Topic 15: Answers
Speed of Reaction

SYLLABUS RELEVANCE & TEXTBOOK CHAPTERS		
O-LEVEL PURE (5072)	✓	Chapter 18
O-LEVEL SCIENCE (5116)[1]	✓	Chapter 16
N-LEVEL SCIENCE (5155)	✗	

Lesson Package & Accompanying Slides Designed by Alex Lee (2008)
Last Modified by Alex Lee (2011)

[1]*except catalysts (pages 15|7 & 15|8)*

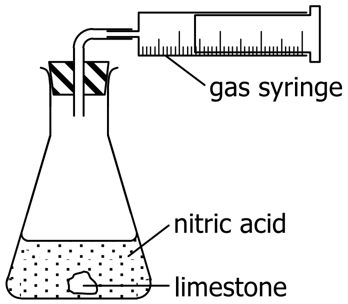
1. **How Do We Measure The Speed of Reaction?**

A student wishes to investigate the speed of reaction between limestone (calcium carbonate) and nitric acid. The chemical equation for the reaction is given below.

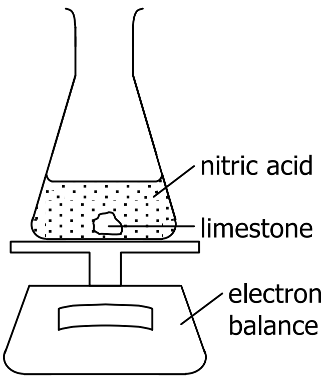
$CaCO_3$ (s)	+	2 HNO_3 (aq)	→	$Ca(NO_3)_2$ (aq)	+	H_2O (l)	+	CO_2 (g)
limestone		nitric acid		salt		water		gas

Below shows four possible experimental set-ups which he can use. In each of the experimental set-ups, a variable mass of limestone is allowed to react with an excess of dilute nitric acid.

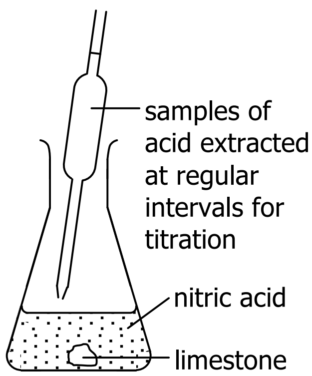
In the spaces provided, state the physical quantity being measured in this experiment.



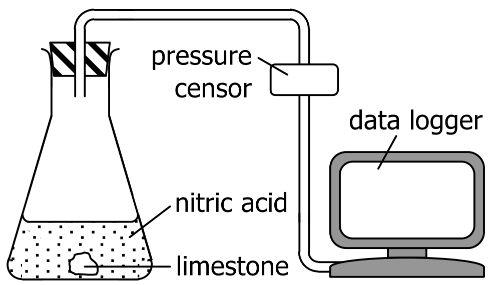
volume of gas produced



mass of reaction mixture



concentration of acid remaining



pressure of reaction vessel

Do note that, in this chapter, we will be using the terms 'speed of reaction' and 'rate of reaction' rather interchangeably.

2. Interpreting Speed of Reaction from Experimental Data

We can deduce the speed of a chemical reaction from experimental data like tables and graphs.

INTERPRETING TABULATED DATA

method 1: time taken for fixed change in physical quantity to occur

e.g. time taken for fixed volume of gas to be collected, or time taken for a piece of magnesium strip to completely dissolve

experiment	time taken for **X** to occur
A	30 seconds
B	20 seconds
C	40 seconds

The ......lesser........ the time taken, the faster the rate of reaction.

method 2: change in physical quantity in a fixed period of time

e.g. volume of gas collected in one minute, loss in mass after one minute, concentration of solution after one minute

experiment	change in **X** after 1 min
A	60 grams
B	40 grams
C	50 grams

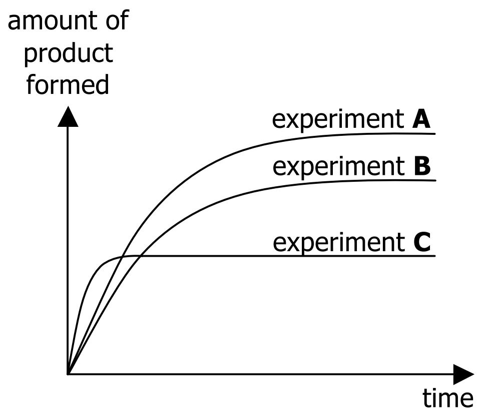
The .....greater...... the change in physical quantity, the faster the rate of reaction.

The limitation of using tabulated data is that it **assumes that the rate is** ....constant.......... through the reaction, and it is difficult to determine how the rate of reaction varies with time.

INTERPRETING GRAPHS

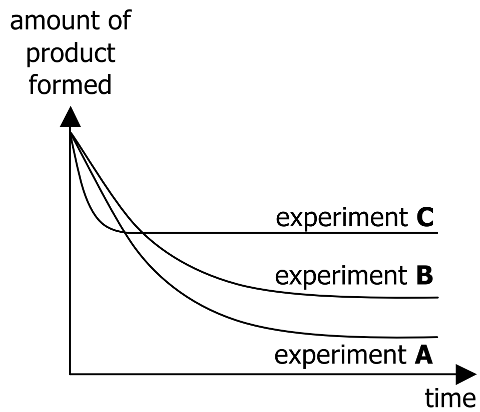
method 1: amount (e.g. mass, volume) of product formed against time

e.g. volume of gas collected against time, mass of precipitate formed against time.



method 2: amount (e.g. mass, volume) of reactant used up against time

e.g. mass of limestone remaining against time, concentration of acid against time.



We can determine the rate of reaction by observing the ....gradient........ of the graphs. A fast rate of reaction will have a steeper gradient, while a slow rate of reaction will have a gentle gradient.

This method is advantageous as we can observe changes in the rate as the experiment proceeds.

3. Review Questions

(a) In separate experiments, a fixed mass of iron metal was allowed to react with excess dilute sulfuric acid in a conical flask. The time taken for the iron to dissolve completely was recorded as follows:

Experiment	**X**	**Y**	**Z**
Time (s)	15.3	22.0	36.7

(i) Rank the three flasks in order of the rate of reaction, starting with the slowest.

Z (slowest), Y, X (fastest)

(ii) The contents of the three flasks, not in any particular order, is given in the table below. Complete the table by identifying which flask – **X**, **Y** or **Z** – corresponds to each row.

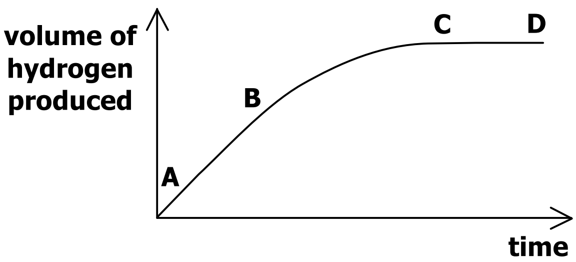
contents	**flask**
5 grams of iron foil, 100 cm^3 of 0.500 mol dm^{-3} sulfuric acid	Z
5 grams of iron foil, 100 cm^3 of 1.500 mol dm^{-3} sulfuric acid	Y
5 grams of iron fillings, 100 cm^3 of 1.500 mol dm^{-3} sulfuric acid	X

(iii) From the above experiments, describe how the rate of reaction is affected by the **particle size** of the iron sample and the **concentration** of the sulfuric acid.

particle size: The smaller the particle size, the faster the rate of reaction.

concentration: The more concentrated the acid, the faster the rate of reaction.

(b) A piece of lithium metal was dropped into a large container of water. The volume of hydrogen gas produced was measured against time, and produced the graph below.



(i) State how the rate of reaction may be deduced from the shape of the graph.

The steeper the gradient of the graph, the faster the reaction.

(ii) Describe how the rate of the above reaction varies between, **AB**, **BC** and **CD**.

At AB, the rate of reaction is relatively constant. At BC, the rate of reaction gradually decreases until it completely stops at CD.

4. **Collision Theory**

The speed of a chemical reaction can be explained using the collision theory.

The **collision theory** states that in order for a reaction to occur, the reactant particles must not only ......collide......, but also collide with ......sufficient energy.......

Such successful collisions, i.e. those with sufficient energy, are known as ......effective...... collisions.

The ......number...... **of effective collisions** determines the total **yield** of the reaction – if there are a hundred successful collisions, then there will be a hundred sets of products formed. However, this does not tell us the rate of a chemical reaction as these collisions may be occurred over a long or short period of time.

It is the ......frequency...... **of effective collisions**, i.e. the number of successful collisions per unit time, which determines the **rate** of the reaction. In explaining any variations in the rate of a reaction, we should make it a point to refer to this phrase – 'frequency of effective collisions'.

Five factors affect the frequency of effective collisions – temperature, pressure, concentration, surface area and a catalyst. We will look at these factors in the subsequent pages.

(a) Indicate if the following statements are **true** or **false**.

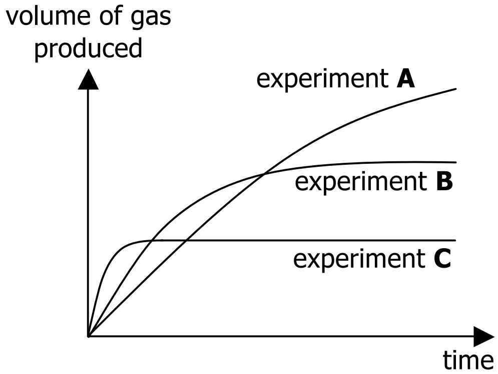
In order for a reaction to occur, the particles must first collide. ......true......

All collisions between particles result in a chemical reaction. ......false......

The rate of a reaction depends on the number of effective collisions. ......false......

It is possible for two particles to collide, but yet not react. ......true......

(b) The results of three experiments are shown below.



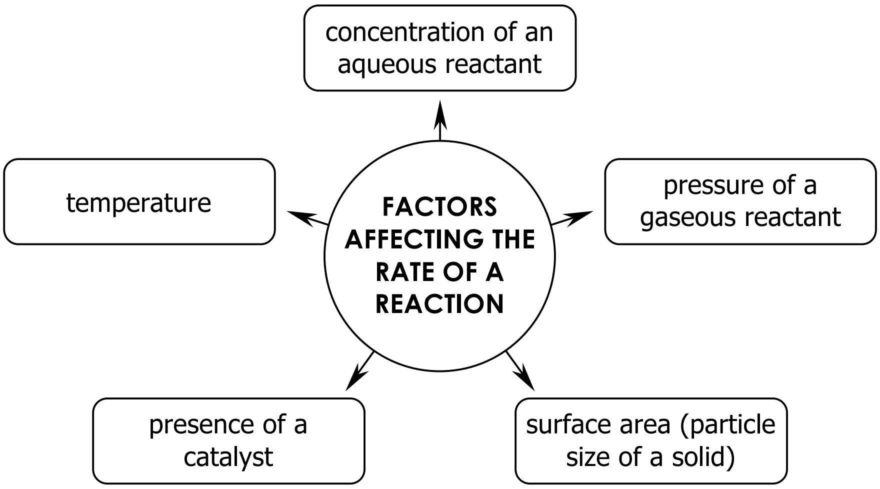
Which of the three experiments, **A**, **B** or **C**,

(i) has the greatest initial rate of reaction? ......C......

(ii) has the greatest yield? ......A......

5. **Factors Affecting The Rate Of Reactions**

Below shows the five factors which affect the speed of a chemical reaction.



Using the collision theory, explain how each of the factors below affect the rate of a reaction.

(a) temperature of reaction vessel

The higher the temperature, the faster the reactant particles move about – hence the particles collide into each other more often and with greater force, leading to an increase in the frequency of effective collisions.

(b) the concentration of a solution

The higher the concentration of a solution, the greater the number of reactant particles per unit volume – hence the particles collide into each other more often, leading to an increase in the frequency of effective collisions.

(c) the pressure of a gas

The higher the pressure of a gas, the greater the number of reactant particles per unit volume – hence the particles collide into each other more often, leading to an increase in the frequency of effective collisions.

(d) particle size of solid reactant (e.g. fine powder or large lumps)

The smaller the particle size, the larger the surface area of contact between the reactant particles – hence allowing more particles to collide into each other at a given time, leading to an increase in frequency of effective collisions.

6. **Review Questions**

In order to investigate the speed of the the reaction between limestone and nitric acid, a student carries out a series of experiments and measured the time taken for a 20 gram sample of limestone to react completely with excess nitric acid. His results are as follows:

experiment	***particle size of limestone sample***	***concentration of HNO_3 (mol dm^{-3})***	***initial temperature (°C)***	***time for complete reaction (s)***
1	large piece	0.500	25.0	37
2	fine powder	0.500	25.0	28
3	large piece	0.350	25.0	49
4	fine powder	0.500	35.0	19

(a) State two experiments which can be used to deduce how the speed of reaction is affected by

(i) the concentration of nitric acid, ...Experiments 1 & 3........

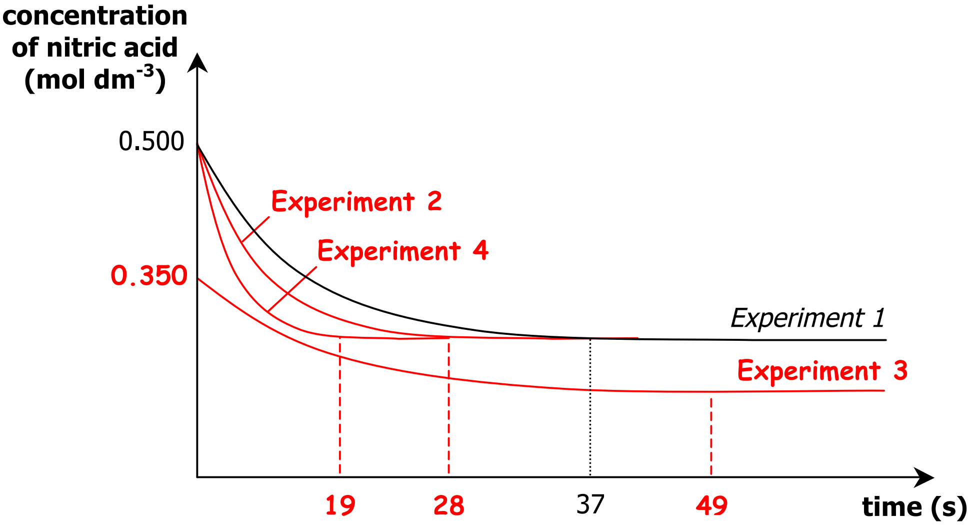
(ii) the particle size of the limestone, ...Experiments 1 & 2........

(iii) the initial temperature of the reaction vessel. ....Experiments 2 & 4........

(b) Explain, in terms of collisions between the particles, why an higher concentration of nitric acid will lead to a faster rate of reaction.

With a higher concentration of nitric acid, there will be more hydrogen ions within a fixed volume of solution – hence allowing the hydrogen ions and the limestone to collide more often, leading to an increase in the frequency of effective collisions.

(c) The graph below shows how the concentration of nitric acid varies with time in Experiment 1. On the same axes, sketch the graphs for the other three experiments.



7. **Catalysts – Definition & Mechanism**

As discussed earlier in this tutorial, the rate of a chemical reaction can be altered by the presence of a catalyst.

A **catalyst** is a substance which increases the rate of a chemical reaction, with itself remaining chemically unchanged at the end of the reaction.

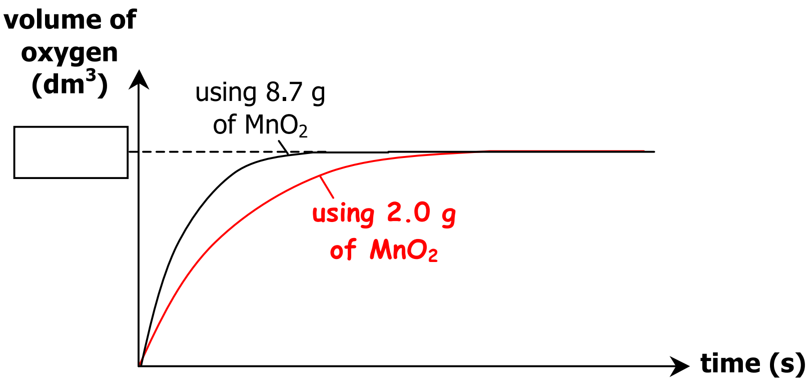
Not all chemical reactions have a possible catalyst. One well-known reaction that uses a catalyst is the decomposition of hydrogen peroxide.

Hydrogen peroxide decomposes very slowly under room conditions, but quickly when placed in contact with a catalyst of manganese(IV) oxide. The equation for this reaction is as follows.

$$2\ H_2O_2\ (aq) \xrightarrow{MnO_2 \text{ catalyst}} 2\ H_2O\ (l)\ +\ O_2\ (g)$$

A reaction may have more than one possible catalyst; for example, copper(II) sulfate may also act as a catalyst in the decomposition of hydrogen peroxide. Do note that it is not compulsory to indicate a catalyst in a chemical equation, but one may do so above the arrow.

(a) In an experiment, 8.7 g of manganese(IV) oxide was used to decompose 1 mol of hydrogen peroxide. The graph below shows how the volume of oxygen collected varies with time.



(i) Suggest the mass of manganese(IV) oxide remaining at the end of the reaction.

8.7 g. (Catalysts do not get used up.)

(ii) Calculate the volume of oxygen gas produced, measured at room conditions, and label this value onto the graph accordingly.

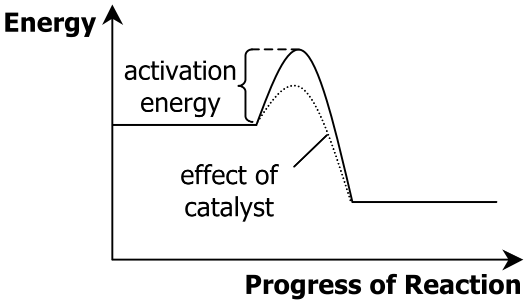
mol of H_2O_2 = 1 mol
mol of O_2 = $\frac{1}{2}$ mol of H_2O_2
= 0.5 mol

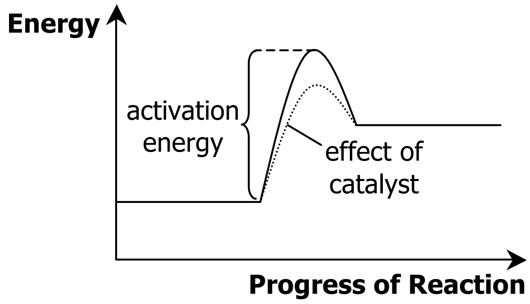
volume of O_2 = mol × 24
= 12.0 dm^3

(iii) On the same axes, sketch the graph for a second experiment using only 2.0 grams of manganese(IV) oxide as a catalyst, with all other factors remaining constant.

A catalyst increases the speed of a chemical reaction by **decreasing the activation energy needed for the chemical reaction.** In other words, a catalyst decreases the minimum energy required for a collision between two particles to become 'successful'.

This can be represented on an energy profile diagram, as shown below.





(b) Using the collision theory, explain how a catalyst affects the rate of a reaction.

In the presence of a catalyst, the activation energy for a reaction is lowered.

Hence for the same frequency and magnitude of collisions, there is an increased

frequency of effective collisions, leading to a faster rate of reaction.

(c) Indicate if the following statements are **true** or **false**.

A catalyst must be physically unchanged at the end of a reaction.	false
A catalyst remains chemically unchanged throughout a reaction.	false
A catalyst increases the yield of a chemical reaction.	false
A catalyst forms an intermediate compound with the reactants.	true

8. Enzymes – Biological Catalysts

Biological catalysts are known as ....enzymes...., and are made up of **proteins**. Enzymes are found all over in nature, in both plants and animals. There are thousands of enzymes in the human body, each performing a specific function.

Some examples of enzymes:

- amylase, found in saliva to digest starch
- protease, used to break down proteins
- helicase, used in protein synthesis by separating the DNA helix

Like all proteins, enzymes are sensitive to ..temperature.. and ....pH..... Most enzymes have the greatest efficiency at body temperature of 37 °C.

However, at higher temperatures, the enzymes will get ....denatured...., i.e. destroyed. Hence, in a biological reaction catalysed by enzymes, a high temperature does not necessarily lead to a faster rate of reaction.

Self-Designed Summary

Supplementary Questions

1. Jonathan wishes to investigate how various factors affect the rate of reaction between limestone and excess dilute sulfuric acid.
   (a) He decides to measure how the loss in mass of the reaction vessel at regular intervals.
      (i) Suggest why this method is suitable for gauging the rate of reaction.
      (ii) Would this method be appropriate for measuring the rate of reaction between aqueous sodium hydroxide and excess dilute sulfuric acid? Why or why not?
   (b) (i) State three factors that will affect the rate of the above reaction.
      (ii) Briefly explain why pressure is not a factor for this reaction.
   (c) Suggest why, in his above experiment, the reaction appears to stop before all the limestone is used up.

2. Ammonia is manufactured industrially through a process known as the Haber process, where nitrogen and hydrogen gases are allowed to react under a pressure of 250 atm.
   (a) What effect does the high pressure of 250 atm have on the speed of the reaction?
   (b) Would the speed of reaction be faster or slower at 350 atm? Suggest then why the reaction is out at 250 atm instead.
   (c) State one factor, other than pressure and a catalyst, that will affect the rate of reaction.

3. The rate of evolution of oxygen gas from the decomposition of hydrogen peroxide can be increased by
   A adding water to the solution.
   B cooling the solution.
   C using a more concentrated solution of hydrogen peroxide.
   D using a more dilute solution of hydrogen peroxide.

4. Why does coal dust form an explosive mixture with air?
   A Powdered coal breaks chemical bonds.
   B Powdered coal catalyses the explosion.
   C Powdered coal has a large surface area.
   D Powdered coal released hydrogen from compounds in coal.

5. Which of the following will not increase the rate of reaction between magnesium and nitric acid?
   A increasing the concentration of the nitric acid
   B increasing the pressure of the reaction vessel
   C increasing the surface area of the magnesium lump
   D increasing the temperature of the nitric acid

6. Which one of the following statements about increasing the speed of a chemical reaction by raising the temperature is **false**?
   A At a higher temperature, the particles are moving faster.
   B At a higher temperature, there are more collisions involving the reactant molecules.
   C For reactants to become products, they must collide with one another.
   D At a higher temperature, the particles have expanded.

7. Which of the following statements are **true**?
   A All collisions between reactant particles lead to a reaction.
   B All particles have the same amount of energy
   C The higher the temperature, the more frequently the particles collide.
   D The higher the pressure, the less frequently the particles collide.

Supplementary Questions (Answers)

Question 1

(a) (i) The reaction between limestone and sulfuric acid evolves carbon dioxide gas, and hence there will be loss in mass of the reaction vessel.
(ii) No, as the reaction between sodium hydroxide and dilute sulfuric acid does not produce a gas.

(b) (i) Temperature of the sulfuric acid, concentration of the sulfuric acid, surface area of the limestone
(ii) Pressure is only a factor for reactions with gaseous reactants – limestone is solid while sulfuric acid is aqueous.

(c) Limestone, being calcium carbonate, reacts with dilute sulfuric acid to form calcium sulfate, which is an insoluble salt. Hence the insoluble salt layer formed will coat the limestone reactant, ceasing the reaction prematurely.

Question 2

(a) It will increase the speed of reaction, compared to normal conditions.
(b) It will be faster, however this will also be more costly.
(c) Temperature of the reaction vessel.

Multiple-Choice Questions

3 C   4 C   5 B   6 D   7 C

Lecture Slides

Speed of Reaction

Anglo-Chinese School (Barker Road)

CHEMISTRY
Prepared by Alex Lee

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Chapter Overview

In This Chapter, We Will Learn …

1. Measuring Speed of Reaction
2. Collision Theory
3. Five Factors
4. Catalysts *

*pure science only

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Investigating Speed of Reaction

A student wishes to investigate the rate of reaction between limestone and dilute nitric acid.

$$CaCO_3 + 2\,HNO_3 \longrightarrow Ca(NO_3)_2 + CO_2 + H_2O$$

What physical measurements could we take?

- volume of gas produced against time?
- loss of mass of reaction vessel against time?
- concentration of nitric acid against time?
- "disappearance" of limestone against time?

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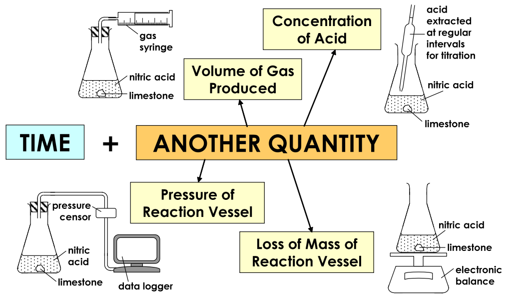
Investigating Speed of Reaction



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Deducing The Speed of Reaction

- We can deduce the speed of a chemical reaction from experimental data such as tables and graphs.
- For tabulated data, there are generally two types:
  - **time taken** for fixed change in physical quantity to occur (e.g. measure the time for a fixed volume of gas to be produced)
  - **change in physical quantity** in a fixed period of time (e.g. measure the volume of gas produced in a fixed amount of time)

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Deducing The Speed of Reaction

TABULATED DATA - TYPE #1

time taken for fixed change in physical quantity to occur

e.g. To *measure the time taken* for a fixed volume of gas (e.g. 50 cm³) of be produced when reaction **X** occurs under varying conditions.

experiment	time taken for 50 cm³ of gas to be collected (s)
A	30.00
B	20.00
C	40.00

the lesser the time taken, the faster the rate of reaction

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Deducing The Speed of Reaction

TABULATED DATA - TYPE #2

***change in physical quantity* in a fixed period of time**

e.g. To *measure the volume of gas produced* in a fixed period of time (e.g. 30 seconds) when reaction **X** occurs under varying conditions.

experiment	volume of gas produced in 30 seconds (cm^3)
A	60
B	40
C	50

the greater the change in physical quantity, the faster the rate of reaction

Investigating Speed of Reaction

TABULATED DATA

- The limitation of such tabulated data is that it **assumes that the rate of reaction** is constant; however,this is seldom true.
- Tabulated data does not allow us to study how the rate of reaction varies with time either.

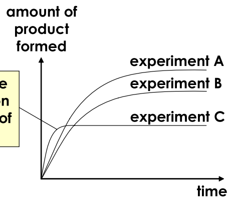
Investigating Speed of Reaction

GRAPHS - TYPE #1

amount (e.g. mass) of product formed against time

e.g. The graph of *volume of gas collected* against time, or the graph of *mass of precipitate formed* against time.

We can determine the rate of reaction from the gradient of the graphs.



Which of the three experiments is the fastest? Does the yield accurately gauge the rate of reaction?

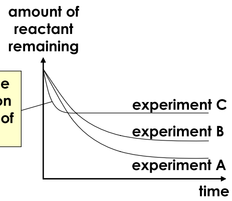
Investigating Speed of Reaction

GRAPHS - TYPE #2

amount (e.g. mass) of reactant used against time

e.g. The graph of *mass of limestone remaining* against time, or the graph of *concentration of acid* against time.

We can determine the rate of reaction from the gradient of the graphs.



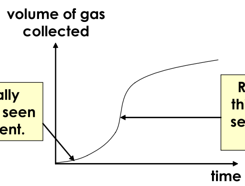
Which of the three experiments is the fastest? How do we gauge the yield from these graphs?

Investigating Speed of Reaction

GRAPHS

- Graphs are more tedious to prepare, but are also more informative. Graphs can help us to identify any changes in the rate of a reaction.

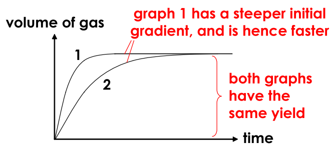
Reaction is initially slow – this can be seen by the low gradient.



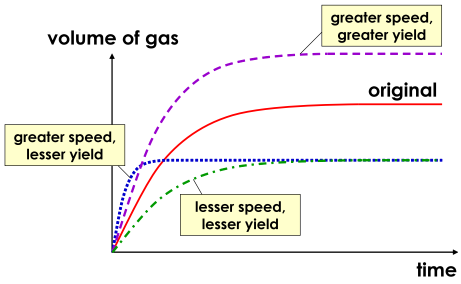
Reaction is fastest at this point – this can be seen as the gradient is the steepest.

Speed Versus Yield

- The **speed of a reaction** can be told by the gradient of a product-time or reactant-time graph.
- The **yield of a reaction** is the amount of product obtained upon completion, and can be told by the height of the graph in which it 'levels off'.



Speed Versus Yield

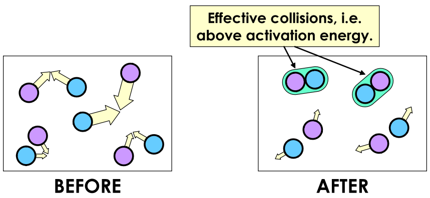


Collision Theory

- The **collision theory** states that **in order for a reaction to occur, the reactant particles must not only collide, but must also collide with sufficient energy**.
- This minimum energy required for a collision to be successful is known as the 'activation energy'.
- Such successful collisions, i.e. those with the minimum activation energy, are known as 'effective collisions'.

Collision Theory

- **Not all collisions lead to a reaction** – there is a minimum amount of energy (activation energy) with which the two particles must collide before it will react.



Collision Theory

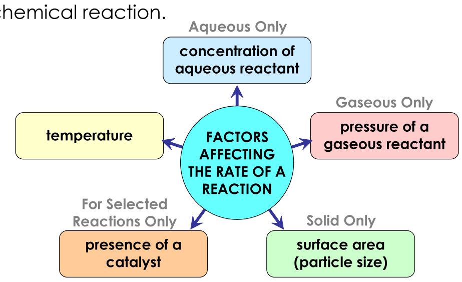
- The **number** of effective collisions **determines the total yield** of the reaction – if there are a hundred successful collisions, then there will be a hundred sets of products formed.
- However, **this does not tell us the rate** of a chemical reaction as these collisions may be occurred over a long or short period of time.

Collision Theory

- Instead, it is the **frequency of effective collisions**, i.e. the number of successful collisions per unit time, which determines the rate of the reaction.
- In explaining any variations in the rate of a reaction, we should make it a point to refer to this phrase – 'frequency of effective collisions'.
- Five factors affect the frequency of effective collisions – temperature, pressure, concentration, surface area and the presence of a catalyst.

Five Factors

- There are five factors which affect the rate of a chemical reaction.



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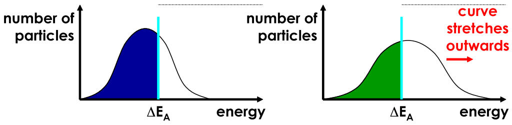
Five Factors & Collision Theory

TEMPERATURE

- The higher the temperature, the **faster the reactant particles move about**.
- Hence the particles collide into each other **more often** and with **greater force**, leading to an **increase in the frequency of effective collisions**.



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Five Factors & Collision Theory

CONCENTRATION

- The higher the concentration of an aqueous solution, the **greater the number of particles per unit volume**.
- Hence particles collide into each other **more often**, leading to an **increase in the frequency of effective collisions**.

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Five Factors & Collision Theory

PRESSURE

- The higher the pressure of a gas, the **greater the number of particles per unit volume**.
- Hence particles collide into each other **more often**, leading to an **increase in the frequency of effective collisions**.

(This explanation is similar to that for concentration.)

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Five Factors & Collision Theory

PARTICLE SIZE (i.e. LUMPS VERSUS POWDER)

- The smaller the particle size, the **larger the surface area of contact** between the reactant particles.
- Hence **more particles collide into each other at a given time**, leading to an **increase in the frequency of effective collisions**.

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Catalysts

- A catalyst is a **substance** which **increases the speed of a chemical reaction** but itself remaining **chemically unchanged at the end of the reaction**.

However, catalysts may be chemically changed, temporarily, during the reaction. This is because the catalyst forms an intermediate compound with the reactants.

Note that catalysts may be <u>physically</u> changed in the process, e.g. break up into smaller pieces.

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Catalysts

- The most well-known example of a catalysed reaction is the decomposition of hydrogen peroxide:

$$2\ H_2O_2\ (aq) \xrightarrow{MnO_2\ catalyst} 2\ H_2O\ (l) + O_2\ (g)$$

- It is optional to indicate the catalyst above the arrow.
- Some reactions may not have any possible catalysts, while other reactions have multiple types of catalysts. For example, the above reaction may also be catalysed by copper(II) sulfate.

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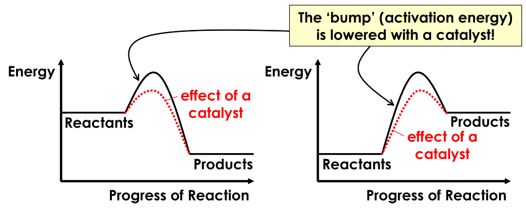
Catalysts - Mechanism

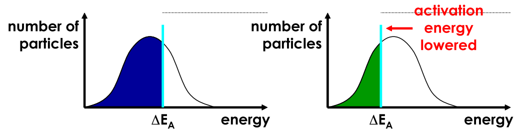
- This can be represented on an **energy-profile diagram**.



Five Factors & Collision Theory

CATALYSTS

- In the presence of a catalyst, the activation energy required for two particles to react is lowered.
- Hence, for the same frequency of collisions, there is an **increase in the frequency of effective collisions**.



Enzymes – Biological Catalysts

- **Biological catalysts** are known as **enzymes**, and are made out of protein molecules.
- Many biological processes may not occur without enzymes, and hence enzymes are vital to sustain life!
- For example, a carbohydrate will take extremely long to break down on its own – but with the enzyme amylase, it breaks down in a matter of seconds.

Enzymes – Biological Catalysts

- Enzymes are found all over in nature – there are over a thousand enzymes found in the human body alone.
- Some examples of enzymes:
  - amylase, found in saliva to digest starch
  - protease, used to break down proteins
  - helicase, used to separate the DNA helix

Enzymes – Biological Catalysts

- Like all other proteins, enzymes are sensitive to pH and temperature. Enzymes have an **optimal pH and temperature** in which they operate.
- For most enzymes, the optimal temperature is body temperature of 37 °C.
- At **high temperatures or at an extreme pH**, the enzymes will get **denatured**, i.e. destroyed. This process is irreversible.

Enzymes – Biological Catalysts

- The rate of reaction varies with temperature for an enzyme-catalysed reaction.