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GCSE Chemistry

AQA Topic – The Rate And Extent of Chemical Change

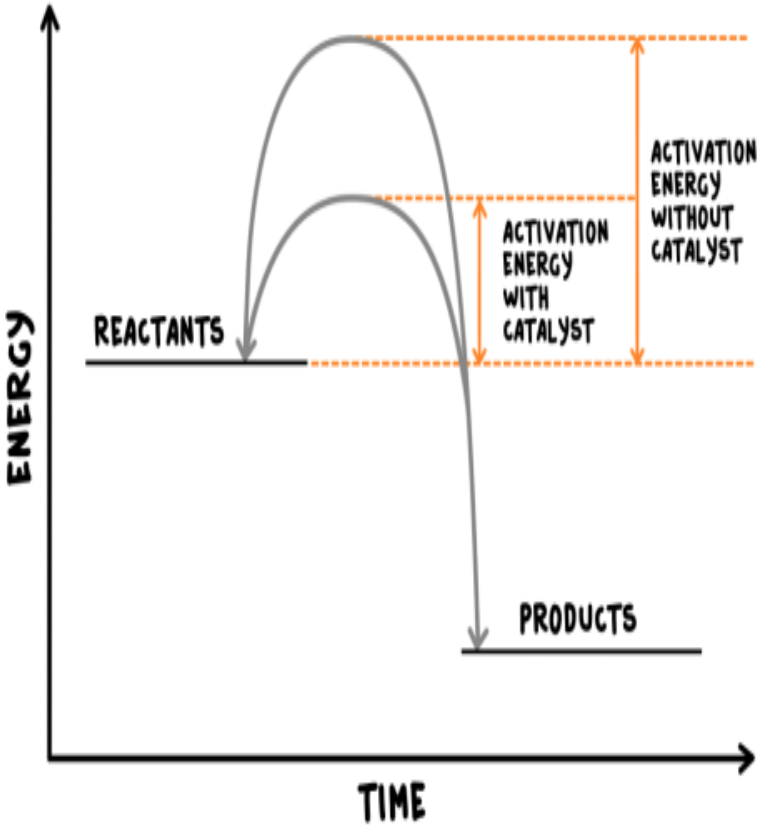
Overview
The Rate And Extent of Chemical Change

Rate of reaction

- Calculating rates of reaction
- Factors which affect the rates of chemical reactions
- Collision theory and activation energy
- Catalysts

Reversible reactions and dynamic equilibrium

- Reversible reaction
- Energy changes and reversible reactions
- Equilibrium
- The effect of changing conditions on equilibrium (HT only)
- The effect of changing concentration (HT only)
- The effect of temperature changes on equilibrium (HT only)
- The effect of pressure changes on equilibrium (HT only)



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Rate of reaction
Part 1

- Calculating rates of reactions

Rate of reactions part 1 – Calculating rates of reactions

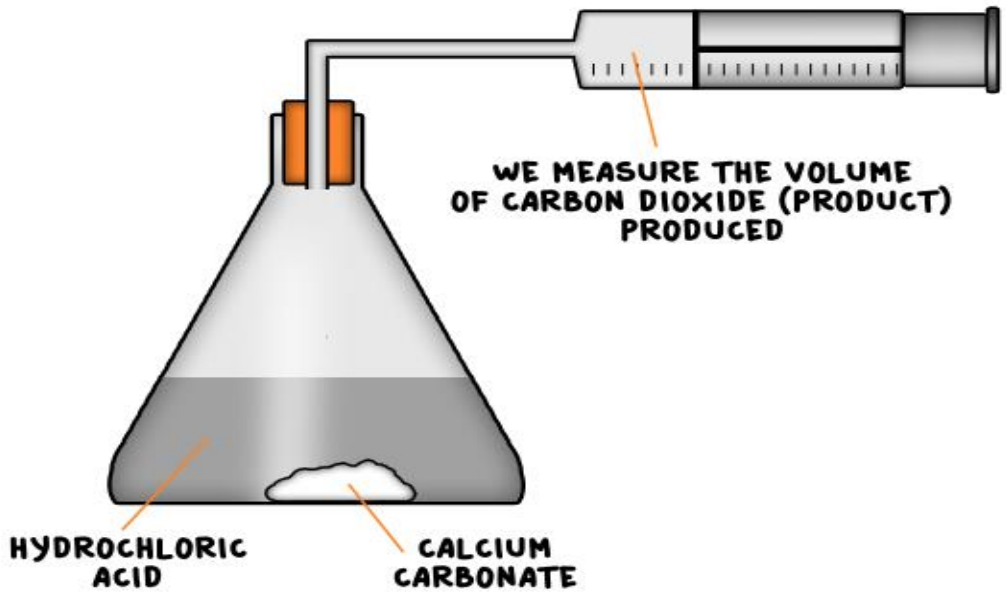
The rate of a chemical reaction can be found by measuring the quantity of a reactant used or the quantity of product formed over time.

$$\text{Mean rate of reaction} = \frac{\text{quantity of reactant used}}{\text{time taken}}$$

$$\text{Mean rate of reaction} = \frac{\text{quantity of product formed}}{\text{time taken}}$$

The quantity of reactant or product can be measured by the mass in grams or by a volume in cm^3.

The units of rate of reaction may be given as g/s or cm^3/s.



Rate of reactions part 1 – Calculating rates of reactions

Worked example 1

25cm^3 of carbon dioxide was given off in the first 2 seconds of a reaction. Calculate the mean rate of reaction and give the units.

Mean rate of reaction = $\frac{\text{quantity of product formed}}{\text{time taken}}$

Mean rate of reaction = $\frac{25\text{cm}^3}{2\text{ s}}$

Mean rate of reaction = 12.5 cm^3/s

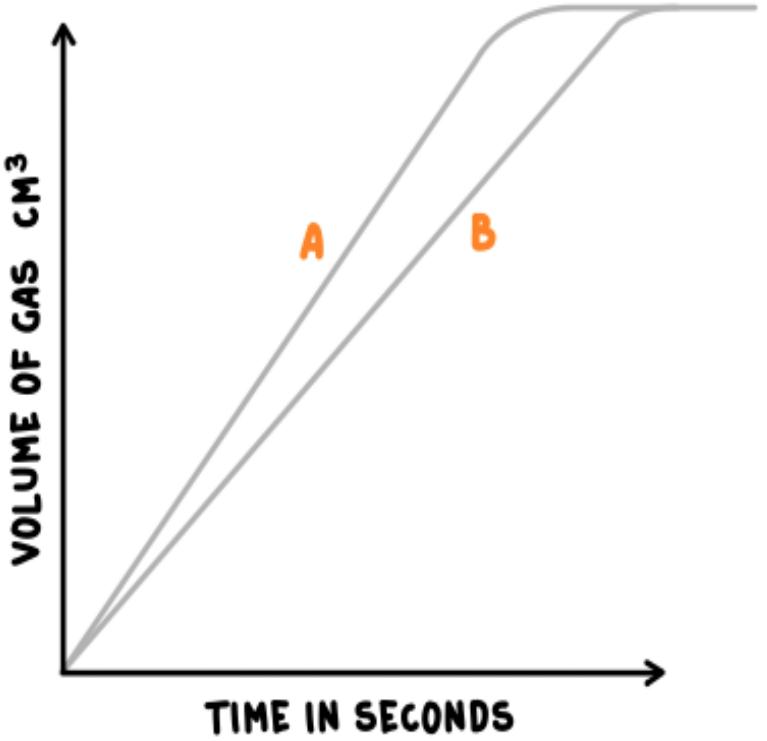
Worked example 2 (Higher Tier)

The above reaction was carried out again. The new results showed that 2 dm^3 of carbon dioxide was released in 200 seconds. Calculate the mean rate of reaction in mol/dm^3

(1 mole of any gas occupies 24 dm^3 at STP)

Moles of carbon dioxide = $\frac{2\text{ dm}^3}{24\text{ dm}^3}$ = 0.83 moles

Mean rate of reaction = $\frac{0.83\text{ moles}}{200\text{ s}}$ = 0.0042 mol/s



Slope A will have a greater rate of reaction as it is steeper.

QuestionIT!

Rate of reaction Part 1

- Calculating rates of reactions

Calculating rates of reactions – QuestionIT

1. State two ways of finding the rate of reaction.

2. State two units of rate of reaction. (HT: state 3)

3. State two ways of measuring the quantity of reactant or product.

4. A student carries out an experiment reacting hydrochloric acid (HCl) with calcium carbonate ($CaCO_3$) to give calcium chloride ($CaCl_2$) carbon dioxide and water. Write the balanced symbol equation for this reaction.

5. The student collects 50 cm^3 of carbon dioxide gas in 10 seconds. What is the rate of reaction? Include the units.

6. (HT only) The student repeats the experiment again, this time they find the mass of the carbon dioxide collected. They collect 11 g of carbon dioxide in 10 seconds. Calculate the rate of reaction in mol/s.

7. (HT only) What mass of carbon dioxide are they collecting per second if the rate of reaction is 0.075 mol/s?

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AnswerIT!

Rate of reaction Part 1

- Calculating rates of reactions

Calculating rates of reactions – QuestionIT

1. State two ways of finding the rate of reaction.

   Measuring the quantity of reactant used or product formed.

2. State two units of rate of reaction. (HT: state 3)

   g/s; cm^3/s; (mol/s)

3. State two ways of measuring the quantity of reactant or product.

   Mass in grams or volume cm^3

Calculating rates of reactions – AnswerIT

4. A student carries out an experiment reacting hydrochloric acid (HCl) with calcium carbonate ($CaCO_3$) to give calcium chloride ($CaCl_2$) carbon dioxide and water. Write the balanced symbol equation for this reaction.

$$CaCO_3\ (s) + 2HCl\ (aq) \rightarrow CaCl_2\ (aq) + CO_2\ (g) + H_2O\ (l)$$

5. The student collects 50 cm^3 of carbon dioxide gas in 10 seconds. What is the rate of reaction? Include the units.

$$\text{rate of reaction} = \frac{\text{volume of gas collected}}{\text{time taken}} = \frac{50}{10}$$

5 cm^3/s

Factors which affect the rates of reactions – AnswerIT

6. (HT only) The student repeats the experiment again, this time they find the mass of the carbon dioxide collected. They collect 11 g of carbon dioxide in 10 seconds. Calculate the rate of reaction in mol/s.

11g/44g = 0.25 moles of carbon dioxide

so 0.25 moles/10 seconds

= 0.025 mol/s

7. (HT only) What mass of carbon dioxide are they collecting per second if the rate of reaction is 0.075 mol/s

0.075 moles of CO_2 is 44 x 0.075 so 3.3 g/s

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Rate of reaction
Part 2

- Factors which affect the rate of reactions
- Collision theory and activation energy

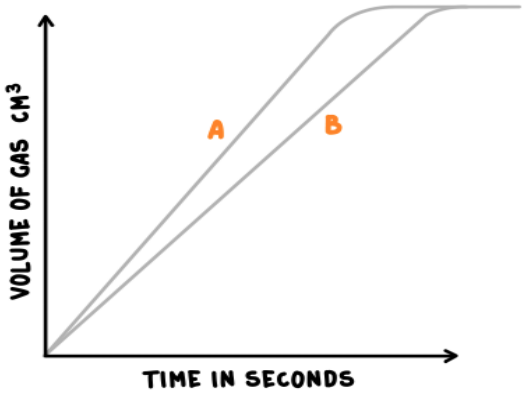
Rates of reactions part 2 – Factors which affect rates of reactions

Factors which affect the rates of chemical reactions include:

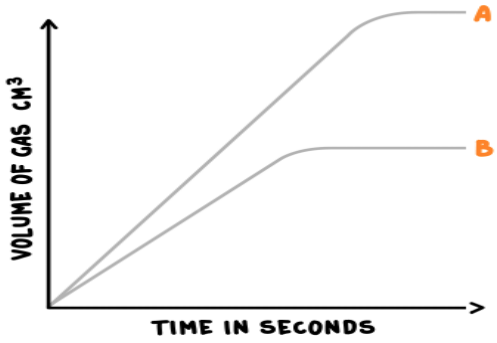
- The concentrations of reactants in solution
- The pressure of reacting gases
- The surface area of solid reactants
- The temperature
- The presence of a catalyst

Collision theory explains how these factors affect rates of reactions. According to this theory, chemical reactions can occur only when reacting particles collide with each other and with sufficient energy. The minimum amount of energy that particles must have to react is called the activation energy.

The explanations on the next slide are very important and you will need to use them accurately in the exams to gain credit.

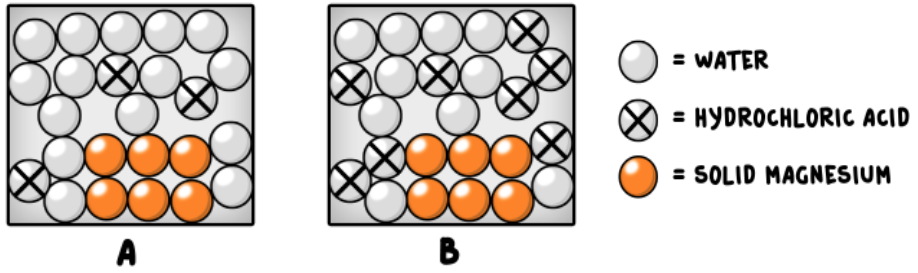


Increasing the surface area, temperature or using a catalyst will increase the rate of reaction so the gradient of the line increases from B to A. The difference is that increasing the concentration provides more reacting particles therefore more product, therefore the graph below is produced.

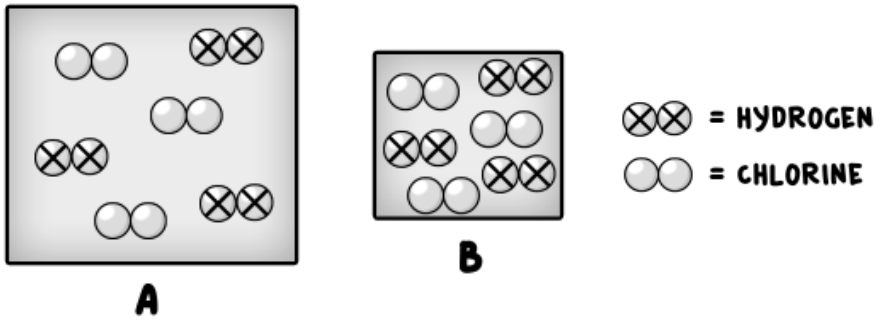


Rates of reactions part 2 – Factors which affect rates of reactions

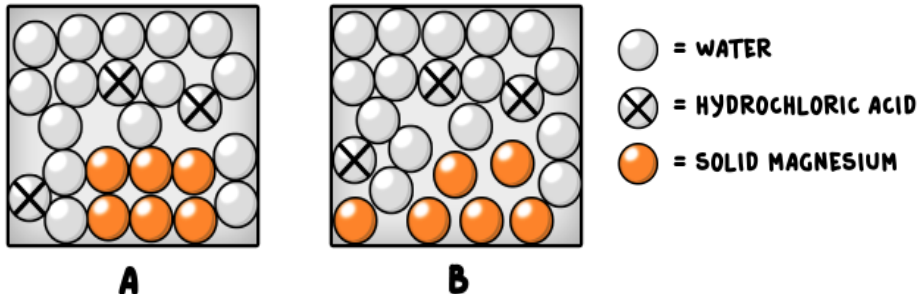
Increasing the concentration of reactants in solution increases the frequency of collisions, and so increases the rate of reaction.



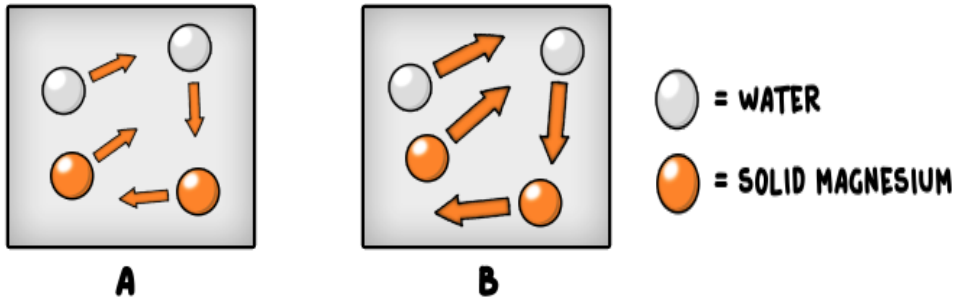
Increasing the pressure of reacting gases increases the frequency of collisions, and so increases the rate of reaction.



Increasing the surface area of solid reactants increases the frequency of collisions, and so increases the rate of reaction.



Increasing the temperature increases the frequency of collisions and makes the collisions more energetic, and so increases the rate of reaction.



QuestionIT!

Rate of reaction
Part 2

- Factors which affect the rate of reactions
- Collision theory and activation energy

Factors which affect rates of reactions – QuestionIT

1. What is meant by the term ‘collision theory’?

2. What is meant by the term ‘activation energy’?

3. What happens to the gradient of a line if the rate of reaction is increased?

4. What is a catalyst?

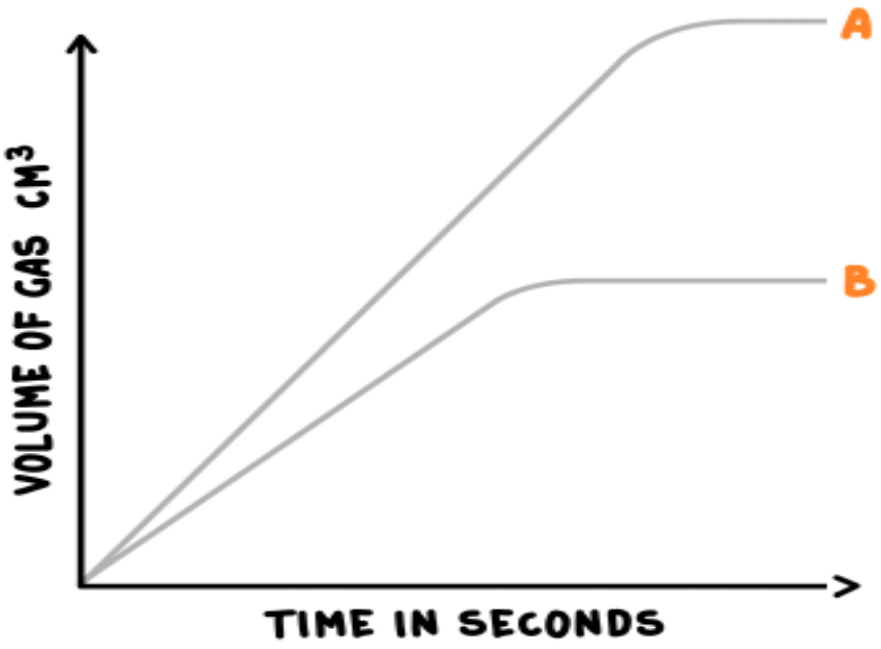
5. According to collision theory, chemical reactions can only occur when…

Factors which affect rates of reactions – QuestionIT

6. Other than concentration give three factors that affect the rate of reaction.

7. Draw a labelled graph to show how changing any one of these factors may affect the rate of reaction. Include the line before and after the change.

8. The graph below shows how the reaction is affected when the concentration of hydrochloric acid is doubled when reacting with excess magnesium. Explain why the amount of hydrogen gas doubles and why the rate of reaction doubles; use collision theory in your response.



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AnswerIT!

Rate of reaction
Part 2

- Factors which affect the rate of reactions
- Collision theory and activation energy

Factors which affect rates of reactions – QuestionIT

1. What is meant by the term ‘collision theory’?

   Explains how factors affect the rate of reaction.

2. What is meant by the term ‘activation energy’?

   Minimum amount of energy that particles must have to react.

3. What happens to the gradient of a line if the rate of reaction is increased?

   Becomes steeper.

4. What is a catalyst?

   Substance which increase the rate of reaction but are not used up during the reaction.

5. According to collision theory, chemical reactions can only occur when…

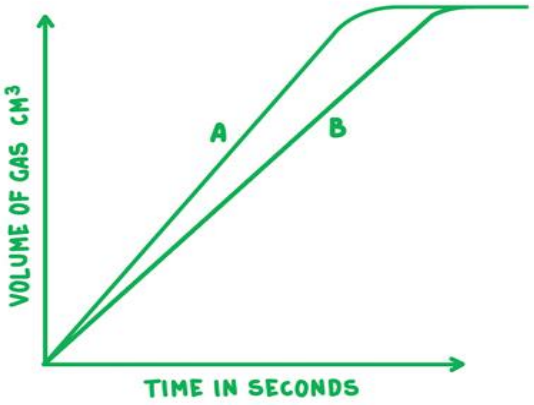
   reacting particles collide with each other with sufficient energy.

Factors which affect rates of reactions – AnswerIT

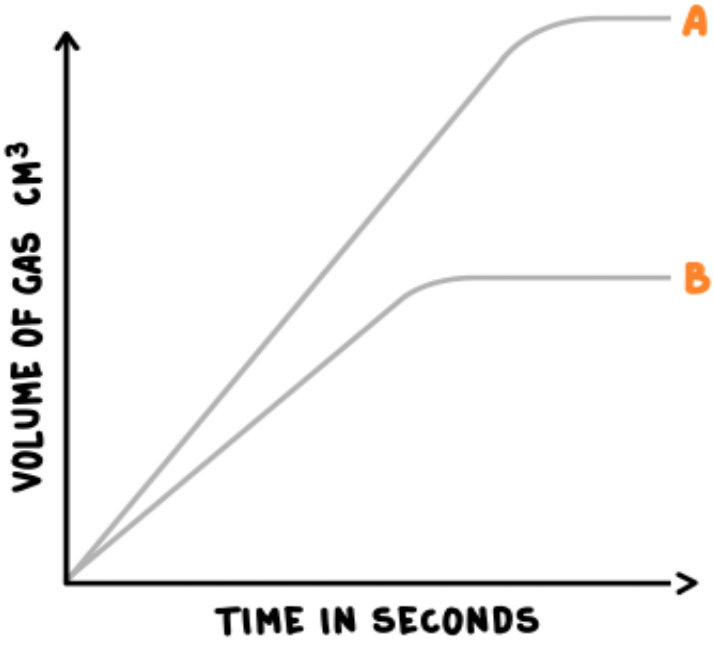
6. Other than concentration give three factors that affect the rate of reaction.

   any from: Temperature, surface area, pressure and a catalyst

7. Draw a labelled graph to show how changing any one of these factors may affect the rate of reaction. Include the line before and after the change.



8. The graph below shows how the reaction is affected when the concentration of hydrochloric acid is doubled when it reacts with excess magnesium. Explain why, using the collision theory the amount of hydrogen gas doubles and why the rate of reaction



If concentration of acid is doubled then there are twice the number of collisions with magnesium atoms.
There will be twice the number of successful collisions so rate of reaction doubles.
As there are twice as many acid particles (and the magnesium is in excess) there will be twice the volume of (hydrogen) gas released

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Rate of reaction
Part 3

- Catalysts

Rates of reactions part 3 – Factors which affect rates of reactions - catalysts

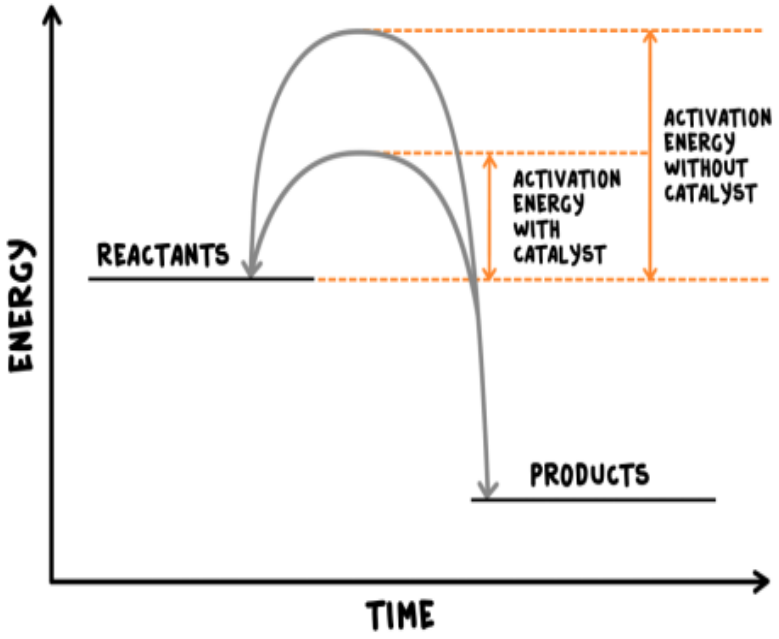
Catalysts change the rate of chemical reactions but are not used up during the reaction.

This means that the catalyst is still there, unchanged, at the end of the reaction.

Different reactions need different catalysts. Enzymes act as catalysts in biological systems.

Carbohydrase is an enzyme/catalyst that only breaks down carbohydrate.
Chlorophyll is the catalyst that enables carbon dioxide and water to react together to make glucose during photosynthesis.

Catalysts increase the rate of reaction by providing a different pathway for the reaction that has a lower activation energy.
A reaction profile for a catalysed reaction can be drawn as shown on the right.



You should be able to explain catalytic action in terms of activation energy. For example, "from the reaction profile I can see that the catalyst **lowers** the activation energy".

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Rate of reaction
Part 3

- Catalysts

Factors which affect rates of reactions - catalysts– QuestionIT

1. What is a catalyst?

2. The symbol equation for photosynthesis is:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

The catalyst for this reaction is chlorophyll, however it does not appear in the equation. Why is this?

3. A student carried out three reactions to investigate how quickly oxygen gas was given off by decomposing hydrogen peroxide.

$$2H_2O_2 \rightarrow O_2 + 2H_2O$$

Each time she changed the chemical she was adding to see if it was a catalyst. Here are her results.

Chemical	Time taken to collect 50 cm^3 in seconds
Without chemical	**33**
A	**33**
B	**No oxygen given off**
C	**15**

Which chemical was a catalyst? How do you know?

Factors which affect rates of reactions - catalysts– QuestionIT

4. Draw the reaction profile for $2H_2O_2 \rightarrow O_2 + 2H_2O$ with and without a catalyst and label the activation energies.

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AnswerIT!

Rate of reaction
Part 3

- Catalysts

Factors which affect rates of reactions - catalysts– AnswerIT

1. What is a catalyst?.

Catalysts change the rate of chemical reactions, but are not used up during the reaction. They provide a different pathway with a lower activation energy.

2. The symbol equation for photosynthesis is:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

The catalyst for this reaction is chlorophyll, however it does not appear in the equation. Why is this?

It is not a chemical that reacts/it is unchanged at the end of the reaction.

Factors which affect rates of reactions - catalysts– AnswerIT

3. A student carried out three reactions to investigate how quickly oxygen gas was given off by decomposing hydrogen peroxide.

$$2H_2O_2 \rightarrow O_2 + 2H_2O$$

Each time she changed the chemical she was adding to see if it was a catalyst. Here are her results.

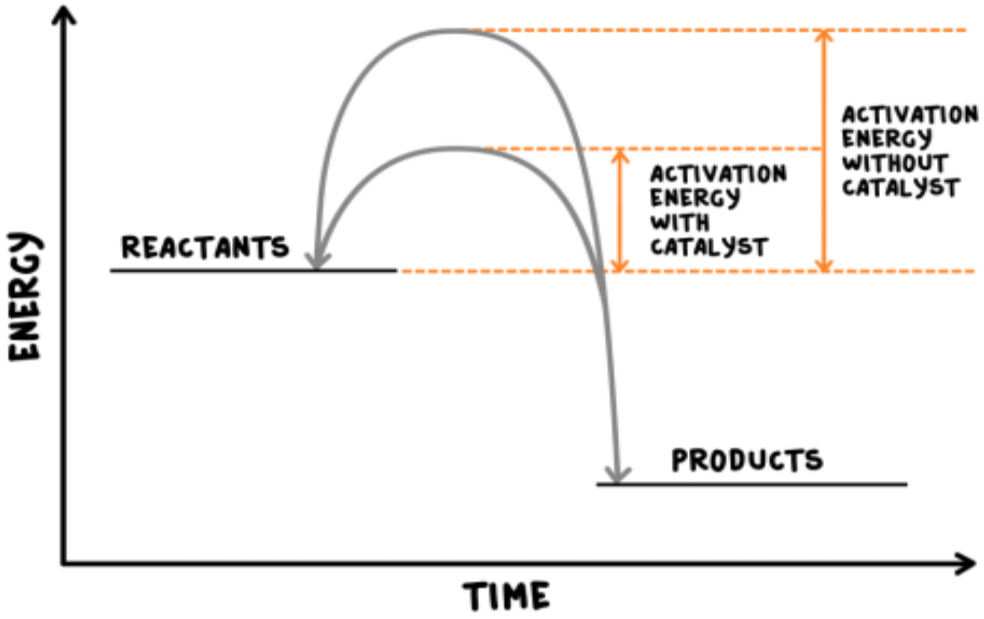
Chemical	Time taken to collect 50 cm3 in seconds
Without chemical	33
A	33
B	No oxygen given off
C	15

Which chemical was a catalyst? Explain your answer.

C, the time taken for the reaction was shorter.

Factors which affect rates of reactions - catalysts– AnswerIT

4. Draw the reaction profile for $2H_2O_2 \rightarrow O_2 + 2H_2O$ with and without a catalyst and label the activation energies.



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Reversible reactions and dynamic Equilibrium (Part 1)

- Reversible reactions
- Energy changes and reversible reactions
- Equilibrium

Reversible reactions

In some chemical reactions, the products of the reaction can react to produce the original reactants. Such reactions are called **reversible reactions** and are represented by:

$$A + B \rightleftharpoons C + D$$

This is different to the usual → or = sign. With these all the reactants change to products in the reaction, but in **reversible reactions** there are always **some reactants** and **some products.**

The direction of reversible reactions can be changed by changing the conditions e.g.

$$\text{Ammonium chloride} \underset{\text{cool}}{\overset{\text{heat}}{\rightleftharpoons}} \text{ammonia} + \text{hydrogen chloride}$$

The reaction above shows that if we heat up the reaction mixture, more ammonium chloride will break down to give ammonia and hydrogen chloride. This is very useful if we are trying to make either of these chemicals.
Conversely if we cool the reaction mixture down we will get more ammonia and hydrogen chloride combining together to make ammonium chloride.

Reversible reactions

If a reversible reaction is **exothermic** in one direction, it is **endothermic** in the opposite direction (they are reversible/opposites). The same amount of energy is transferred in each case e.g.

Hydrated copper sulfate ⇌ **anhydrous copper sulfate + water**

(⇌: endothermic above, exothermic below)

Blue — **White**

What will happen then in the above reaction if we heat it up?
We will get more anhydrous copper sulfate and water, because the **endothermic direction** from left to right will **absorb the heat** we add.
What will happen if we cool it down?

When a reversible reaction occurs in apparatus which prevents the escape of reactants and products, **equilibrium** is reached as the rate of the forward and reverse reactions occur at **exactly the same rate**.

If we enclose in this box nitrogen N_2 , hydrogen H_2 and ammonia NH_3 the following reactions take place

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

When the **forward reaction** is happening at the **same rate** as the **backwards reaction**, there will be no overall change in the amount of any of the three chemicals- **equilibrium** has been reached.

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QuestionIT!

Reversible reactions and dynamic Equilibrium (Part 1)

- Reversible reactions
- Energy changes and reversible reactions
- Equilibrium

Reversible reactions QuestionIT

1. What is meant by a reversible reaction?

2. Draw the symbol for a reversible reaction.

3. If a reaction is endothermic in one direction, what is it in the other direction?

4. What is meant by the term equilibrium?

5. What needs to happen for equilibrium to be reached?

6. What can be said about the amount of energy being transferred in a reversible reaction?

7. The following reversible reaction occurs: The reaction that makes C and D is exothermic. What happens if we heat up A and B?

AnswerIT!

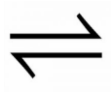
Reversible reactions and dynamic equilibrium (Part 1)

- **Reversible reactions**
- **Energy changes and reversib reactions**
- **Equilibrium**

Reversible reactions QuestionIT

1. What is meant by a reversible reaction?

   The products of a reaction can react to produce the original reactants.

2. Draw the symbol for a reversible reaction. 

3. If a reaction is endothermic in one direction, what is it in the other direction?

   Exothermic.

4. What is meant by the term equilibrium?

   Forward and reverse reactions occur at the same rate.

5. What needs to happen for equilibrium to be reached?

   Closed system; apparatus prevents the escape of reactants and products.

6. What can be said about the amount of energy being transferred in a reversible reaction?

   Same amount of energy is transferred in both directions.

7. The following reversible reaction occurs: The reaction that makes C and D is exothermic. What happens if we heat up A and B?

We will get less C and D

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Reversible reactions and dynamic equilibrium (Part 2) The Effects of changing Conditions on equilibrium (HT Only)

- **Concentration**
- **Temperature**
- **Pressure**

The Effect of changing conditions on equilibrium (HT only)

The relative amounts of all the reactants and products at equilibrium depend on the conditions of the reaction.

Using Le Chatelier's Principle we can predict what might happen when we change the conditions of a system. A system is simply the reversible reaction that is taking place in an apparatus which prevents any escape of chemicals.

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 three conditions which could be changed and are:

- Concentration
- Temperature
- Pressure

You must use Le Chatelier's principle in your explanation.

The two equations we are going to use to explain these changes are:

$$I_2\,(g) + H_2\,(g) \rightleftharpoons 2HI\,(g)$$

and

$$N_2\,(g) + 3H_2\,(g) \rightleftharpoons 2NH_3\,(g)$$

How could you change the concentration, temperature or pressure in either of these reactions?

The Effect of changing conditions on equilibrium (HT only)

The Effect of Changing 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.

e.g. the hydrogen iodine and hydrogen iodide equilibrium:

$$I_2\,(g) + H_2\,(g) \rightleftharpoons 2HI\,(g)$$

Increasing the concentration of HI by putting more HI gas into the system makes it react to break down the HI gas to H_2 and I_2 so that we have the same proportions of HI, H_2 and I_2

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.

So if we increase the amount of hydrogen and iodine, more hydrogen iodide gas will be made.
If we decrease the amount of hydrogen iodide, more hydrogen and iodine will react to make hydrogen iodide.

The Effect of changing conditions on equilibrium (HT only)

The Effect of Changing 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.

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.

If we apply these to the equation below:

$$N_2\,(g) + 3H_2\,(g) \underset{\text{endothermic}}{\overset{\text{exothermic}}{\rightleftharpoons}} 2NH_3\,(g)$$

Increasing the temperature will give more nitrogen N_2 and hydrogen H_2 and less ammonia NH_3.
Decreasing the temperature the opposite result occurs- we would get more ammonia NH_3 and less nitrogen N_2 and hydrogen H_2.

The Effect of changing conditions on equilibrium (HT only)

The Effect of Changing 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 **larger** number of molecules, as shown by the symbol equation for that reaction.

As 1 mole of gas at STP occupies 24 $dm^{3,}$ we can apply this knowledge to the equation.

$$N_2\,(g) + 3H_2\,(g) \rightleftharpoons 2NH_3\,(g)$$

There are 4 moles of reactants: 1 mole of nitrogen N_2 and 3 moles of H_2

There are only 2 moles of the ammonia NH_3 product.

The reactants will have 96 dm^3 at STP and the products will only occupy 48 dm^3 .

So if we **increase** the pressure, the equilibrium position will shift towards the right hand side simply because the two moles of ammonia take up a **smaller** volume so, from **Le Chatelier's principal,** making more of the product that has less volume reduces the pressure that we have just increased.

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QuestionIT!

Reversible reactions and dynamic equilibrium (Part 2) The Effects of changing Conditions on equilibrium (HT Only)

- **Concentration**
- **Temperature**
- **Pressure**

1. What is Le Chatelier's Principle?

2. What three factors can be changed in a system at equilibrium?

3. If the concentration of a reactant is increased what will happen to the products of the reaction?

4. What will happen to the amount of product in an endothermic reaction at equilibrium if the temperature is increased?

5. What will happen to the amount of product in an exothermic reaction at equilibrium if the temperature is increased?

6. What will happen to the amount of product in an endothermic reaction at equilibrium if the temperature is decreased?

7. What is meant by the term ‘gaseous reaction’?

8. What would happen to the position of equilibrium in a gaseous reaction if the pressure is increased?

9. Using Le Chatelier’s principle, explain what will happen in the following reaction if we increase the concentration of the hydrogen and iodine?

$$I_2\,(g) + H_2\,(g) \rightleftharpoons 2HI\,(g)$$

Fuel Cells (Chemistry only)AnswerIT

10. What will happen if we increase the temperature of the reaction below? Explain why you think this.

$$N_2\,(g) + 3H_2\,(g) \rightleftharpoons 2NH_3\,(g)$$

11. Explain what will happen if we decrease the pressure in the reaction above.

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AnswerIT!

Reversible reactions and dynamic equilibrium (Part 2) The Effects of changing Conditions on equilibrium (HT Only)

- **Concentration**
- **Temperature**
- **Pressure**

1. What is 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.

2. What three factors can be changed in a system at equilibrium?

   Concentration, temperature and pressure.

3. If the concentration of a reactant is increased what will happen to the products of the reaction?

   More products will be produced; until equilibrium is reached.

4. What will happen to the amount of product in an endothermic reaction at equilibrium if the temperature is increased?

   More products will be produced.

5. What will happen to the amount of product in an exothermic reaction at equilibrium if the temperature is increased?

   Relative amount of products will decrease.

6. What will happen to the amount of product in an endothermic reaction at equilibrium if the temperature is decreased?

   Relative amount of products will decrease.

7. What is meant by the term 'gaseous reaction'?

   Reaction where all the reactants and products are gases.

8. What would happen to the position of equilibrium in a gaseous reaction if the pressure is increased?

   Equilibrium would shift towards the side with the smaller number of molecules shown in the balanced chemical equation.

9. Using Le Chatelier's principle, explain what will happen in the following reaction if we increase the concentration of the hydrogen and iodine?

$$I_2\,(g) + H_2\,(g) \rightleftharpoons 2HI\,(g)$$

   The extra iodine and hydrogen will react together to make more hydrogen iodide.

10. What will happen if we increase the temperature of the reaction below? Explain why you think this.

$$N_2\,(g) + 3H_2\,(g) \rightleftharpoons 2NH_3\,(g)$$

More hydrogen and nitrogen will be made as the backward reaction is endothermic.

11. Explain what will happen if we decrease the pressure in the reaction above.
We will get more nitrogen and hydrogen as there are four moles of gas/higher volume for the reactants.