particles must collide with the correct orientation (or geometry).
- Collisions that result in a chemical reaction are successful collisions.
- Not all collisions between reactant particles are successful; only those with sufficient energy and the correct orientation.

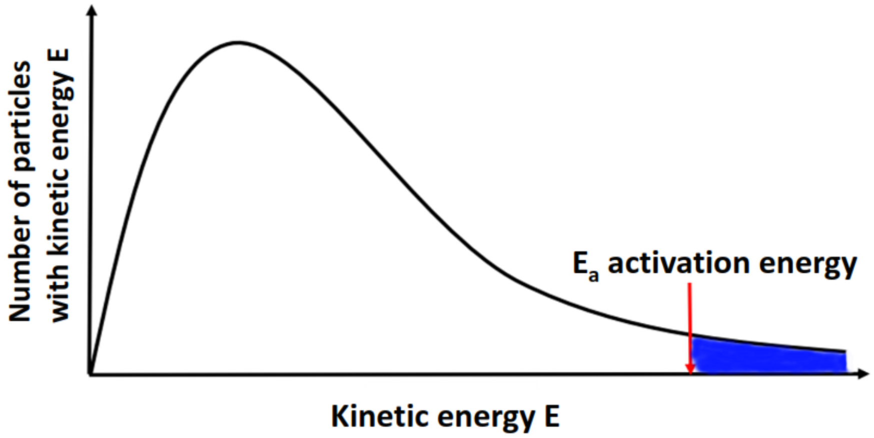
Energy of collision

- For a chemical reaction to happen, the reactant particles must have energy equal to, or greater than, the activation energy.
- Activation energy (E_a) is the minimum energy that colliding molecules need in order to have a successful collision leading to a chemical reaction.

Energy level profiles for an exothermic and endothermic reaction showing activation energy



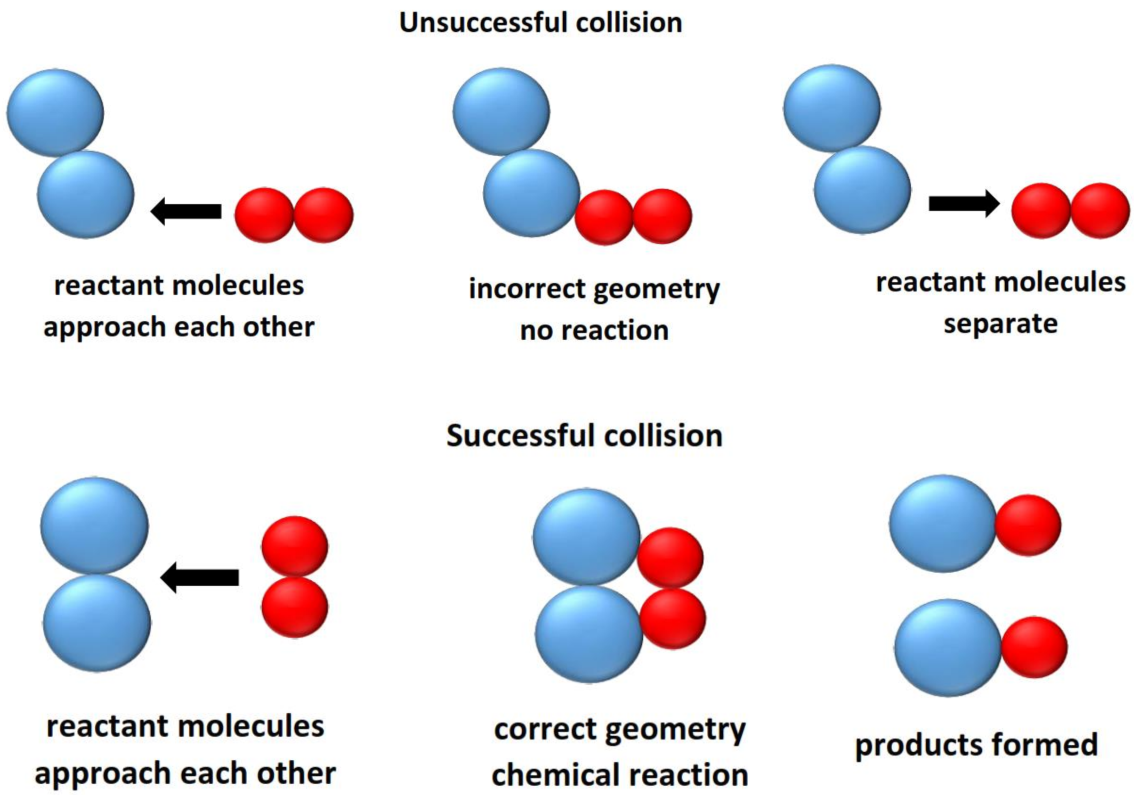
Maxwell- Boltzmann curve showing the distribution of kinetic energy in a sample of gas



- The area under the curve in white shows the number of particles that have kinetic energy less than the activation energy.
- The area under the curve in blue shows the number of particles that have kinetic energy equal to, or greater than, the activation energy.

Geometry of collision

- Particles must also collide with the correct orientation (or geometry) to have a chemical reaction as can be seen in the diagram below:



Exercises:

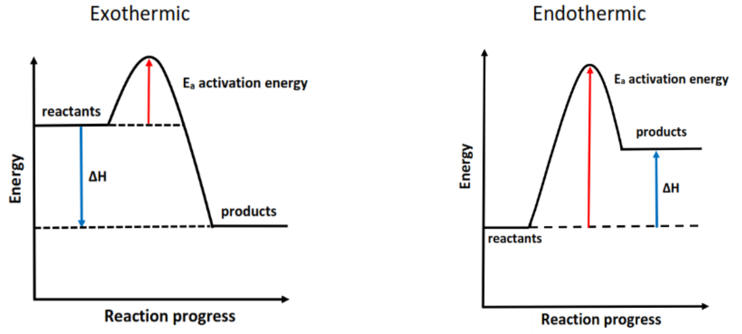
1. State two conditions necessary for a reaction to take place between reactant particles.
   Reactant particles must collide with energy equal to, or greater than, the activation energy, and reactant particles must collide with the correct geometry (or orientation).

2. Define the term activation energy, E_a.

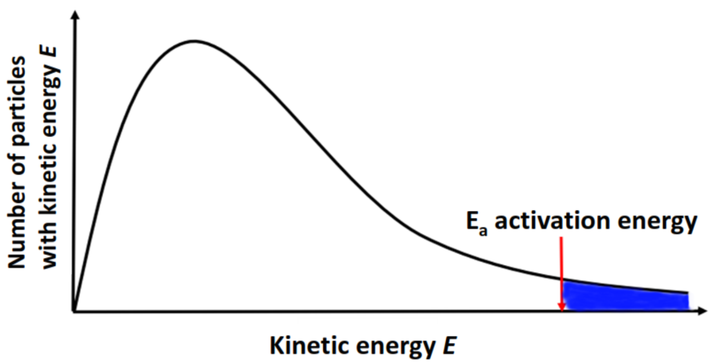
   The minimum energy required by reactant particles to have a successful collision leading to a chemical reaction.

3. Sketch an energy profile for an exothermic and an endothermic reaction, showing the activation energy.

3)



4. Explain what is represented by the white and blue areas in the Maxwell-Boltzmann distribution curve below.

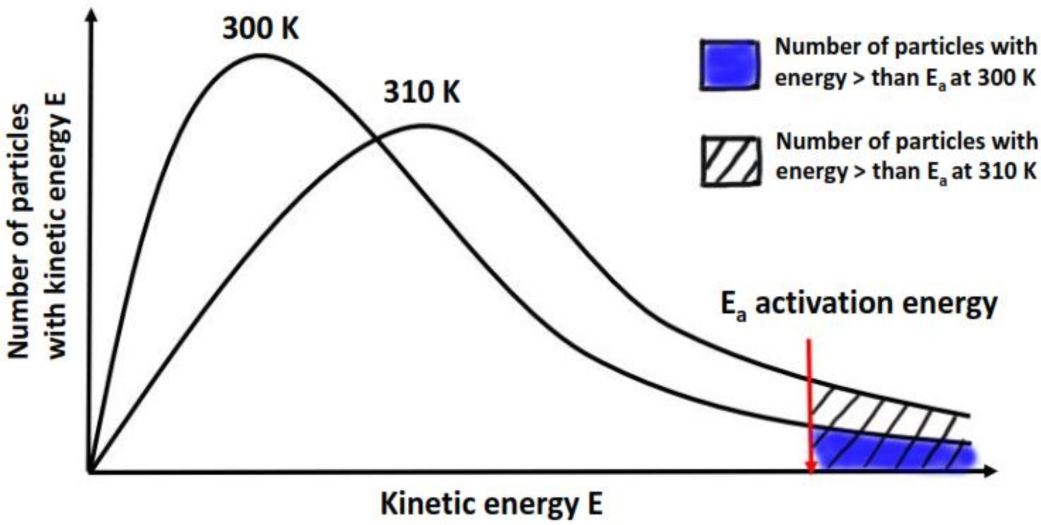


4) The area in white is the proportion of particles that have energy less than the activation energy ($E < E_a$). These particles do not have sufficient energy for a successful collision.
The area in blue is the proportion of particles that have energy greater than the activation energy ($E > E_a$). These particles do have sufficient energy for a successful collision.

Factors that affect the rate of reaction

Temperature

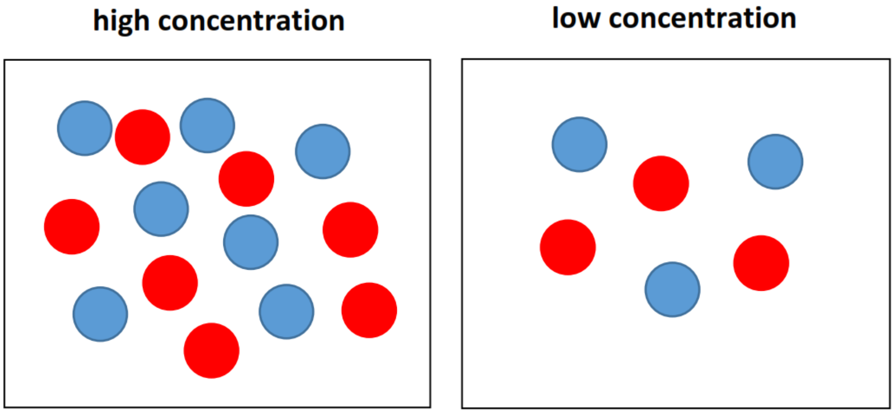
- Increasing the temperature increases the rate of reaction.
- Temperature is a measure of the average kinetic energy of the particles.
- Increasing the temperature increases the average kinetic energy of the particles.



- At a higher temperature, there is an increase in the frequency of collisions between reactant particles due to the higher kinetic energy of the particles.
- There is also an increase in the number of particles that have energy equal to or greater than the activation energy.
- For many chemical reactions, a 10°C increase in temperature can double the rate of reaction.

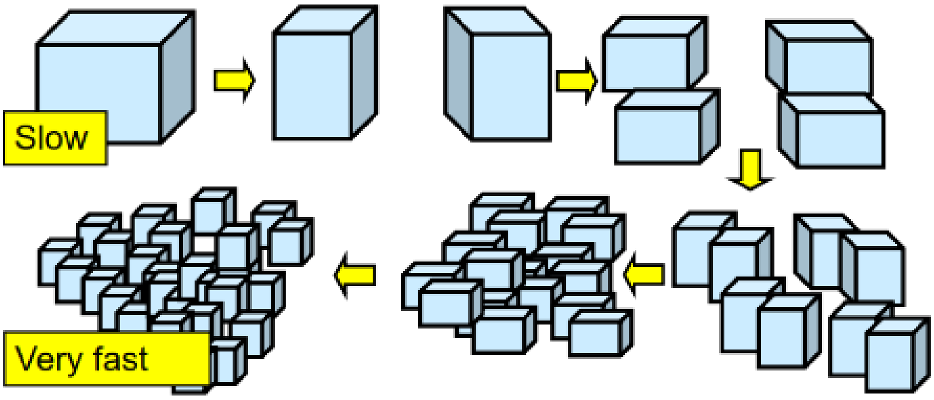
Concentration

- Increasing the concentration of a reactant increases the rate of reaction.
- As the concentration of reactant particles increases, the frequency of collisions between reactant particles also increases.



Particle size

- Decreasing the particle size increases rate of reaction.
- Decreasing the size of the particles increases the surface area per unit volume of the reactant particles (powders react faster than large lumps).

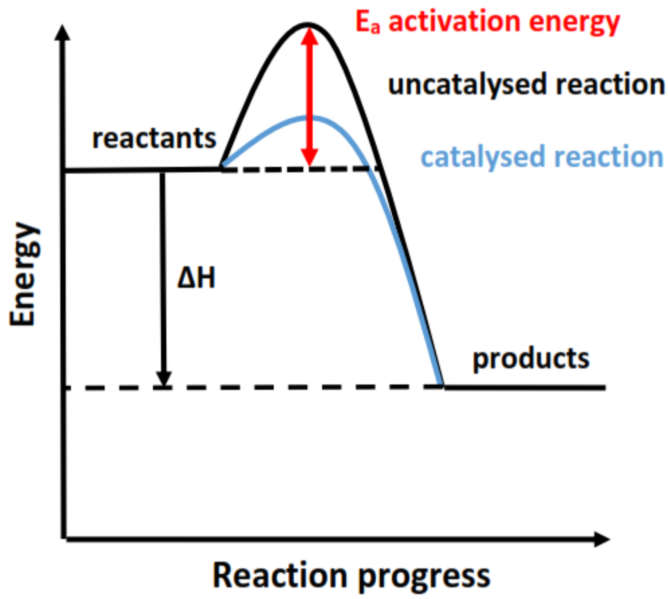


Pressure

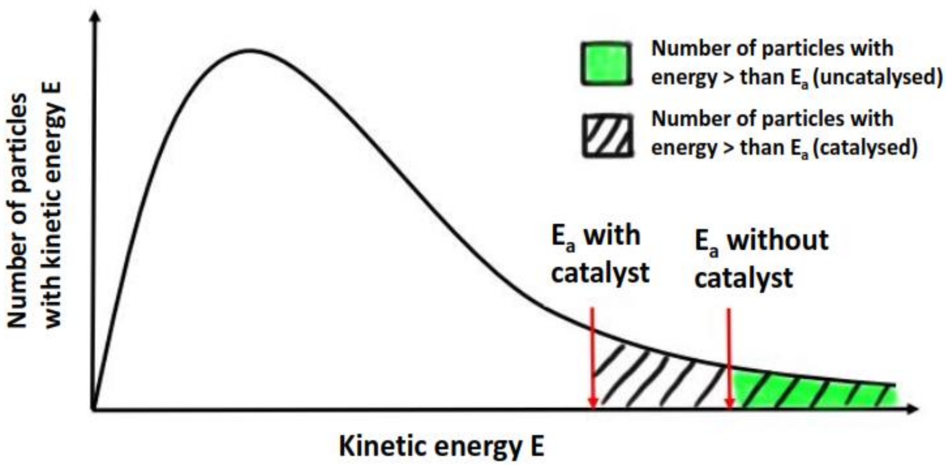
- For reactions involving gases, increasing the pressure increases the rate of reaction (by effectively increasing the concentration).
- At higher pressures, there are a greater number of reactant particles per unit volume which leads to an increase in the frequency of collisions between reactant particles.

Catalysts

- A catalyst is a substance that increases the rate of a reaction without being consumed in the reaction.
- Catalysts provide an alternative route for the reaction that has a lower activation energy.
- As can be seen in the energy level profile below, the catalysed reaction pathway has a lower activation energy than the uncatalysed pathway.



- Below is a Maxwell Boltzmann curve showing the effect of a catalyst on the number of particles with energy greater than the activation energy.



- As can be seen from the above diagram, the lower the activation energy, the greater the number of particles that have energy greater than the activation energy.

Exercises:

1. State and explain the effect of the following changes on the rate of reaction for the following reaction:

$$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$$

a) Increasing the temperature of the hydrochloric acid.
The rate of reaction increases. Increasing the temperature increases the average kinetic energy of the reactant particles resulting in a higher frequency of collisions between reactant particles. The proportion of reactant particles with energy equal to or greater than the activation energy also increases.

b) Increasing the concentration of the hydrochloric acid.
Increasing the concentration of the hydrochloric acid increases the frequency of collisions between reactant particles, therefore, the rate of reaction increases.

c) Increasing the particle size of the calcium carbonate.
Increasing the particle size will decrease the rate of reaction. Larger particles have a smaller surface area per unit volume which results in a lower frequency of collisions between reactant particles.

2. When magnesium ribbon is added to hydrochloric acid, the following reaction takes place:

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$$

State and explain one change that could be made to the reactants to increase the rate of reaction and one change to decrease the rate of reaction.
Increase the rate of reaction:

- Increase the concentration of the hydrochloric acid
- Increase the temperature of the hydrochloric acid
- Use powdered magnesium

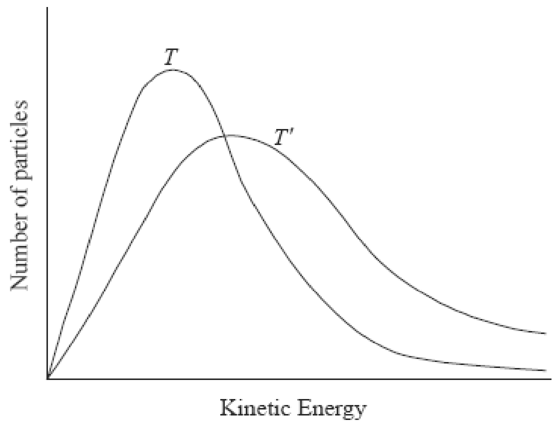
The explanation for these is the same as in question one above.

Decrease the rate of reaction:

- Decrease the concentration of the hydrochloric acid
- Decrease the temperature of the hydrochloric acid

3.

a. Draw a graph to show the distribution of energies in a sample of gas molecules. Label the axis and label your curve T_1. Using the same axis, draw a second curve to represent the distribution of energies at a higher temperature. Label this curve T_2.



b. State and explain, with reference to your graph, what happens to the rate of a reaction when the temperature is increased.

Increasing the temperature increases the average kinetic energy of the reactant particles resulting in a higher frequency of collisions between reactant particles. The proportion of reactant particles with energy equal to or greater than the activation energy also increases.

4. Explain how a catalyst increases the rate of a reaction.

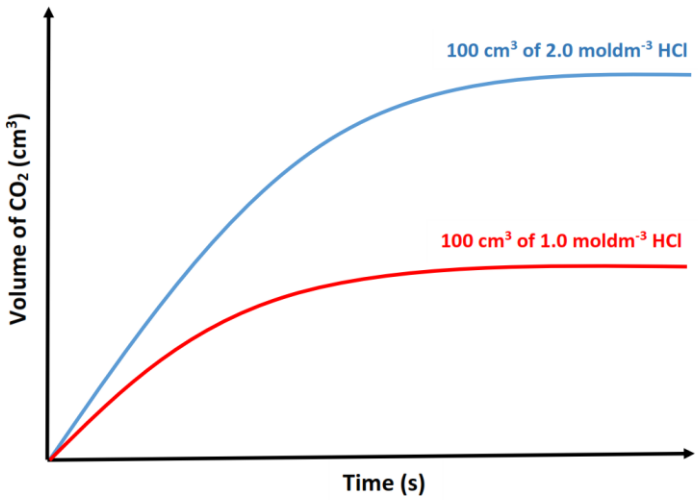
A catalyst increases the rate of reaction by providing an alternative reaction pathway with a lower activation energy.

Analysing rates of reaction graphs

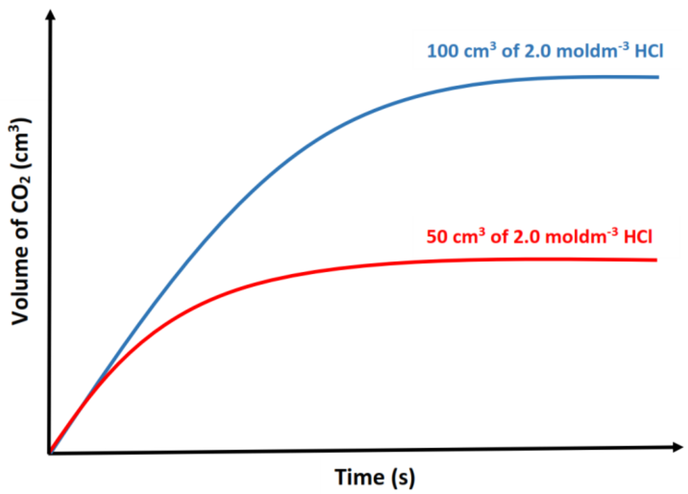
- In the following graphs of volume of CO_2 produced against time, the HCl is the limiting reactant, therefore it determines the amount (in mol) of CO_2 produced.

$$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$$

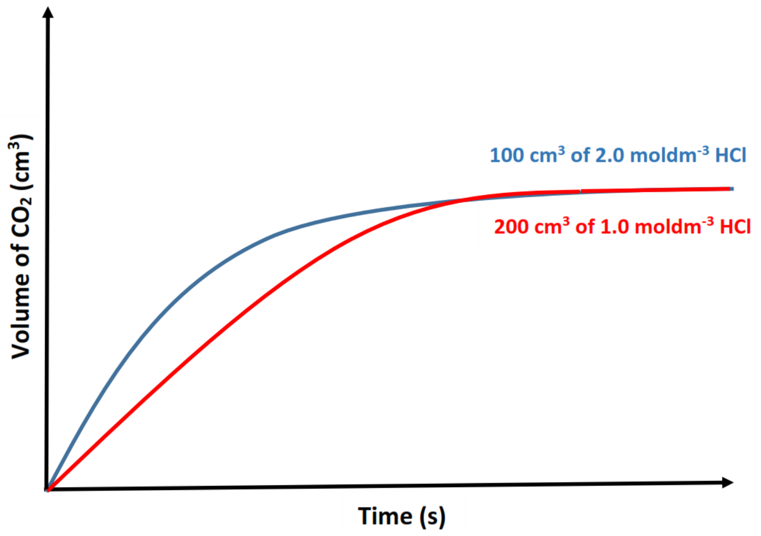
Graph 1



Graph 2



Graph 3



Summary

- The initial rate of reaction depends on the concentration of the HCl – the higher the concentration, the faster the initial rate and the steeper the gradient of the curve.
- The volume of gas produced depends on the amount (in mol) of the limiting reactant.

Graph 4

- The same mass of powdered and large lumps of $CaCO_3$ were added to separate samples of excess hydrochloric acid.