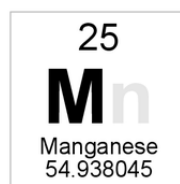
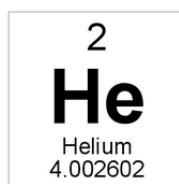
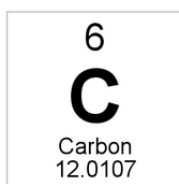
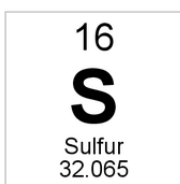
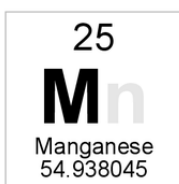


# Kinetics SL

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IB CHEMISTRY SL



**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**

<b>Objective</b>	<b>I am confident with this</b>	<b>I need to review this</b>	<b>I need help with this</b>
Outline the meaning of the term <i>rate of reaction</i>			
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 <i>activation energy</i>			
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:

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

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

The rate of reaction can also be defined as:

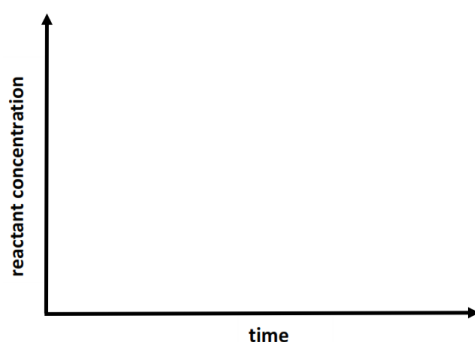
$$\text{rate of reaction} = \frac{\text{increase in product concentration}}{\text{change in time}}$$

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

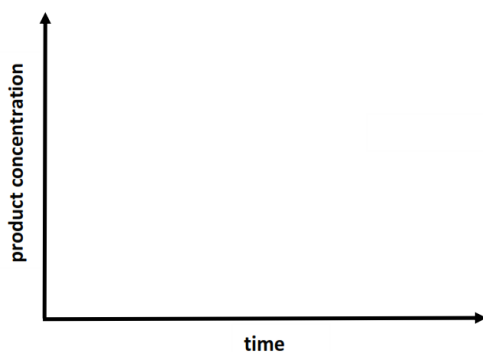
$$\text{rate of reaction} = \frac{\Delta[\text{P}]}{\Delta t} \quad \text{or} \quad - \frac{\Delta[\text{R}]}{\Delta t}$$

On the axis below sketch the following graphs:

- 1) The change of concentration of reactants against time.

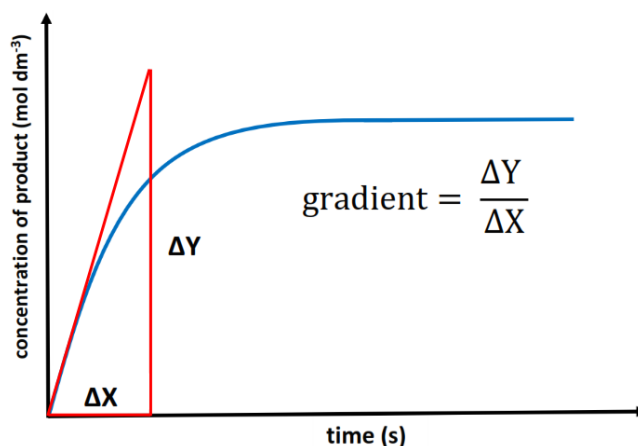


- 2) The change of concentration of products against time.



## 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 fewer 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.

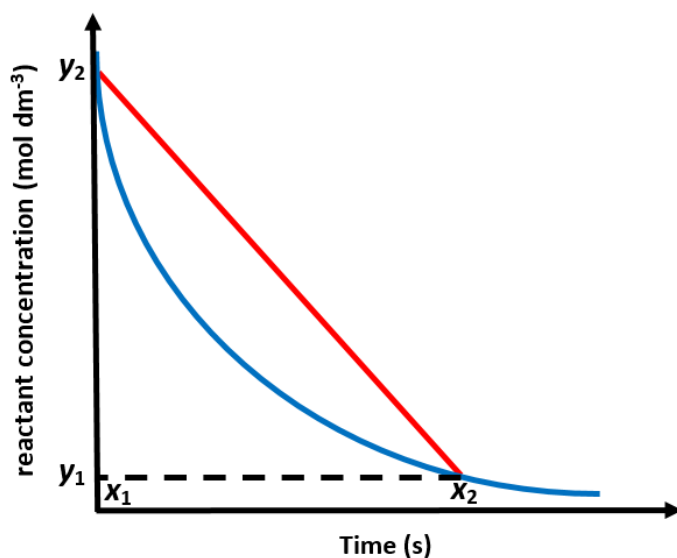


## How to measure the rate of reaction from a graph

- 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.

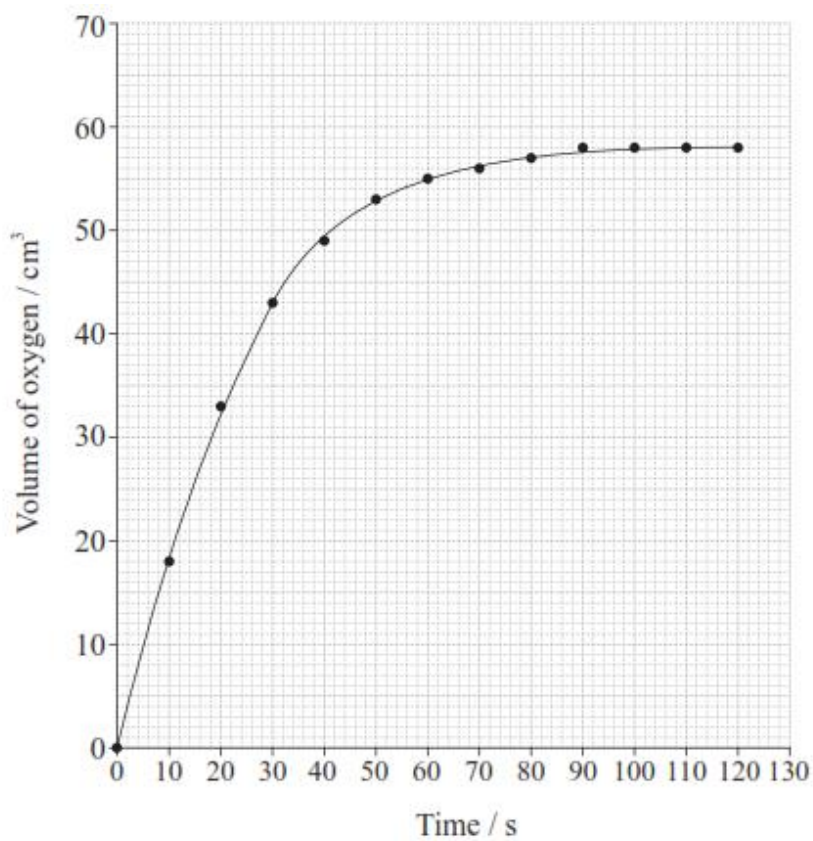
## Average rate of reaction

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



**Exercises:**

- 1) Define the term 'rate of reaction'
- 2) Outline how the initial rate of reaction can be determined from a graph.
- 3) Explain how the rate of reaction changes with time.
- 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.



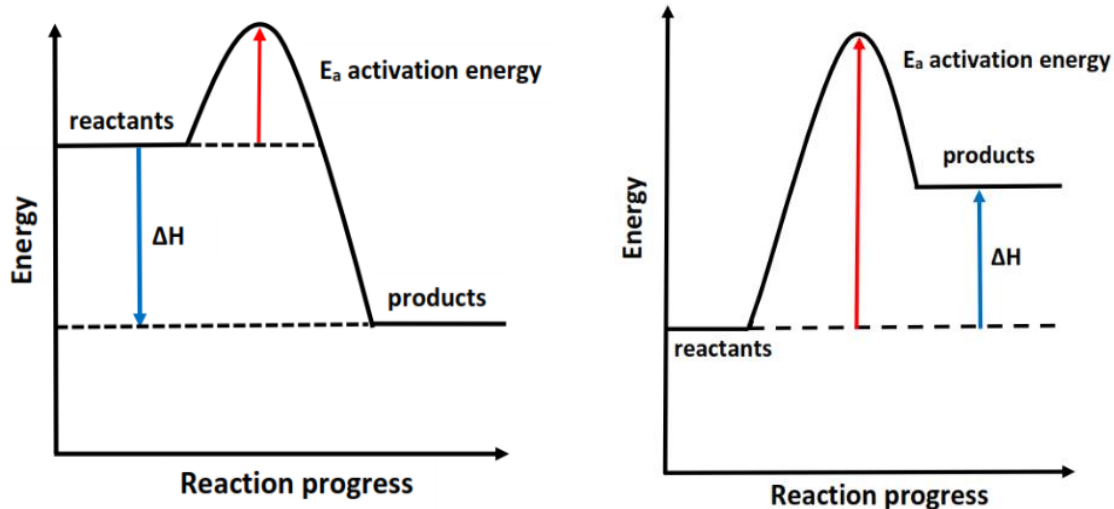
## Collision theory

- 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.

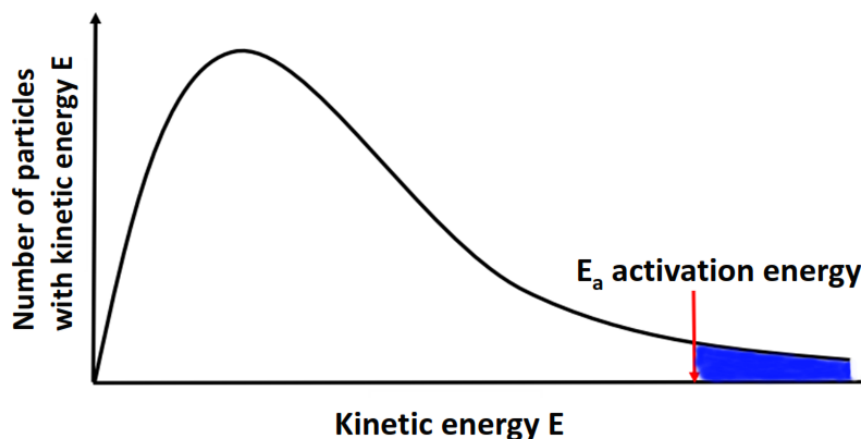
## Energy of collision

- 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 to have a successful collision leading to a chemical reaction.

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



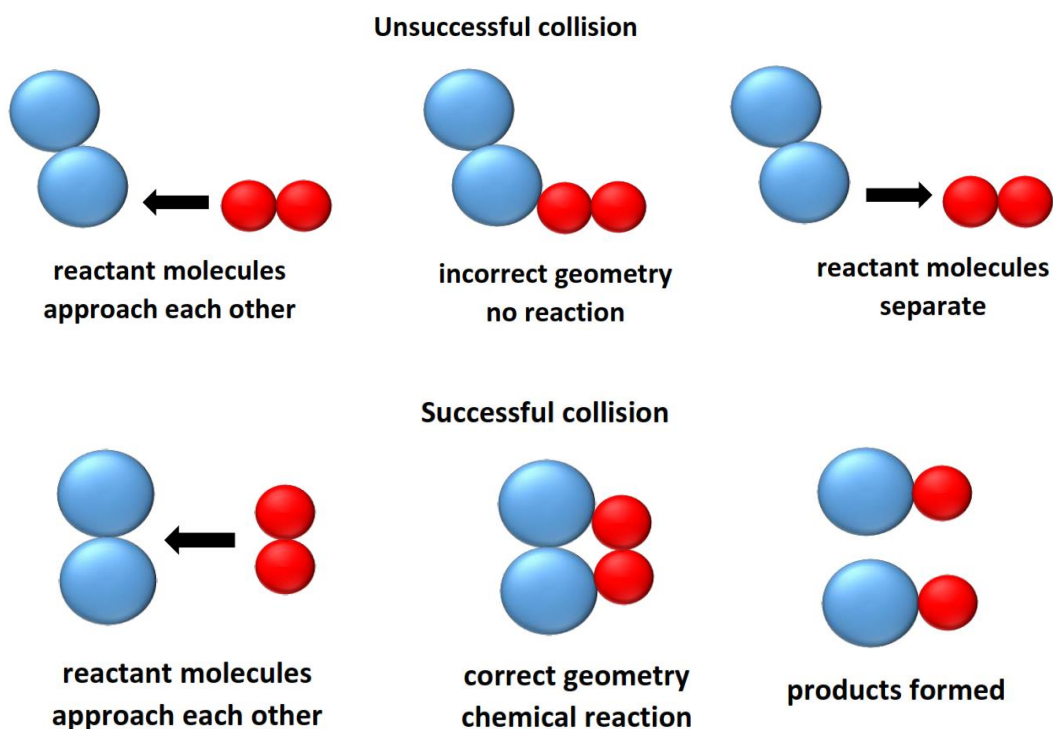
Maxwell- Boltzmann curve showing the distribution of kinetic energy in a sample of gas.



- 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 greater than the activation energy.

### Geometry of collision

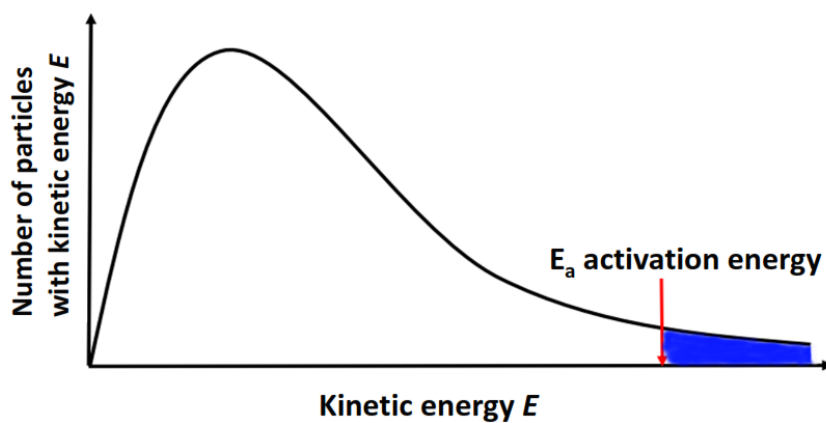
- Particles must also collide with the correct orientation (or geometry) to have a chemical reaction as can be seen in the diagram below:





### Exercises:

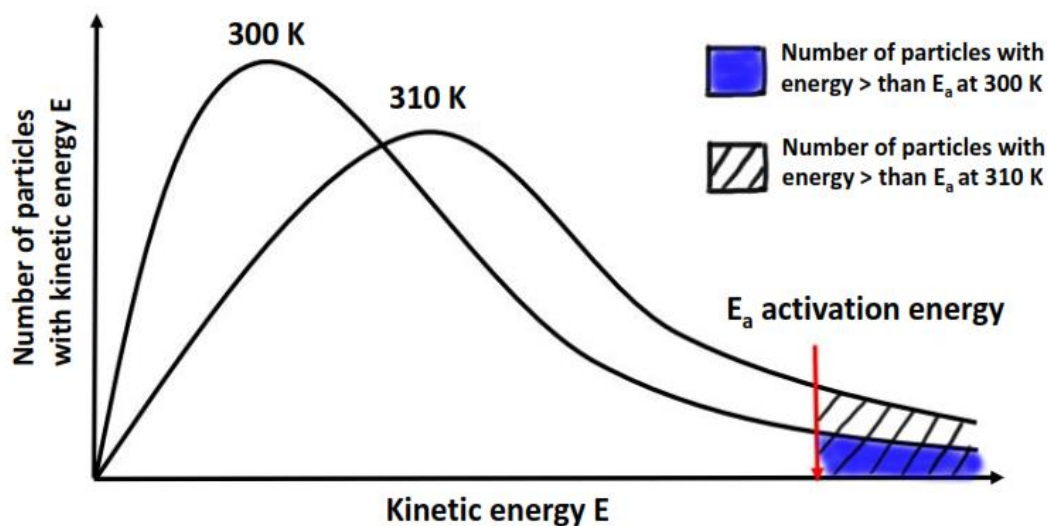
1. State three conditions necessary for a reaction to take place between reactant particles.
2. Define the term *activation energy*,  $E_a$ .
3. Sketch an energy profile for an exothermic and an endothermic reaction, showing the activation energy.
4. Explain what is represented by the white and blue areas in the Maxwell-Boltzmann distribution curve below.



## Factors that affect the rate of reaction

### Temperature

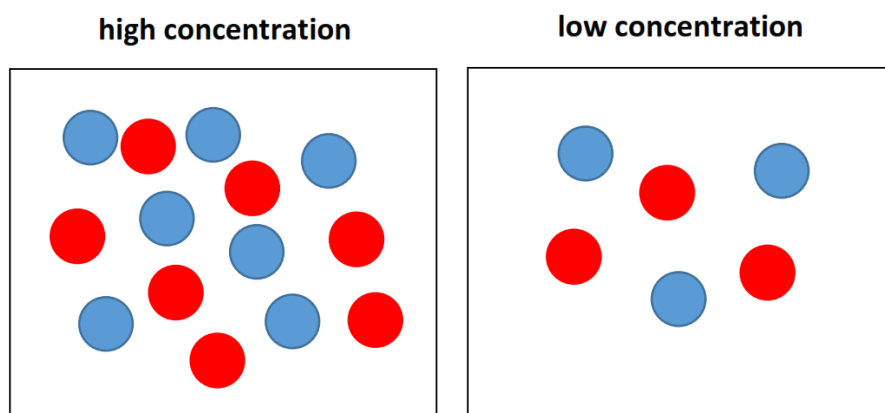
- Increasing the temperature increases the rate of all reactions.
- Temperature is a measure of the average kinetic energy of the particles.
- Increasing the temperature increases the average kinetic energy of the particles.



- 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.
- The frequency of successful collisions increases; therefore, the rate of reaction increases at higher temperatures.
- For many chemical reactions, a 10 °C increase in temperature can double the rate of reaction.

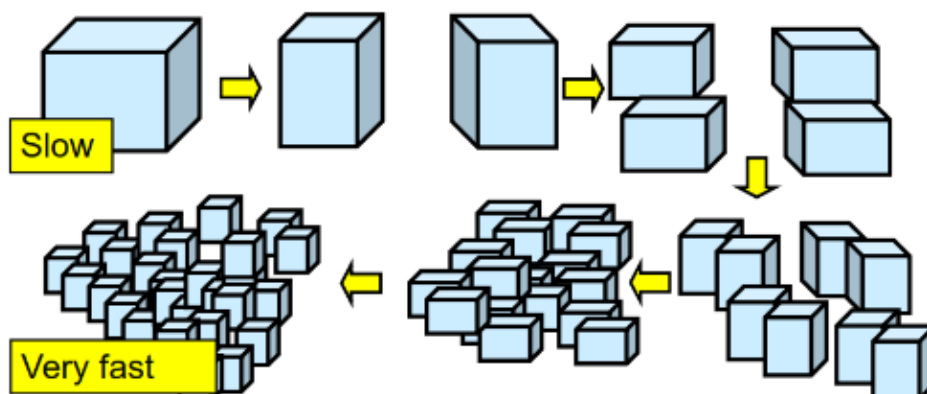
## Concentration

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



## Particle size

- Decreasing the particle size increases rate of reaction.
- Decreasing the size of the particles increases the surface area of the reactant particles.

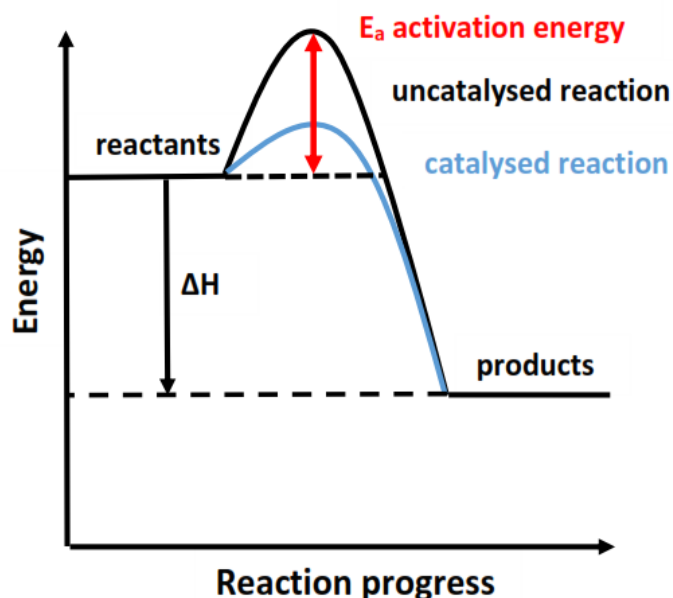


## Pressure

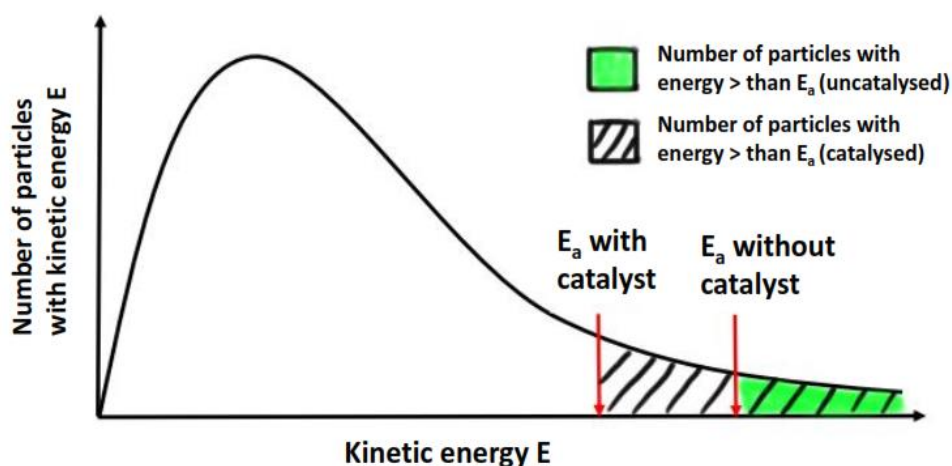
- For reactions involving gases, increasing the pressure increases the rate of reaction (by effectively increasing the concentration).
- At higher pressures, there are a greater number of reactant particles per unit volume with increases the frequency of collisions between reactant particles.

## Catalysts

- A catalyst is a substance that increases the rate of a reaction without being consumed in the reaction.
- Catalysts provide an alternative reaction pathway 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 equal to, or 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:

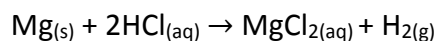


a) Increasing the temperature of the hydrochloric acid.

b) Increasing the concentration of the hydrochloric acid.

c) Increasing the particle size of the calcium carbonate.

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



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.

**3.** Graphs are an effective method to follow the rate of a chemical reaction.

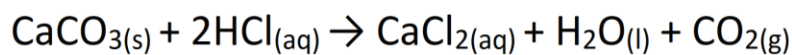
a. Draw a graph to show the distribution of energies in a sample of gas molecules. Label the axis and label your curve  $T_1$ . Using the same axis, draw a second curve to represent the distribution of energies at a higher temperature. Label this curve  $T_2$ .

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

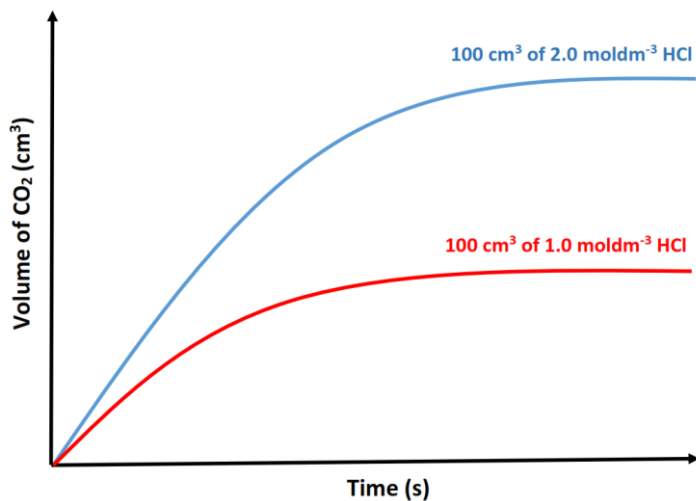
**4.** Explain how a catalyst increases the rate of a reaction.

### Analysing rates of reaction graphs

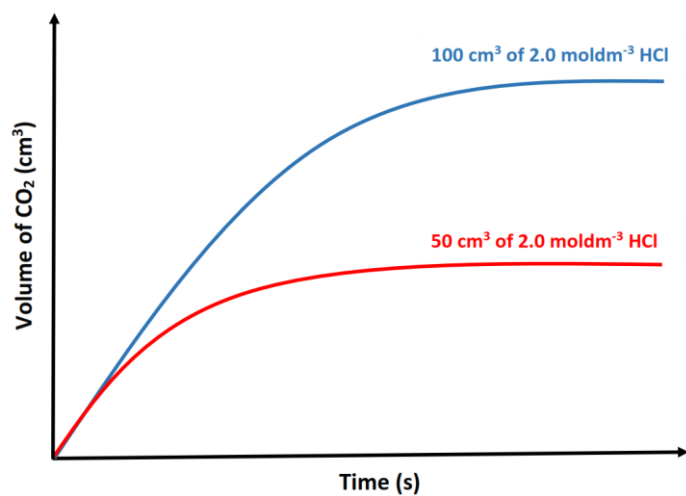
- In the following graphs of volume of CO<sub>2</sub> produced against time, the HCl is the limiting reactant, therefore it determines the amount (in mol) of CO<sub>2</sub> produced.



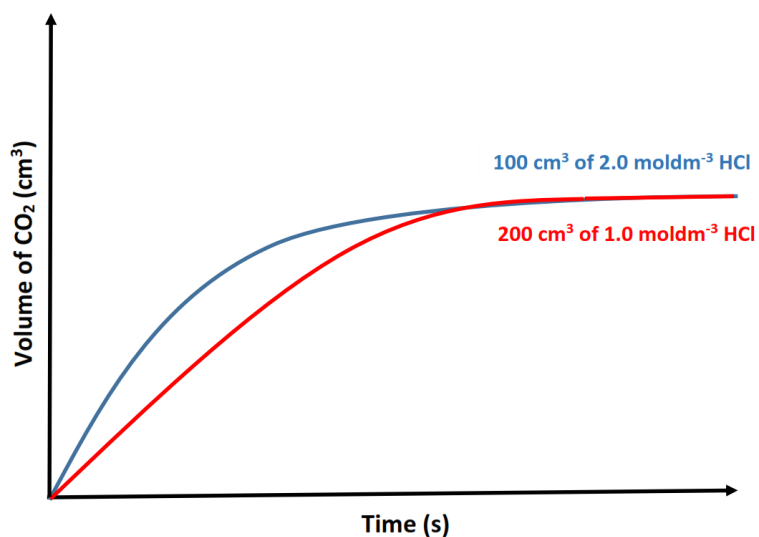
Graph 1



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  $\text{CaCO}_3$  were added to separate samples of excess hydrochloric acid.

