2.2 Rates of Reaction

wjec cbac

$$\text{Rate} = \frac{\text{change in concentration}}{\text{time}} \quad \frac{(\text{mol dm}^{-3})}{(\text{s})} = \text{mol dm}^{-3}\text{s}^{-1}$$

Other values, like mass or volume, can be measured, and the corresponding units such as g s^{-1} or cm s^{-1} are used.

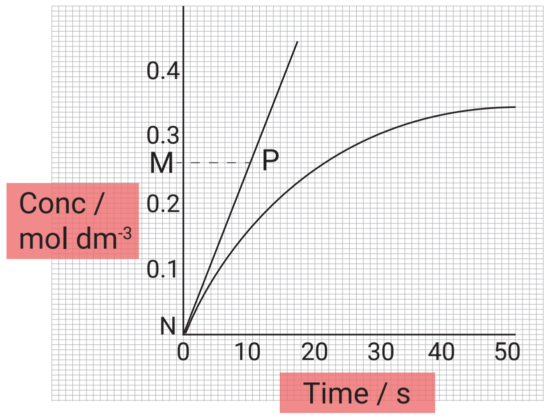
The rate changes as reactions proceed. Usually for reactions:

- The rate is fastest at the start; the concentration of reactants is at their highest.
- Rate slows down as the reaction proceeds; the concentration of reactants has decreased.
- The rate is zero when reaction stops; one of the reactants has been used up.

Calculating rates

Rates are calculated by measuring the amount of a reactant used up, or amount of a product formed, over a period of time. A graph is drawn of the results and the gradient of this line gives the initial rate of reaction. If the line is a curve, a tangent has to be drawn to find the gradient.

For example, to find the initial rate of reaction for this curved line graph:



A tangent must be drawn at t = 0 (since this graph is a curve) and the gradient of the tangent calculated.

$$\text{Initial rate} = \text{gradient of tangent} = \frac{MN}{MP} = \frac{0.26}{10} = 0.026 \text{ mol dm}^{-3} \text{ s}^{-1}$$

To find the rate of a reaction at a specific time, a tangent is drawn at that time, e.g. to find the rate after 10 seconds: draw a tangent at t = 10s.

Factors affecting rates of reaction

- concentration of a solution (pressure of a gas)
- surface area of a solid
- temperature
- catalyst
- light (in some reactions).

Collision theory

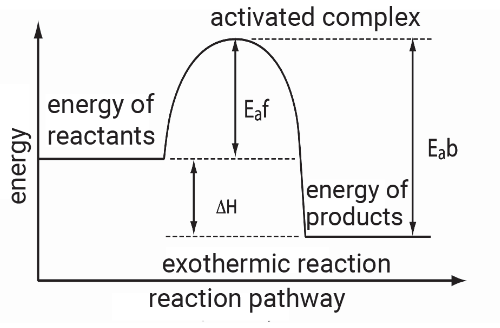
We use collision theory to help us explain how these factors affect rates of reaction.

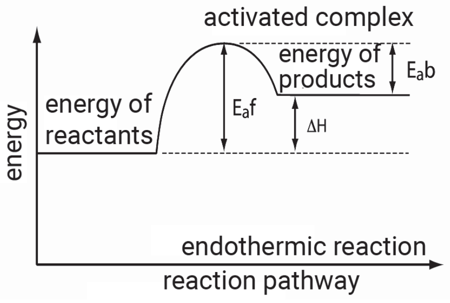
For a chemical reaction to take place, reacting molecules must collide effectively. The reaction rate is a measure of how frequently effective collisions occur.

For a collision to be effective the molecules must collide in the correct orientation and have sufficient energy. The minimum energy needed is called the **activation energy**. Any factor that increases the chance of effective collisions will also increase the rate of reaction.

Energy Profiles

Activation energy, E_a, may be shown on diagrams called energy profiles. These compare the enthalpy of the reactants with the enthalpy of the products.





In the **exothermic reaction**, the products have less energy than the reactants and the excess energy is lost from the reaction as heat, so **ΔH is negative**. Even though the products have a lower energy than the reactants, there still has to be an input of energy, $E_a f$, to break bonds and start the reaction.

In the **endothermic reaction**, the energy of the products is more than the energy of the reactants and heat is taken in from the surroundings, so **ΔH is positive**.

The enthalpy change of reaction is given by:

$\Delta H = E_a f - E_a b$

Effect of concentration/pressure/ particle size on reaction rates

Increasing the concentration of reactants increases the rate of reaction. There are more molecules in a given volume. The distance between molecules is reduced, so there is an increase in the number of collisions per unit time. Therefore, there is a greater chance that the number of effective collisions increases; hence, the rate of reaction increases.

For a gaseous reaction, increasing the pressure is the same as increasing the concentration.

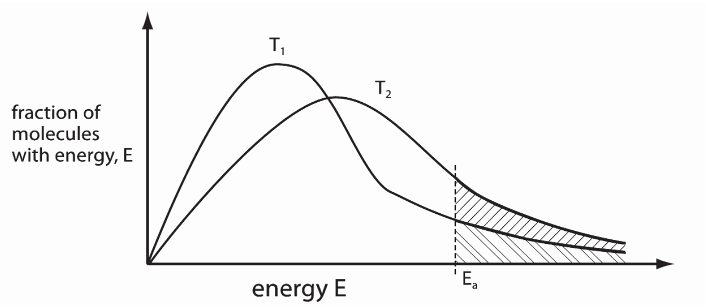
For a solid, reducing the particle size increases the surface area and has the same effect.

Effect of temperature on reaction rates

Increasing the temperature of reactants increases the rate of reactants. Molecules have greater kinetic energy at higher temperatures, so they move faster. More molecules have

energy that is greater than the activation energy, so more successful collisions occur in a given time.

This can be shown using the Boltzmann energy distribution curve. In the diagram, temperature T_2 > temperature T_1.



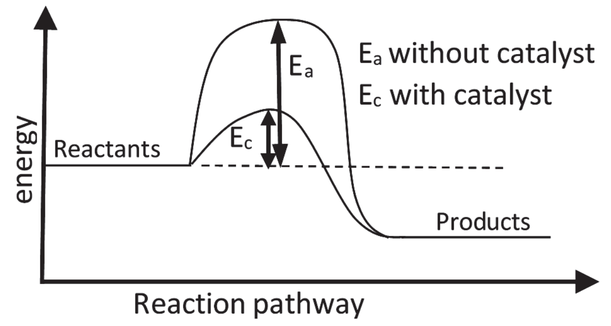
When drawing a distribution curve, remember to draw the E_a line far to the right and make sure the curve does not touch the x-axis.

Effect of catalysts on reaction rates

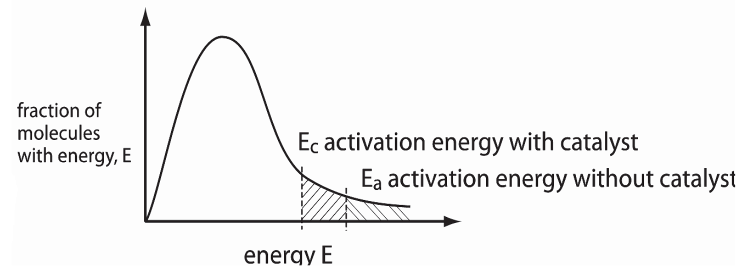
A catalyst increases the rate of a chemical reaction without being used up in the process. A catalyst does take part in the reaction but can be recovered unchanged at the end of the reaction.

Catalysts work by providing a different reaction pathway for the reaction. The rate increases because the new pathway has a lower activation energy.

You can see the different pathways on an energy profile diagram.



You can see the number of molecules with energy greater than the activation energy on an energy distribution curve.



There are two types of catalyst.

- A **homogeneous** catalyst is in the same phase as the reactants. These are typically involved with liquid mixtures or substances in solution.
  - Concentrated sulfuric acid in the formation of an ester from an alcohol and a carboxylic acid.
- A **heterogenous catalyst** is in a different state from the reactants. These include transition metals used in industrial processes.
  - Iron in the Haber process

New catalysts are being developed all the time for industrial processes. Catalysts lower the activation energy of a reaction. Therefore, less energy is needed for the molecules to react, saving energy costs. Using less energy is also beneficial to the environment because less fossil fuel is burnt, meaning less carbon dioxide is released into the atmosphere

Studying rates of reaction

Change in gas volume

The volume of the gas can be recorded using a gas syringe at various times.

Change in gas pressure

If there is a change in the number of moles of gas, the changes in pressure over time can be followed using a manometer.

Change in mass

If a gas forms in a reaction and is allowed to escape, the change in mass over time can be followed using a weighing balance.

Change in colour

If there is a change of colour as the reaction proceeds, the concentration of the substance changing colour can be monitored using a colorimeter.

Remember there are two specified practical tasks:

- using a gas collection method
- studying an 'iodine clock' reaction.