The rate of a reaction can be measured by the rate at which a reactant is used up, or the rate at which a product is formed.

- We can **measure the rate** of a reaction by looking at:
- how fast solid **reactants are used** up,
- how quickly **gas is produced** or
- how **quickly light is blocked** (the disappearing cross)

The quantity of reactant or product can be measured by:

- mass in grams or volume in cm^3. The units are: **g/s or cm^3/s.**
- **HT:** quantity of reactants in terms of moles and units for rate of reaction in **mol/s.**

$$\text{mean rate of reaction} = \frac{\text{quantity of reactant used}}{\text{time}} \text{ or } \frac{\text{quantity of product formed}}{\text{time}}$$

There are **3 different methods** that can be used to measure the rate of a reaction. Measuring the;

1. **Decreasing mass of a reaction mixture (e.g. marble chips (calcium carbonate) & HCl**
2. **Increasing volume of a gas given off**
3. **Decreasing light passing through a solution (i.e. disappearing X)**

Reactions, particles and collisions

Reactions take place when particles collide with a certain amount of energy.

The minimum amount of energy needed for the particles to react is called the **activation energy**, and is different for each reaction.

The rate of a reaction depends on two things:

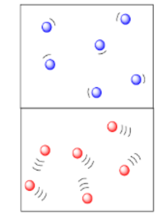
- the **frequency** of collisions between particles
- the **energy** with which particles collide.

If particles collide with less energy than the activation energy, they will not react. The particles will just bounce off each other.

What factors affect the rate of reactions?

- increased **temperature**
- increased **concentration** of dissolved reactants
- increased **pressure** of gaseous reactants
- increased **surface area** of solid reactants
- use of a **catalyst**

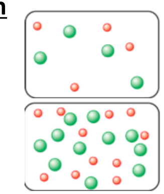
Effect of temperature on rate of reaction



At a higher temperature, particles have more energy. This means they move faster and are more likely to collide with other particles.

When the particles collide, they do so with more energy, and so the number of successful collisions increases.

Effect of concentration on rate of reaction



At a higher concentration, there are more particles in the same amount of space. This means that the particles are more likely to collide and therefore more likely to react.

Effect of pressure on rate of reaction

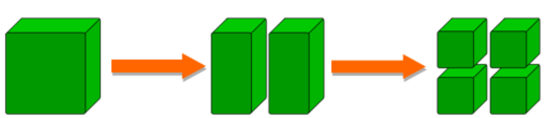
As the pressure increases, the space in which the gas particles are moving becomes smaller.

The gas particles become closer together, increasing the frequency of collisions. This means that the particles are more likely to react.

Effect of surface area on rate of reaction

This means that there is an increased area for the reactant particles to collide with.

The smaller the pieces, the larger the surface area. This means more collisions and a greater chance of reaction.



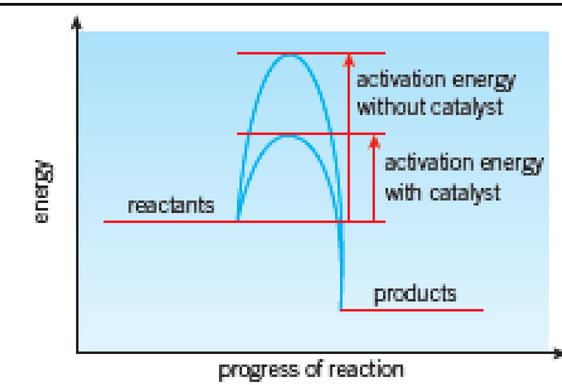
Effect of catalysts on rate of reaction

Catalysts are substances that change the rate of a reaction without being used up in the reaction.

Catalysts never produce more product – they just produce the same amount more quickly.

Different catalysts work in different ways, but most lower the reaction's activation energy (E_a).

- **Nickel** is a catalyst in the production of margarine (hydrogenation of vegetable oils).
- **Iron** is a catalyst in the production of ammonia from nitrogen and hydrogen (the Haber process).
- **Platinum** is a catalyst in the catalytic converters of car exhausts. It catalyses the conversion of carbon monoxide and nitrogen oxide into the less polluting carbon dioxide and nitrogen.

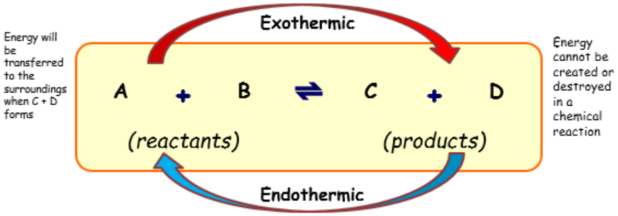


Why are catalysts so important for industry?

- Products can be made more quickly, saving time and money.
- Catalysts reduce the need for high temperatures, saving fuel and reducing pollution.
- Catalysts often come in the form of **powders, pellets** or **fine gauzes,** this provides the largest possible surface area for them to work.

Reversible reactions

Reversible reactions occur when the backwards reaction (reactants → products) takes place relatively easily under certain conditions. The products turn back into the reactants.



Litmus is a complex molecule. This can be represented as HLit (where H is hydrogen). HLit is red. If you add alkali, HLit turns into the Lit− ion by losing an H+ ion. Lit− is blue. If you then add more acid, blue Lit− changes back to red HLit, and so on.

$$HLit(aq) \rightleftharpoons H^+(aq) + Lit^+(aq)$$

red litmus   blue litmus

Equilibrium

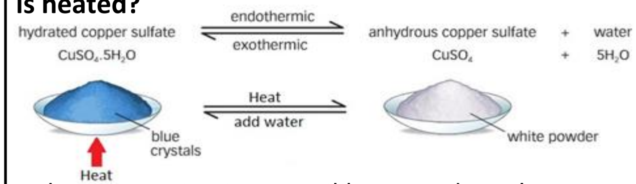
When reversible reactions **reach equilibrium** the forward and reverse reactions are still happening but at the same rate, so the concentrations of reactants and products do not **change**. The balance point can be affected by temperature, and also by pressure for gasses in **equilibrium**

When you heat ammonium chloride, a reversible reaction takes place. Ammonium chloride breaks down on heating. It forms ammonium chloride and hydrogen gases (colourless gases). This is an example of a DECOMPPOSITION REACTION.

ammonium chloride	⇌	ammonia	+	hydrogen chloride
$NH_4Cl\ (s)$	⇌	$NH_3\ (g)$	+	$HCl\ (g)$

NH_4Cl decomposes back into NH_3 and HCl gases, when heated. White solid NH_4Cl reforms in the cooler part of the test tube.

What happens when hydrated copper (II) sulfate is heated?



When a reaction is at equilibrium it doesn't mean the amounts of reactants and products are equal.

- If the equilibrium **lies to the right,** the concentration of **products** is **greater** than that of the reactants.
- If the equilibrium **lies to the left**, the concentration of **reactants** is **greater** than that of the products.

The **position of equilibrium** depends on the following conditions:

1. **Temperature**
2. **Pressure** (this only affects equilibria of gases)
3. **Concentration** of the reactants and products

Reversible reactions can be endothermic and exothermic. The energy transferred **from** the surroundings by the endothermic reaction is **equal to** the energy transferred **to** the surroundings during the exothermic reaction. E.g. thermal decomposition of hydrated copper sulfate.

HT: Le Chatelier's Principle

If a system is at equilibrium and a change is made to any of the conditions, then the system responds to counteract the change. The effects of changing conditions on a system at equilibrium can be predicted using Le Chatelier's Principle.

1. **Temperature…**

If the temperature of a system at equilibrium is increased:

- the relative amount of products at equilibrium increases for an endothermic reaction
- the relative amount of products at equilibrium decreases for an exothermic reaction.

1. **Temperature continued…**

If the temperature of a system at equilibrium is decreased: • the relative amount of products at equilibrium decreases for an endothermic reaction •the relative amount of products at equilibrium increases for an exothermic reaction.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
Here the forward reaction is exothermic – a decrease in temperature moves equilibrium to the right (more NH_3).

2. **Pressure…**

For gaseous reactions at equilibrium:

- an **increase in pressure** causes the equilibrium position to shift towards the side with the smaller number of molecules as shown by the symbol equation for that reaction
- a **decrease in pressure** causes the equilibrium position to shift towards the side with the larger number of molecules as shown by the symbol equation for that reaction.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
There are 4 moles to the left (1 of N_2 and 3 of H_2) but only 2 on the right. So if you increase the pressure, the equilibrium shifts to the right (more NH_3).

3. **Concentration…**

If the concentration of one of the reactants or products is changed, the system is no longer at equilibrium and the concentrations of all the substances will change until equilibrium is reached again.

- If the concentration of a reactant is **increased**, more products will be formed until equilibrium is reached again.
- If the concentration of a product is **decreased**, more reactants will react until equilibrium is reached again.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
If more N_2 or H_2 is added, the forward reaction increases to produce more NH_3.