BioMedical Admissions Test (BMAT)

Section 2: Chemistry

Topic C10: Rates of Reaction

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What does the "rate of reaction" mean?

The rate of reaction gives information relating to the **speed** that the reaction is occuring at, **ranging from very slow to very fast**.

The rate of a reaction can be calculated by dividing the measured change either in the concentration of the reactant or the product by the time taken for that change to occur; in other words **how quickly the reactants are used up or how quickly the products are formed.**

$$Rate\ of\ reaction\ =\ \frac{Amount\ of\ reactant\ used\ or\ product\ formed}{time}$$

The rate of a chemical reaction can be **increased** by:

- Increasing the concentration of a solution
- Raising the pressure of a gas
- Increasing the temperature of the reaction
- Increasing the surface area of a solid
- Adding a catalyst

The **collision theory** can be used to explain why the above factors all contribute to increasing the rate of reaction.

Collision Theory

The collision theory states that in **order for a reaction to occur** particles of the reacting substances must **collide** with one another in the **right direction** and with **enough energy** to break existing bonds and so cause the reaction between the particles.

The **minimum energy required to cause the reaction is known as the activation energy**. This minimum energy is required to **break existing bonds** between particles to start the reaction.

The **greater the frequency and energy** with which the particles are colliding, the **greater the rate of reaction**. And therefore factors which act to increase the frequency or increase the energy of collisions will also increase the rate of reaction.

Increasing the concentration of a solution:
- There is a now **greater number** of particles of the reactant substance mixed in the water, i.e. the **ratio of reactant:water increases**.
- For example increasing the concentration of a copper sulfate solution means there is a greater number of copper sulfate particles within the water.
- **A greater number of reactant particles means a greater chance of collisions occurring**, and so there will be **more successful collisions** taking place and **more frequently**, which i**ncreases the rate of reaction.**

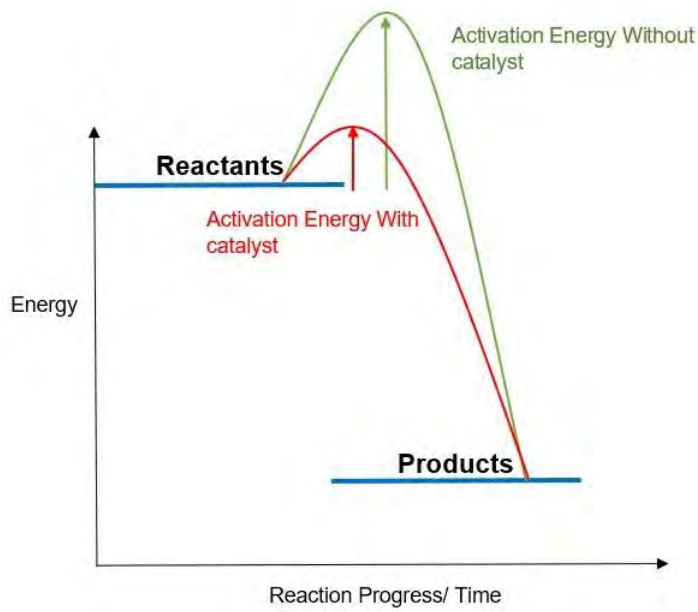
Increasing the pressure (gases only):
- The **reactant particles are pushed closer together** and therefore will **collide more easily due to being close**r.
- This therefore in**creases the frequency of successful collisions** and so **increases the rate of reaction.**

Increasing the temperature of the reaction:
- The reacting particles now have **more kinetic energy** and so they **move around more quickly**, which leads to **more frequent collisions** happening. Furthermore, the **collisions will have more energy**, with a **greater number of particles** having the r**equired activation energy**, which in**creases the likelihood of the collisions being successful collisions, i.e ones that lead to a reaction.**
- More successful collisions in a given amount of time increases the rate of reaction

Increasing the surface area of a solid:
- The surface area of a solid can be increased by **breaking up or crushing up the solid** into many smaller pieces; **smaller particles have a larger surface area.**
- Increasing the surface area of a solid means **more of its particles are exposed** and therefore **more 'available'** to collide with other particles, i**ncreasing the frequency of collisions, which increases the rate of reaction.**

Adding a catalyst:
- The catalyst **provides an alternative pathway** for the reaction to occur. This alternative pathway **requires particles to have less energy** to collide successfully, leading to a **greater number of successful collisions,** which i**ncreases the rate of reaction.**
- The catalyst **does not change the frequency of collisions**, but increases the frequency of **successfu**l collisions in a given amount of time because more of the colliding particles have **energy greater than the required activation energy**. T**he catalyst is providing an alternative reaction pathway with a lower activation energy than the uncatalysed reaction.**
- The catalyst will **not be chemically changed or used up** in the reaction and so can be **reused**. This makes it very **economical** to use a catalyst in reactions because not only do they lower the temperature requirement for the reaction, they can also be reused.

- Catalysts are also **beneficial to the environment** because of the **lower temperature** requirement. This means energy is saved and so less CO_2 which contributes to global warming is released into the atmosphere and stores of fossil fuels are preserved.
- Not all reactions have a catalyst that can be used. Different reactions have different catalysts and so **catalysts are specific to reactions**. Catalysts can also be **expensive to buy** and after time they can become **"poisoned" by impurities** and so stop working.



The graph above demonstrates how a catalyst acts to provide a different pathway for which the reaction can occur. This pathway has a **lower activation energy** and so in a certain amount of time, there are more successful collisions occurring. The red arrow shows the activation energy with a catalyst and the green arrow shows the activation energy without a catalyst.

Factor increasing the rate of reaction	Example experiment to show this effect
Increasing the concentration of a solution	**React magnesium metal with dilute HCl** Using a mass balance **measure the amount of hydrogen gas given off**. The experiment is repeated with more concentrated solutions of HCl ***Observed results***: *the greater the concentration of the HCl, the greater the loss in mass in a given time interval, showing a faster rate of reaction.*
Increasing the temperature of the reaction	**React sodium thiosulfate with hydrochloric acid.** Mixing these chemicals will form a **cloudy precipitate. Measure the time taken for the precipitate to form** by observing when a black cross placed underneath the flask containing the reagents can no longer been seen. Repeat the experiment but this time **heat the individual solutions of sodium thiosulfate and HCl using a water bath.** ***Observed results:*** *The **higher the temperature of the solutions, the less time taken for the black cross to disappea**r upon mixing the reagents due to a precipitation forming faster, which demonstrates the **faster rate of reaction** caused by increasing the temperature of the solutions.*
Increasing the surface area of solid particles	React HCl acid with marble chips **Measure the volume of CO_2 gas evolved with a gas syringe** to determine the rate of reaction. Repeat the experiment but this time **crush the marble chips into finer** ***Observed results:*** *An **increased rate of reaction when the HCl is reacted with powdered chalk** than with the smaller crushed piece of marble chips or with the original large marble*

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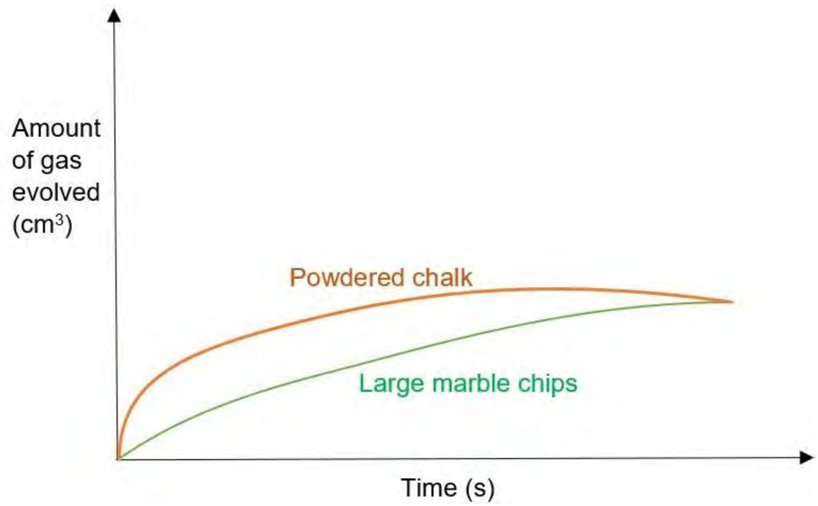
*chips. This is because **using finer particles increases the surface area of the solid, which increases the frequency of collisions and so increases the rate of reaction.***



The green line represents the original reaction with the large marble chips. The curve is not too steep.
The orange line represents the reaction when the marble chips have been ground to a fine powder. The **slope of the graph is steeper**, representing a faster rate of reaction.
This is because the **powder has a larger surface are**a and so **more frequent collisions leading to a faster rate of reaction**- more gas is evolved in a certain amount of time. However both curves converge at the same level showing that the same **amount of product is produced.**

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Using a catalyst

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The decomposition of hydrogen peroxide, H_2O_2:

$$2H_2O_{2(aq)} \rightarrow O_{2(g)} + 2H_2O_{(l)}$$

Using **magnesium(IV) oxide** as a **catalyst** in this reaction will speed up the rate of reaction of the decomposition of hydrogen peroxide than if the catalyst was not used. On a rate graph, using a catalyst would produce a curve with a steeper slope, showing a faster rate of reaction.

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Measuring Rates of Reaction

To assess the rate of reaction, there are some key methods which you need to know and be able to apply to varying situations.

Measuring change in volume:

- The **change of volume** of either the reactant or the product can be measured as the reaction occurs when **liquids or gases are involved**. It is usually easier to measure the volume of product formed.
- If the volume of a liquid is being measured, a measuring cylinder can be used.
- If the volume of a gas is being measured, a gas syringe can be used.
- The **greater the volume of liquid or gas product collected in a given time, the faster the rate of the reaction**; there would be a **steeper line** on a graph of gas/liquid volume against time, **showing the greater rate of reaction.**

Formation of a Precipitate:

- If the product of a reaction is a **cloudy precipitate**, the **time taken to form the precipitate** and therefore to form the product can be measured.
- Place a mark, such a black cross, under the reaction flask and **time how long it takes for the cloudy precipitate to form until the mark can no longer be seen**. **The less time taken, the faster the reaction**.
- This is not a very accurate measure of rate:
  - The point at which the mark disappears is **subjective** and not consistent.
  - The initial solution has to be see-through to allow the differentiation to when it becomes cloudy.

Loss of Mass:

- If the product formed is a gas, the **system will lose mass**. **Measure the loss of mass at regular time intervals using a balance.**
- The **greater the mass loss in a set time interval, the faster the rate of the reaction**.

Reactant state	Product State	Method to use	Equipment
Liquid/Gas	Liquid/gas	Measure change in volume of reactant/product	Liquid - measuring cylinder Gas - gas syringe
Liquid	Solid (precipitate)	Disappearing cross	Conical flask Paper with cross on it
Solid/liquid	Gas	Loss of mass over a time period	Crucible Mass balance (scales)