# Rate of Reaction

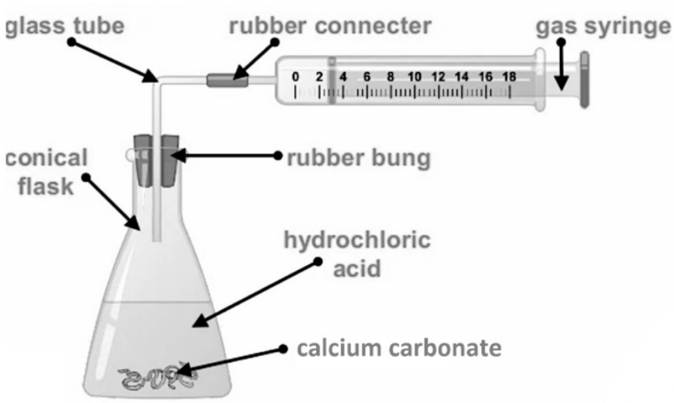
## Definition: Rate of Reaction

- The **rate (or speed)** of a chemical reaction tells us **how quickly or slowly** a reaction takes place.
- It is defined as the **change in amount of product formed or reactant used per unit time.**

## Methods to Determine Rate of Reaction

### Method 1: Measuring Volume of Gas Produced Per Unit Time

> When 0.50 g of $CaCO_3$ solid is added to excess hydrochloric acid, carbon dioxide is formed. The carbon dioxide gas can be collected in the gas syringe using the following apparatus. To determine the rate of the reaction, the volume of gas collected in the gas syringe can be measured over a period of time. A graph of volume of gas collected against time is plotted.




**_*note: you need to know how to diagram the experimental set-up._**

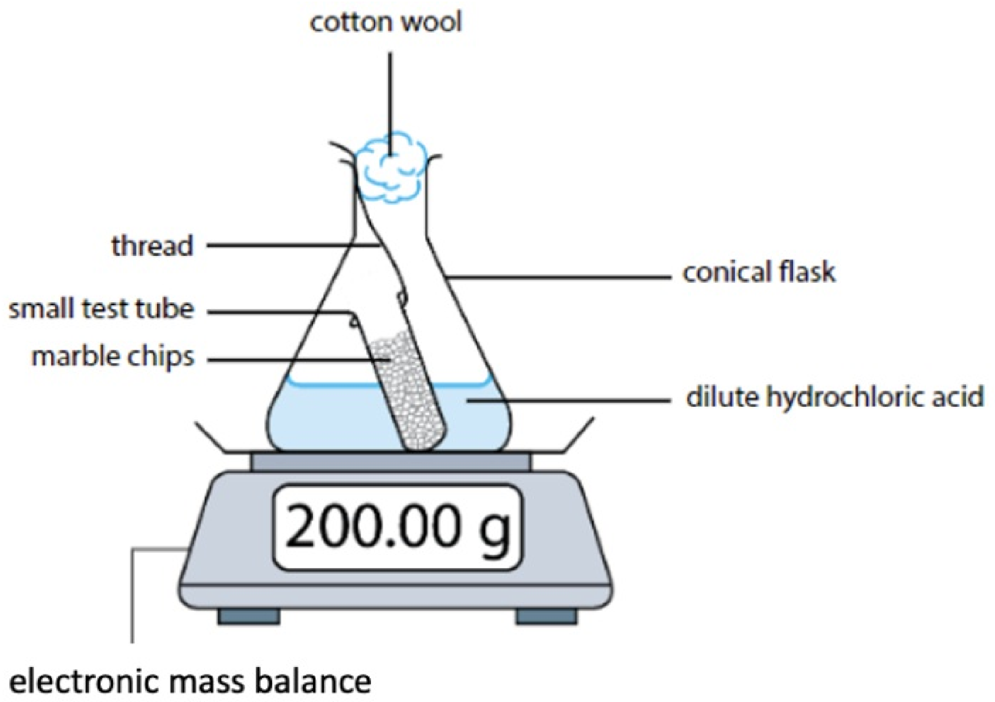
# Method 2: Measuring loss in mass of reaction per unit time

To determine the rate of reaction between 0.50 g of $CaCO_3$ solid and excess hydrochloric acid.

## Apparatus

- Conical flask
- Electronic mass balance
- Stopwatch

## Experimental Setup




### Procedure

1. Set up the apparatus as shown above.
2. Use a cotton wool plug to cover the mouth of the conical flask to prevent acid from splashing out during the reaction (resulting in a loss in reactants).
3. Record the mass of the conical flask and its contents.
4. Release the thread and ensure that the calcium carbonate are added into the acid. Start the stopwatch immediately.
5. Record the mass of the conical flask and its contents at regular time intervals (e.g. every 1 minute) until mass remains constant.
6. Use the data collected to plot a graph of mass of conical flask and contents against time.
7. The rate of reaction can be determined from the gradient of the graph of mass against time.

## Method 3: Measuring a changing quantity

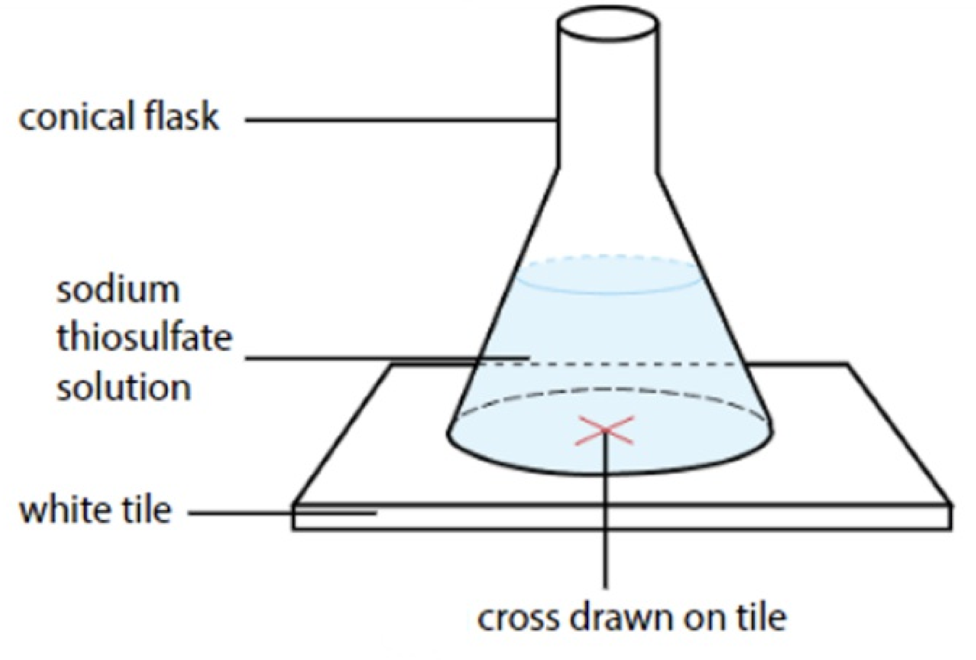
To determine the rate of the reaction between 50 cm^3 of 0.200 mol/dm^3 sodium thiosulfate solution and hydrochloric acid.

$$Na_2S_2O_3\ (aq) + 2\ HCl\ (aq) \rightarrow 2\ NaCl(aq) + H_2O(l) + SO_2\ (g) + S(s)$$

## Apparatus

- Conical flask/beaker
- Stopwatch
- White tile with cross or colourimeter

## Experimental Setup




## Procedure

1. Set up the apparatus as shown above.
2. Using a measuring cylinder, measure 50 cm^3 of 0.2 mol/dm^3 of sodium thiosulfate solution into the conical flask
3. Using a measuring cylinder, add 100 cm^3 of 0.2 mol/dm^3 dilute

hydrochloric acid into the conical flask and start the stopwatch immediately.

4. Look at the cross through the mouth of the flask. Stop the stopwatch when the cross is no longer visible. (yellow solid sulfur produced is opaque and blocks the cross from view as more of it is formed.)
5. Repeat the experiment with a changed variable (e.g. temperature, concentration of solution).
6. The change in rate of reaction can be determined by comparing the change in time taken fro the cross to be covered.

### Alternative Method

1. Use the colourimeter to measure the colour intensity of the reaction mixture in the conical flask at regular time intervals (e.g. every 1 minute).
2. Use the data collected to plot a graph of colour intensity against time.
3. The rate of reaction can hence be determined through the gradient of the graph of colour intensity against time.

# Collision Theory

- For a reaction to occur and products to form, **the reactant particles must collide with each other.**
- However, only **effective collisions will result in a reaction.** An effective collision must fulfil the following conditions:
  - The reactant particles must **collide with sufficient energy, equal to or greater than the reaction's activation energy.**
  - The reactant particles must also collide with the **correct orientation**, i.e., "the right way round".

# Factors Affecting Rate of Reaction

There are five factors affecting the rate of reaction. They are:

1. **Concentration:** applicable for reactants in **aqueous** state
2. **Pressure:** applicable for reactants in **gaseous** state
3. **Particle Size:** applicable for reactants in **solid** state.
4. **Temperature**
5. **Presence of Catalyst**

## Factor 1: Concentration

| Lower Concentration | Higher Concentration |
|---|---|
| **Fewer** reactant particles per unit volume | **More** reactant particles per unit volume |
| Reactant particles are **further** from each other. | Reactant particles are **closer** to each other |
| **Fewer** collisions per unit time between particles | **More** collisions per unit time between particles |
| Frequency of effective collisions is **lower** | Frequency of effective collisions is **higher** |
| **Slower** rate of reaction | **Faster** rate of reaction |

## Factor 2: Pressure

| Lower Pressure | Higher Pressure |
|---|---|
| **Fewer** reactant particles **per unit volume** | **More** reactant particles **per unit volume** |

| Lower Pressure | Higher Pressure |
|---|---|
| Reactant particles are **further** from each other | Reactant particles are **closer** to each other |
| **Fewer collisions** per unit time between particles | **More collisions** per unit time between particles |
| Frequency of effective collisions is **lower** | Frequency of effective collisions is **higher** |
| **Slower** rate of reaction | **Faster** rate of reaction |

## Factor 3: Particle Size

| Large Particle Size (Granulated Solid) | Small Particle Size (Powdered Solid) |
|---|---|
| **Bigger** pieces of solid reactants | **Smaller** pieces of solid reactants |
| **Smaller** surface area of solid reactants (given same mass, less number of particles) | **Bigger** surface area of solid reactants (given same mass, more number of particles) |
| **Fewer** collisions per unit time between particles | **More** collisions per unit time between particles |
| Frequency of **effective collisions is lower** | Frequency of **effective collisions is higher** |
| **Slower** rate of reaction | **Faster** rate of reaction |

## Factor 4: Temperature

| Lower Temperature | Higher Temperature |
|---|---|

| Lower Temperature | Higher Temperature |
|---|---|
| Particles have **less** kinetic energy and move **slower** | Particles have **more** kinetic energy and move **faster** |
| **Less** frequent collisions between particles | **More** frequent collisions between particles |
| **Less** particles collide with energy **greater or equal** to activation energy, $E_a$ | **More** particles coliide with energy greater or equal to activation energy, $E_a$ |
| Frequency of effective collisions is **lower** | Frequency of effective collisions is **higher** |
| **Slower** rate of reaction | **Faster** rate of reaction |

# Catalysts

A catalyst increases the rate of chemical reactions without being chemically changed at the end of the reaction.

**Characteristics of Catalysts**

- Increased rate of reaction but not the yield
- Not used up in the reaction as it can be regenerated at the end of the reaction
- Selective in action (i.e. each catalyst only catalyses certain reactions)
- Can be poisoned by impurities
- Physical appearance may change but remain chemically the same
- Provide an alternative pathway with a lower activation energy, $E_a$, for the reaction

## Factor 5: Presence of Catalyst

| Uncatalysed reaction | Catalysed reaction |
|---|---|
| No catalysts to provide alternative pathway of lower activation energy for the reaction to proceed. | Catalysts increase the speedo f reaction by providing an **alternative pathway of lower activation energy** for the reaction to succeed. |
| **Less** particles collide with energy greater or equal to **activation energy,** $E_a$ | **More** particles collide with energy greater or equal to **activation energy,** $E_a$ |
| Frequency of effective collisions is **lower** | Frequency of effective collision is **higher** |
| **Slower** speed of reaction | **Faster** rate of reaction |

## Industrial Catalyst

- Industrial catalysts are usually transition metals and their compounds due ot the ability to have variable oxidation states
- By using catalysts, less extreme physical conditions (heat and pressure) are required, saving energy.

| Catalyst | Use |
|---|---|
| Iron | Manufacture of ammonia in the Haber process |
| Aluminium or Silicon Dioxide | Cracking of hydrocarbons |
| Nickel | Manufacture of margarine from vegetable oils |

| Catalyst | Use |
|---|---|
| Platinum, Palladium, and rhodium | Catalytic converters |

## Biological Catalysts (Enzymes)

- Enzymes are biological catalysts, which catalyse biological processes such a s digestion, energy production, detoxification etc.
- Enzymes are made of proteins
- Sensitive to temperature - most enzymes operate best at body temperature (between 35 degrees Celsius and 40 degrees Celsius). Enzymes are dormant/inactive at low temperatures and **denatured** at high temperatures. Denaturation is when the specific active site changes and enzyme cannot catalyse the specific reaction anymore.
- Sensitive to pH - operates best at optimal pH range. Different enzymes have different optimal pH range.

### Specific Catalytic Action

- The active site of each enzyme is specific, and can only fit certain reactant molecules in a specific orientation.
- Applications - Manufacture of food such as cheese, yoghurt and bread, in laundry detergent.

# Graphical Analysis

- Graphs are often used to describe information about a chemical reaction.
- Gradient of graph indicates the speed of the reaction. The steeper the

gradient, the faster the speed of reaction. The gradient can change as reaction proceeds as reactants are used up.

- The final volume of gas / mass of the reaction indicates the yield of the reaction. The yield of the products depends on the amount of limiting reagents.