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VCE Chemistry ¾
Rates of Reaction [2.6]
Workbook

Outline:

Learning Objectives:

- ☐ **CH34 [2.6.1]** - Explain How Factors Increase Frequency of Collisions
- ☐ **CH34 [2.6.2]** - Explain How Temperature & Catalyst Affect the Proportion of Successful Collisions
- ☐ **CH34 [2.6.3]** - Graph Differences in Rate & Yield

Section A: Collision Theory

Sub-Section: Introduction to Collision Theory

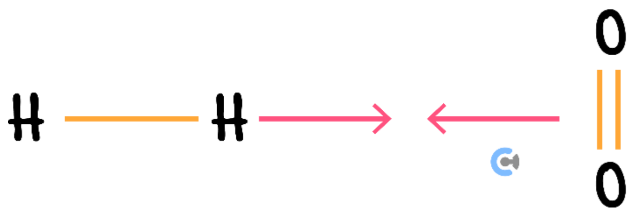
What is the rate of reaction?

Rate of Reaction

- **Definition:** how quickly something is reacting.

Before we look at rates of reactions, how do reactions occur in the first place?

Discussion: What requirements need to be fulfilled for two reactants to react with each other?



- sufficient energy
- correct orientation
- collide

NOTE: The idea of 'sufficient energy' will be explored later in the booklet!

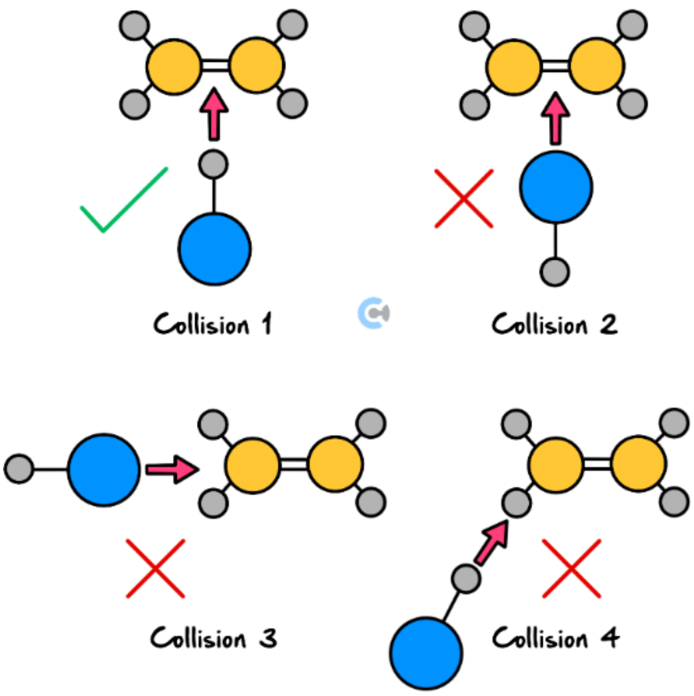
Let's first look at the idea of 'Correct Orientation'.

Sub-Section: Correct Orientation

Exploration: Correct Orientation

- Consider the following reaction:

$$C_2H_4 + HCl \rightarrow C_2H_5Cl$$



- You don't have to know **what** the **correct orientation is**!
- You only need to know that **there is** a **particular correct orientation**.

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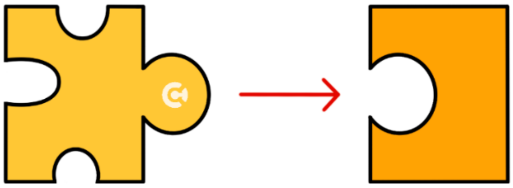
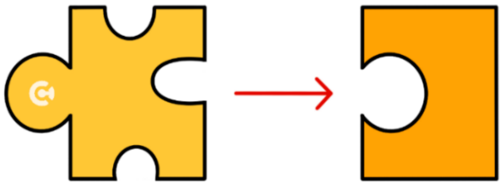
Analogy: Jigsaw Puzzle

- **Consider a jigsaw puzzle:**



What if you were blind & you couldn't feel the ridges of the puzzle piece?

- Consider this scenario:



- How might you get the two pieces to fit together? trial & error
- How can success be achieved quicker? more trials
- **Example**: Consider a $10\ \%$ chance of a successful collision, and there are $10\ collisions\ /\ sec.$

Total Frequency of Collisions	Expected Frequency of Successful Collisions
$10\ collisions/s$	1 c/s
$100\ collisions/s$	10 c/s

- Effect of the increased total frequency of collisions on the frequency of successful collisions:

[increases] / [decreases] / [stays constant]

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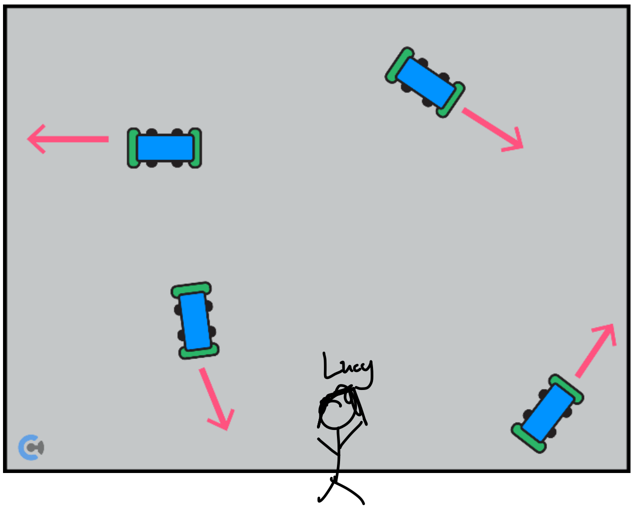
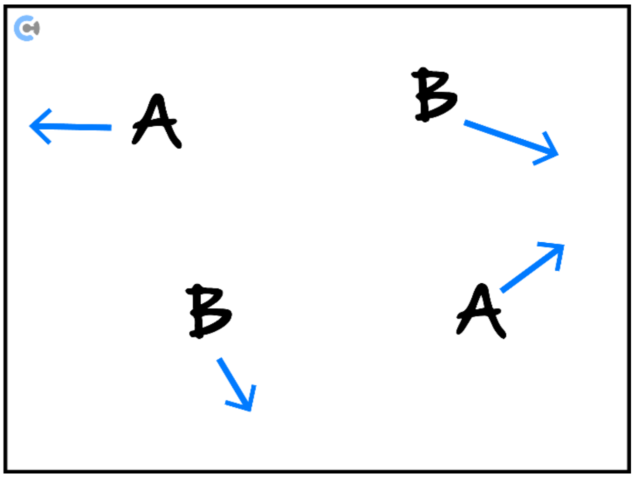
Section B: Frequency of Collisions

We need to increase the frequency of total collisions. But how do we do this?

Exploration: Increasing Frequency of Collisions

- Consider bumper cars at the carnival:





- **Scenario**: You have the **capability to alter the setup** of the bumper cars at the carnival.
- How can the **frequency of collisions be increased?**

Bumper Cars	Collisions between Reactants
more cars	more reactants (n↑)
less driving space	↓V
speed of cars	↑ avg KE (temp↑)

- The amount of **particles** (n) and **volume** (V) is related to concentration of the reacting species.

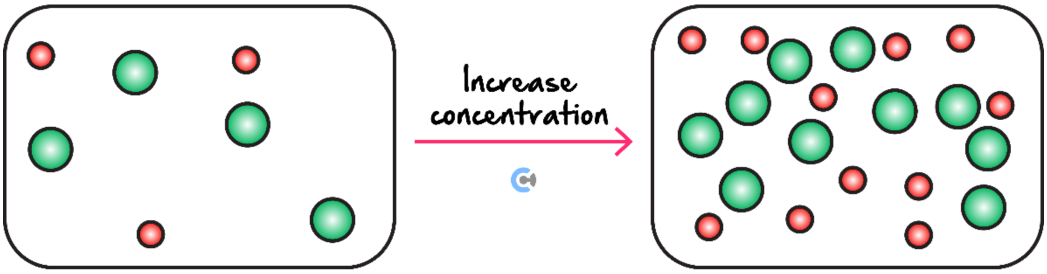
$c = \frac{n}{V}$

Sub-Section: Concentration and Pressure

Concentration and Pressure

- **Definition:** How tightly packed a mixture is.

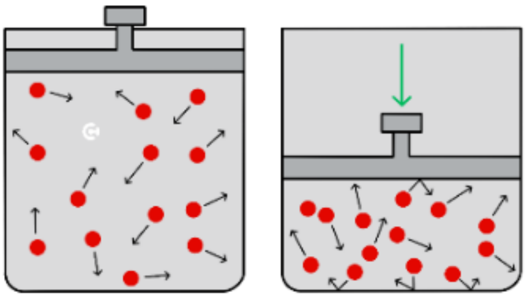
Concentration	Pressure
Used for [aqueous (aq)] / [gaseous (g)] mixtures	Used for [aqueous (aq)] / [gaseous (g)] mixtures



More/ Less collisions   More/ Less collisions

Exploration: Decrease in Volume

- Consider the **volume** of a gas mixture is **decreased**.



- **The pressure** of gas mixture: [increases] / [decreases] / [no change]
- **Relationship:**

$$\uparrow P \propto \frac{1}{V} \downarrow$$

Exploration: Increase in Volume

- Consider a cup of orange juice which has water added to it.

- **Concentration of Orange Juice:** [increases] / [decreases] / [no change]

Extension: Mathematical Relationship of Concentration/Pressure on Moles (n) and Volume (V)

Concentration	Pressure
$C = \frac{n}{V} \rightarrow C \propto \frac{n}{V}$	$P = \frac{nRT}{V} \rightarrow P \propto \frac{n}{V}$

Concentration on Rate

- To increase to frequency of **successful** collisions with **correct orientation**, the frequency total collisions must be [increased] / [decreased].
- **Concentration/Pressure** can be **increased** by:

Amount (n)	Volume (V)
[increase] / [decrease] amount of particles	[increase] / [decrease] volume of container

Let's look at a question together!

Question 1 (3 marks) **Walkthrough.**

The rate of reaction of a particular gaseous mixture was attempted to be altered by adding more reactant gas particles in same volume.

a. State what happens to the rate of reaction. (1 mark)

increase.

b. Explain your answer in **part a**. (2 marks)

1. By increases amount of particles in same volume, concentration/pressure increases, particles are forced closer together
2. This increases total frequency of collisions.
3. This increases frequency of successful collisions with correct orientation
4. ∴ rate of reaction (R.O.R) increases

R.O.R

NOTE: The hardest part of these questions is [identifying what happens to rate] / [explaining why], so be sure to explain every detail!

Sample Response: Increase in Concentration or Pressure

- When concentration/pressure is increased, **particles are moved**: [closer together] / [further apart]
- **Frequency of total collisions:** [increases] / [decreases]
- **Frequency** of **fruitful/successful collisions** with **correct orientation** collisions: [increases] / [decreases]
- **Overall rate of reaction:** [increases] / [decreases]

Definition

Explanation Flow Chart for Frequency of Collisions

Key Feature → total ***Freq. Collisions***
→ ***Frequency of*** successful ***Collisions with Correct Orientation***
→ ***Rate of Reaction***

Let's now have a look at a sample response from a student, and let's grade it together!

Question 2 (3 marks) **Mark, Improve.**

How does increasing the volume of a gaseous mixture affect the rate of reaction?

Student's Response:

- *As the volume of the gaseous mixture is increased, particles drift further apart, resulting in a lower ~~concentration~~ pressure of the gaseous reactants.*

↓ total freq. of collisions

- *This decreases the ~~number~~ frequency of successful collisions with the correct orientation, per unit time thereby decreasing the rate of reaction.* ①

Mark (/3) : 1/3

Comments:

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Misconception

"Increasing concentrations increase the number of collisions."

Truth: When responding, you need to relate to either the:

- The **number of collisions/unit time** (e.g. number of collisions per second or per minute).
- The **frequency** of collisions.

REMINDER: Link the **total frequency** of collisions first, before linking to the **frequency of successful collisions** with correct orientation!

Your Turn! (Write Full Sentences)

Question 3

Matthew drops a sheet of magnesium metal into a beaker containing 1.0 M sulphuric acid which will react to form magnesium sulphate and hydrogen gas.

State the effect on the rate of reaction if the 1.0 M sulphuric acid is replaced with 2.0 M sulphuric acid. Justify your answer with reference to collision theory.

~~By replacing concentration from 1.0 M to 2.0 M, particles are forced closer together, resulting in more frequent~~ collisions overall, thereby increasing frequency of successful collisions with correct orientation, which increases rate of reaction.

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To save time, you can shorthand this one!

Question 4 (3 marks)

In a solution mixture of hydrochloric acid and sodium hydroxide are mixed together. A large volume of water is added to the mixture.

Explain whether the reaction will take a longer or shorter time to react to completion.

farther

By adding water, concentration decreases, particles drift further apart, as a result there are less frequent total collisions ,resulting in less frequent successful collisions with correct orientation, thereby leading to slower rate of reaction,

This reaction takes a longer time to reach completion.

Question 5 Additional Question.

If the volume of a reaction vessel is doubled for a gaseous reaction, what happens to the frequency of successful collisions per unit time?

A. It increases because the molecules have more space.

B. It decreases because the concentration of gas molecules decreases.

C. It remains unchanged because only temperature affects successful collisions.

D. It increases because molecules gain more kinetic energy.

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Question 6 Additional Question.

If the number of successful collisions per second in a gaseous reaction is doubled, what happens to the reaction rate?

A. It remains the same because total collisions matter more than successful ones.

B. It decreases because more molecules are colliding incorrectly.

C. It increases as it means the total number of collisions per second has also doubled.

D. It doubles because successful collisions are directly linked to the rate of reaction.

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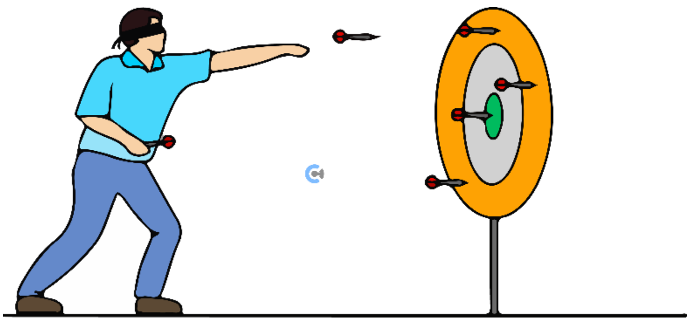
Sub-Section: Proportion of Successful Collisions

Discussion: How does increasing the concentration/pressure change the proportion or probability of fruitful/successful collisions?

[increases] / [decreases] / [no change]

Analogy: Darts

- **Scenario**: You were **blindfolded** playing darts and you had a 10% chance of hitting a **bullseye**.



	10 Darts Thrown Per Minute	100 Darts Thrown Per Minute
Expected Number of Bullseyes Hit Per Minute:	1 p/m	10 p/m
Number of Bullseyes Hit	[greater] / [lesser]	[greater] / [lesser]
Probability of Hitting a Bullseye	10%	10%

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Definition

Proportion/Probability of Successful Collisions for Concentration/Pressure Change

- As the **frequency** of total collisions is increased, the **frequency** of successful collisions is increased!

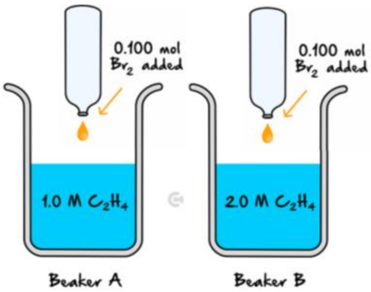
DO NOT MENTION PROBABILITY/PROPORTION OF SUCCESSFUL COLLISIONS

- Probability/Proportion of Successful Collisions will be properly covered later!

Try some questions!

Question 7 (5 marks)

There are two beakers of 1000 mL each which contain differing concentrations of ethene (C_2H_4). In beaker A, 1.0 M concentration of C_2H_4 is used, and in beaker B, 2.0 M concentration is used.



One drop of 0.100 mol bromine liquid ($Br_2(l)$) is dropped into each beaker and the time taken for a reaction to occur is recorded.

The reaction that takes place is as follows:

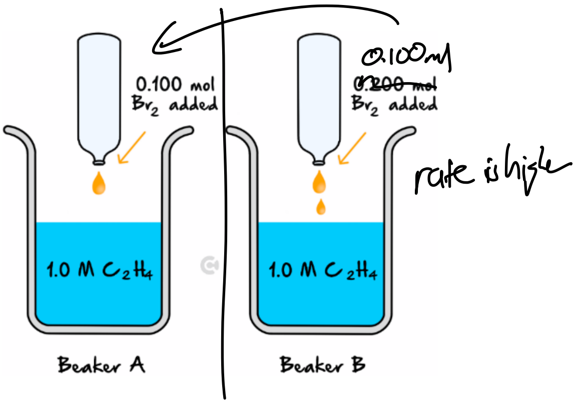
$$C_2H_4(aq) + \underset{brown}{Br_2(l)} \rightarrow C_2H_4Br_2(aq)$$

a. State which beaker will require the most amount of time for the brown colour to fade, giving justification for your response. (3 marks)

Beaker A. As beaker A has a lower concentration than B, this results in less frequent total collisions, and thus less frequent successful collision with correct orientation, leading to a slower rate of reaction and thus taking a longer time for brown colour to fade.

The experiment is then repeated with a slightly different setup.

b. This time, beakers *A* and *B* both have a 1.00 *M* concentration of ethene (C_2H_4), however, different amounts of bromine (Br_2) is added to each beaker, as shown in the diagram below.



i. Given that the volume of water in the beakers is still 1000 *mL*, state which beaker will have a greater concentration of bromine (Br_2) added.

B

ii. Explain which beaker will require the most amount of time for the colour to fade. (2 marks)

Beaker B - although it has a greater concentration resulting in greater rate, however, as more Br2 is added, the beaker starts off as more intensely brown than beaker A, and thus takes a longer time to fade as more Br2 needs to be reacted away.

NOTE: As we need to wait for all the bromine to react, adding more bromine results in a quicker rate of reaction, but as more bromine needs to react, the overall time required for the brown colour to fade is longer.

Space for Personal Notes

Sub-Section: Inert Gas

Context

- Sometimes, an inert gas is added to the mixture.

Let's have a look at what happens when we add an inert gas to a gas reaction chamber!

Discussion: What are some examples of inert gases?

Noble Gas

Ne, He, Ar   V, K, W

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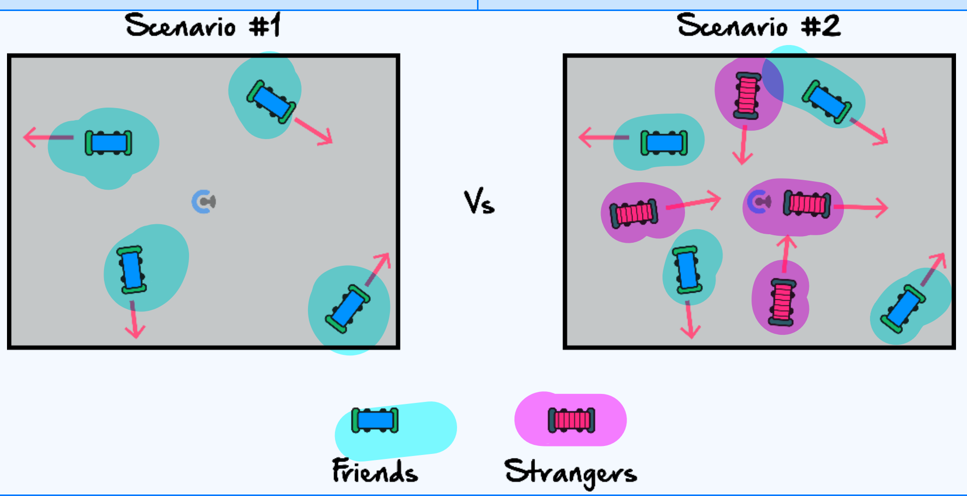
<u>Analogy</u>: Bumper Cars

- Consider the following bumper cars with **just your friends** compared to **with random people**:

<u>Scenario #1: Just Friends</u>	<u>Scenario #2: Friends & Strangers</u>
 	
Overall Concentration of Cars: [greater] / [lesser]	**Overall Concentration of Cars:** [greater] / [lesser]
Overall Frequency of Bumps: [greater] / [lesser]	**Overall Frequency of Bumps:** [greater] / [lesser]
Concentration of Friends: [greater] / [lesser] / [same]	**Concentration of Friends:** [greater] / [lesser] / [same]

- **In scenario #2 v/s Scenario #1:**
  - Concentration of Friends: [greater] / [lesser] / [same]
- Frequency of Bumps between Friends: [greater] / [lesser] / [same]

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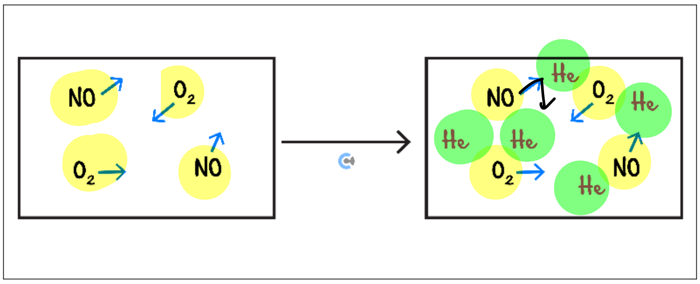
Let's link to a real example!

Exploration: Inert Gas in Reaction Chamber

- Consider the following reaction:

$$NO(g) + O_2(g) \rightarrow NO_2(g)$$



Overall:

- **Overall Concentration of Container:** [increases] / [decreases] / [stays same]
- **Overall Frequency of Collisions:** [increases] / [decreases] / [stays same]

Just between NO and O_2:

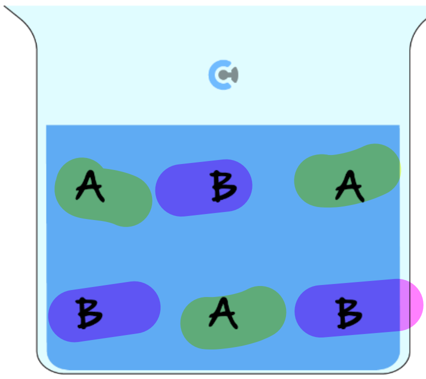
- **Concentrations of NO and O_2:** [increases] / [decreases] / [stays same]
- **Frequency of collisions between NO and O_2:** [increases] / [decreases] / [stays same]
- **Rate of reaction between NO and O_2:** [increases] / [decreases] / [stays same]
- **Conclusion:**
  - While overall concentration has increased,
  - The partial concentration of NO and O_2 has [increased] / [decreased] / [stayed same]
  - The **frequency of collisions** between them [increase] / [decrease] / [stays same]
  - Rate of reaction: [increase] / [decrease] / [stays same]

NOTE: Instead of 'partial concentration', as the mixture is a gaseous mixture, the term 'partial pressure' is used!

Definition

Partial Pressure/Partial Concentration

- **Definition**: The pressure or concentration of certain substance in a mixture of substances.
- **Example**: Consider $1.00\ L$ of water which has had $3.00\ mol$ each of substance A and B added to it.



1.00 L water

- The overall concentration is: 6M
- The concentration of only substance A is: 3M

Definition

Effect of Inert Gas on Rate of Reaction

- When an inert gas is added, the **overall pressure:** [increases] / [decreases] / [stays same]
- Partial pressure of reactants: [increases] / [decreases] / [stays same]
- Frequency of collisions between reactants: [increases] / [decreases] / [stays same]
- Rate of reaction: [increases] / [decreases] / [stays same]

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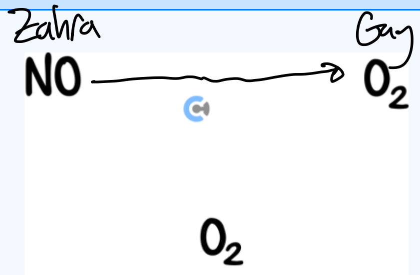
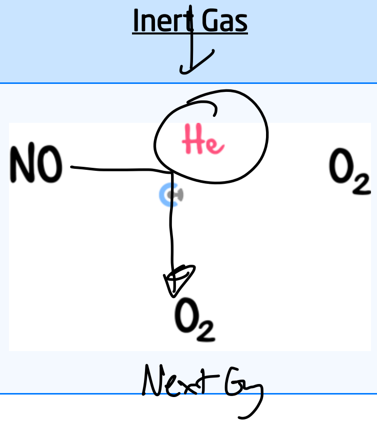
Extension: Won't the inert gas get in the way of the collisions?

No Inert Gas	Inert Gas
	

- For every collision that is '**missed**' because an inert gas was in the way, a **new collision** that wouldn't have happened will occur!

Your Turn!

Question 8 (3 marks)

Consider a reaction vessel containing nitrogen monoxide and oxygen which react in the following equation:

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

Neon gas is then added to the reaction chamber.

a. Identify the effect of the addition of neon gas on the overall pressure of the reaction vessel. (1 mark)

increases

b. Explain what would happen to the rate of reaction. (2 marks)

By adding neon gas, it is inert, so it will not react, while overall pressure will increase, the partial pressure of the reactants (NO & O2) will stay the same, and thus there frequency of collisions between reactants stays same, so rate of reaction stays same.

Sub-Section: Surface Area

How does surface area affect the rate of reaction?

Analogy: Cutting Cake

- Consider a full v/s cut cake.

- Which cake has a greater surface area exposed? [Full Cake] / [Cut Cake]

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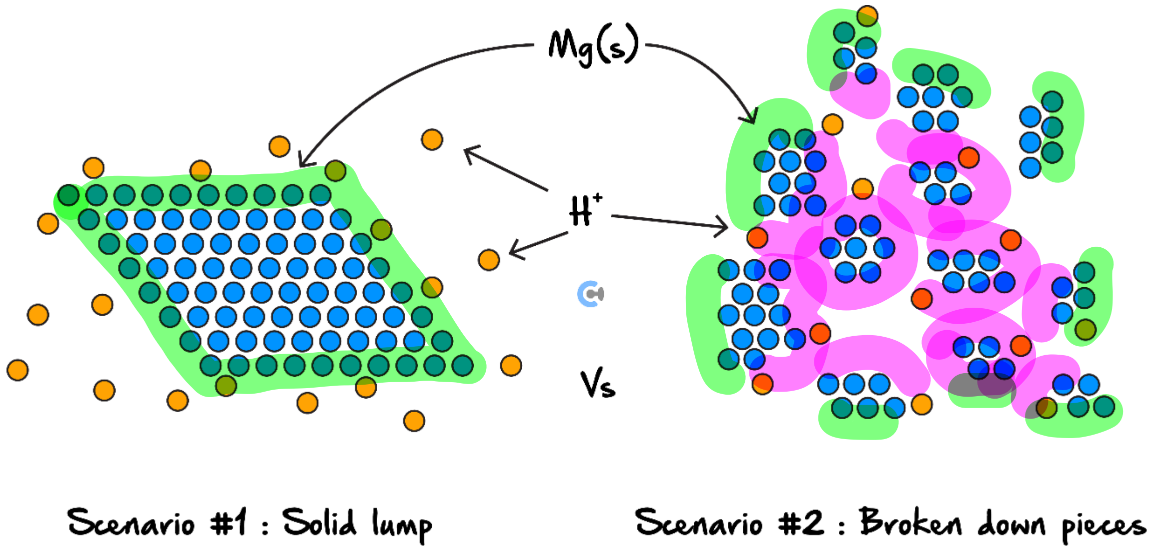
Similar thing applies to chemicals!

Exploration: Surface Area

- Consider the following scenarios:

$$Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$$



- In scenario #2 (broken down pieces):
  - Surface Area: [greater] / [lesser] / [same]
  - Frequency of Collisions: [greater] / [lesser] / [same]
  - Rate of Reaction: [greater] / [lesser] / [same]

Space for Personal Notes

Sample Response: Surface Area

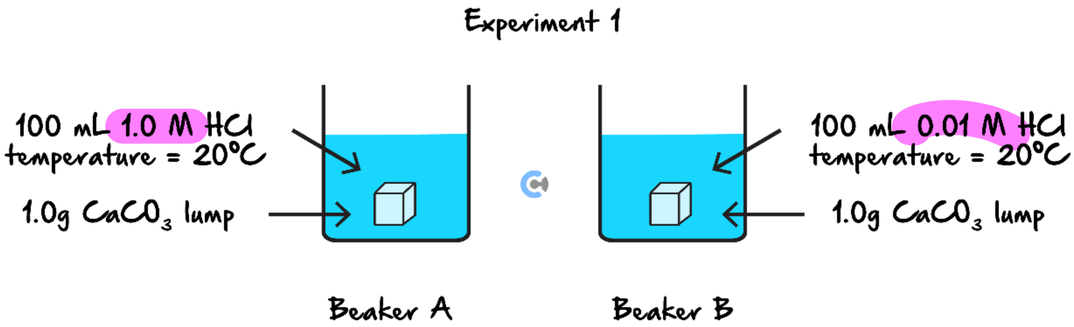
- Cutting/dividing substance into thin powder [increases] / [decreases] surface area.
- **Contact between reactants:** [increases] / [decreases]
- **Total Frequency of Collisions:** [increases] / [decreases]
- **Frequency** of **fruitful/successful collisions** with **correct orientation** collisions: [increases] / [decreases]
- **Overall rate of reaction:** [increases] / [decreases]

Try some questions!

Question 9 (5 marks)

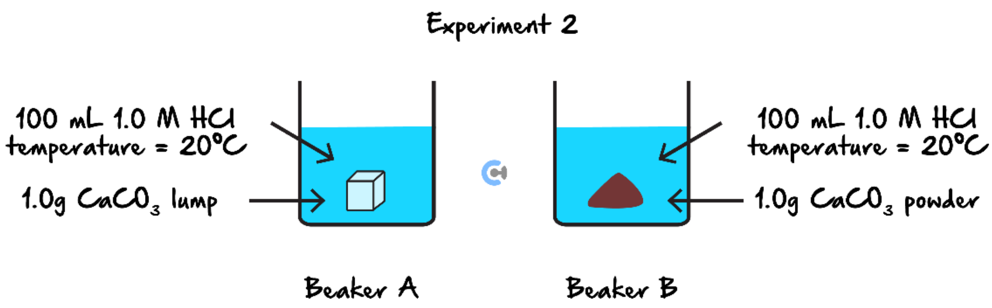
Two experiments were conducted to investigate various factors that affect the rate of reaction between calcium carbonate and diluted hydrochloric acid. The two experiments are summarised in the diagrams below.

a. Identify the rate-determining factor that is investigated in **Experiment 1**. (1 mark)



concentration of HCl

b. In **Experiment 2**, will the rate of reaction be faster in beaker *A* or beaker *B*? Explain your selection in terms of collision theory. (2 marks)



~~Beaker B - finely divided powder results in greater surface area, and thus more frequent collisions overall.~~ This increase frequdncy of successful collisions with correct orientation, thereby increasing rate.

c. Why is the following statement **incorrect**?

'Collision theory states that all collisions between reactant particles will result in a chemical reaction.' (2 marks)

- collide w/ correct orientation
- collide w/ sufficient energy

Question 10 Additional Question.

If the surface area of a solid reactant is increased, what happens to the rate of reaction?

A. The rate increases because more reactant particles are exposed to collisions.

B. The rate decreases because molecules move more slowly.

C. The rate remains unchanged because only temperature affects the reaction rate.

D. The reaction stops because equilibrium is reached faster.

Question 11 Additional Question.

A student is conducting different experiments to investigate factors affecting reaction rates. Which of the following changes would result in an increased reaction rate?

A. A reaction between hydrogen gas (H_2) and oxygen gas (O_2) occurs in a sealed container. The student increases the volume of the container while keeping the temperature constant.

B. Adding argon gas to hydrogen and oxygen gas combustion reaction vessel.

C. A reaction between magnesium (Mg) and hydrochloric acid (HCl) is performed. Instead of using a single strip of magnesium metal, the student uses finely powdered magnesium.

D. A reaction between calcium carbonate ($CaCO_3$) and hydrochloric acid (HCl) is performed. The student removes some of the calcium carbonate from the flask, keeping all other conditions the same.

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Section C: Proportion of Successful Collisions

Sub-Section: Sufficient Energy

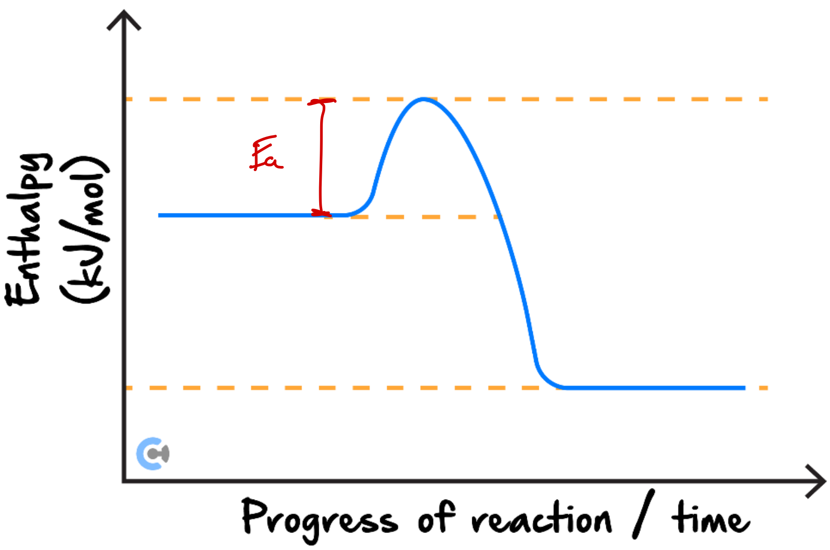
Context

- Successful collisions are based on two factors:
  - Colliding with the **correct orientation**.
  - Colliding with **sufficient energy**.

Discussion: How much energy is sufficient energy?

Overcome Ea

Activation Energy

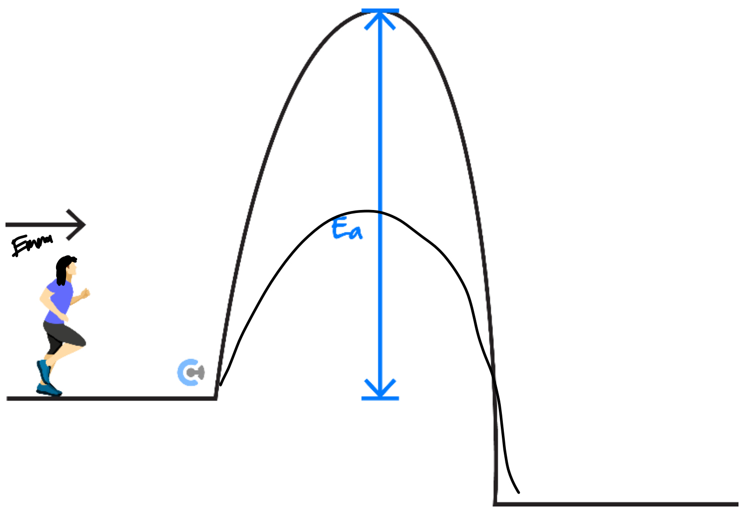


- **Definition**: Energy required to be inputted to break the pre-existing bonds before a reaction can proceed.
- **For Successful Reactions**: Energy greater than the activation energy must be inputted.

How can the proportion of particles which can overcome the activation energy be increased?

Exploration: Factors that affect the energy required to overcome the activation energy.

- Consider a boy trying to run over a hill with a particular height (activation energy).



- How can we increase the chances of him being able to go completely over the hill?

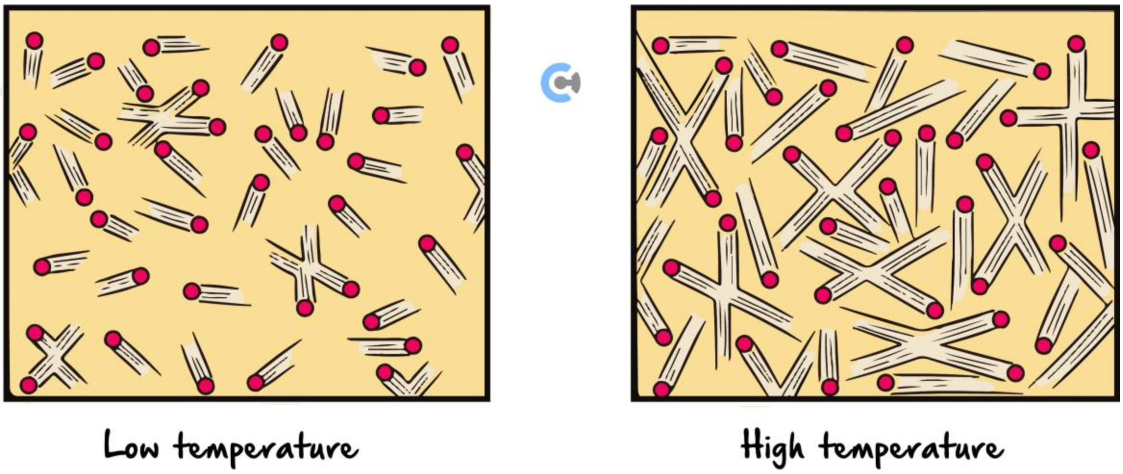
Changes in Hill Scenario	Changes in Reactions
run faster	↑ avg. KE (temp↑)
hill shorter	↓ Ea (catalyst)

Space for Personal Notes

Sub-Section: Temperature

REMINDER

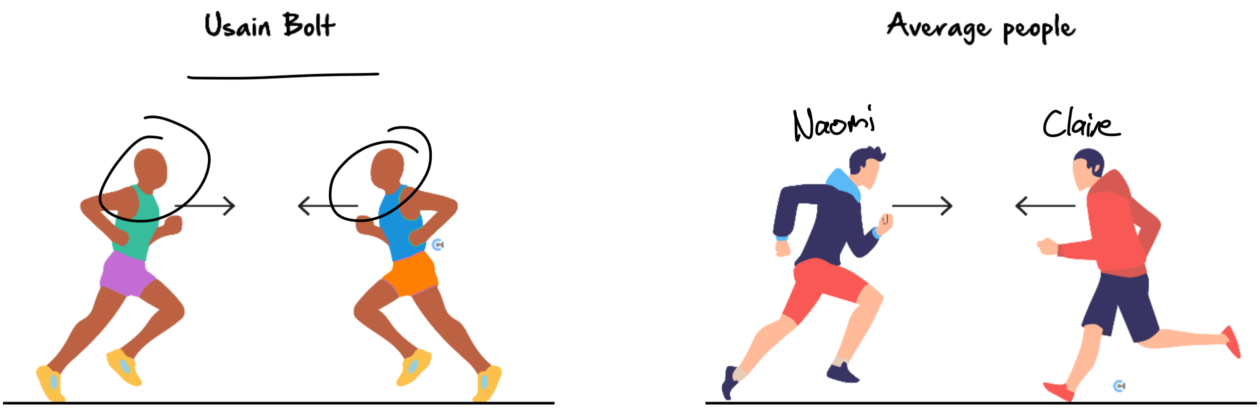
- Temperature is a type of kinetic energy!



- At higher temperatures, particles move faster.

Analogy: Usain Bolt

- Consider the two scenarios:



- Who will collide with greater force? [Usain Bolt] / [average people]
- Who is more likely to break their bones upon collision? [Usain Bolt] / [average people]

Breaking Bones (Humans) ↔ Breaking Bonds (Chemicals)

Let's link this to an actual collision!

Exploration: Linking to an Actual Collision

Scenario: Temperature is Increased

- **Average kinetic energy:** [increases] / [decreases]
- **Impact upon collision:** [more forceful] / [less forceful]
- **Probability for sufficient energy to overcome the activation energy:** [increases] / [decreases]
- Rate of reaction: [increases] / [decreases]

NOTE: Increasing temperature has increased the **proportion** of successful collisions as more particles have sufficient energy to react!

ALSO NOTE: While '**proportion/probability**' should not have been mentioned before, it **should be mentioned now**!

Exploration: Frequency of Collisions

- At greater temperatures, **particles move with greater speed**.
- What happens to the frequency of collisions? [more] / [less] frequent collisions.

Space for Personal Notes

Effect of Temperature on Rate

- Increasing the temperature has a **dual** effect on the rate of reaction:
  - It increases the proportion of particles with **sufficient energy** to react.
  - It increases the frequency of successful collisions with the **correct orientation**.

Which factor has the greatest effect on the rate of reaction?

Discussion: **Does energy upon collision or frequency of collisions affect the rate of reaction more?**

[energy upon collision] / [frequency of collisions]

Analogy: Punching

- Imagine people punching each other.

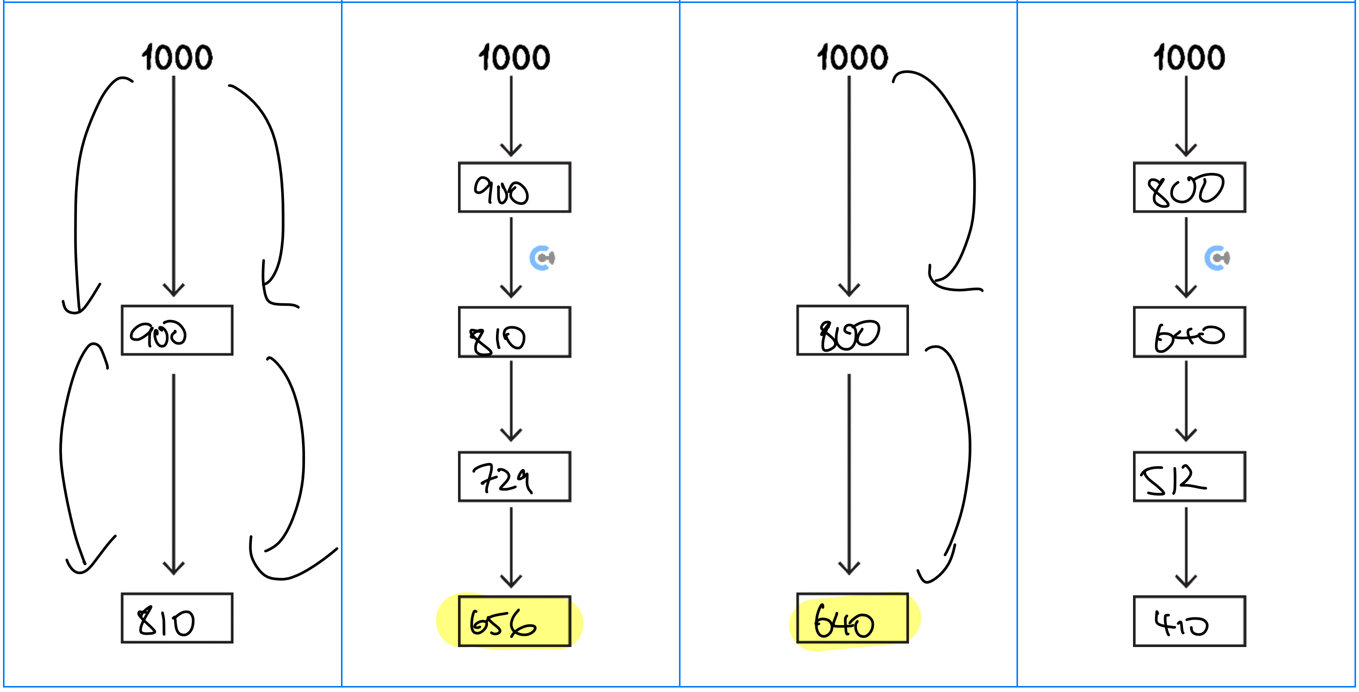
- Imagine someone punching someone with a 1% chance of knocking them out.

Increasing Frequency of Collisions	Increasing Energy Upon Collision
Punching someone **multiple times** with 1% chance of knockout.	Punching someone **harder** with a 10% chance of knocking them out.

Exploration: Sufficient Energy to React vs Frequency of Collisions

- Suppose a scenario with **1000 particles**, whereby **10%** of them have sufficient energy to react.
- **How many particles** out of **1000** have **sufficient energy** to react? 100
- Let's consider two scenarios:
  - **Scenario #1:** The frequency of collisions is doubled.
  - **Scenario #2:** The proportion of successful collisions is doubled.
  - **Scenario #3:** Both the frequency & proportion of successful collisions are doubled.

Original	Scenario #1: Increase Frequency of Collisions	Scenario #2: Increase Proportion of Successful Collisions	Scenario #3: Increase in Both
10% of particles react.	10% of particles react at double the rate.	20% of particles react.	20% of particles react at double the rate.



- We see that a greater proportion of particles results in a greater rate of reaction!

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Definition

Greatest Effect on Rate of Reaction

- Greatest effect on the rate of reaction: [frequency of ~~collisions] /~~ [energy upon collision]
- When explaining the rate of reaction for temperature, both factors must be referenced!

Sample Response: Effect of Temperature

- **Overall**: Increasing temperature [increases] / [decreases] average kinetic energy.
- **Energy Upon Collision:**
  - Reacting particles collide with [greater] / [lesser] force.
  - Probability of colliding with sufficient energy to overcome the activation energy. [increases] / [decreases] / [same]
  - Proportion/probability of successful/fruitful collisions. [increases] / [decreases] / [same]
- **Frequency of Collisions:**
  - Average moving speed of particles: [increases] / [decreases] / [same]
  - Total frequency of collisions: [increases] / [decreases] / [same]
  - Frequency of successful collisions: [increases] / [decreases] / [same]
- **Overall Rate:** [increases] / [decreases]

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Question 12 (3 marks) **Mark, Improve.**

How does increasing the temperature of a gaseous mixture affect the rate of reaction?

Student's Response:

- *As the temperature of a gaseous mixture is increased, the kinetic energy of the reactants is increased, ~~resulting in a greater proportion of particles which can successfully react.~~*
- *Additionally, particles move at a greater speed, resulting in more frequent collisions. This results in a greater rate of reaction.*

Mark (/3) : 1/3

Comments:

____

____

____

Energy Upon Collision Flow Chart

avg K Energy → Greater force upon collisions → Greater proportion/probability for Collisions with sufficient energy to overcome Ea → Greater Rate

NOTE: As the increase in the proportion of particles with sufficient energy has the greatest effect on the rate of reaction, it is best to mention this point first.

ALSO NOTE: 'average Kinetic Energy' must be referenced and not 'kinetic energy'.

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Question 13 (5 marks)

Explain the following phenomena using collision theory:

a. The chemicals mixed by a panel beater make body filler harden faster on a hot day than on a cold day. (3 marks)

On a hot day, greater temperature resulting in a greater average kinetic energy. This results in particles collide with greater force, resulting in greater proportion of particles colliding successfully with sufficient energy to overcome activation energy.

Particles also move with greater average speed, increasing frequency of total collisions, and thus frequency of successful collisions with correct orientation.

Both these factors result in greater rate of reaction, resulting in chemicals mixed by a panel beater to make body filler harden faster.

b. Nail polish remover evaporates faster if you shake your fingers than if you don't. (2 marks)

By shaking your fingers, airp articles collide with the nail polish on your fingers with greater kinetic energy.

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Question 14 Additional Question.

What factor is the major reason for the increased rate of reaction when temperature is increased?

When the temperature of a chemical reaction is increased, the rate of reaction also increases. Which of the following factors has the greatest effect in explaining this increase?

A. The reactant molecules move faster, leading to a greater frequency of collisions.

B. The total number of reactant molecules increases, providing more particles to react.

C. The increase in temperature increases the concentration of the reactants, making collisions more likely.

D. The proportion of reactant molecules with energy greater than or equal to the activation energy increases, leading to more successful collisions.

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Sub-Section: Catalyst

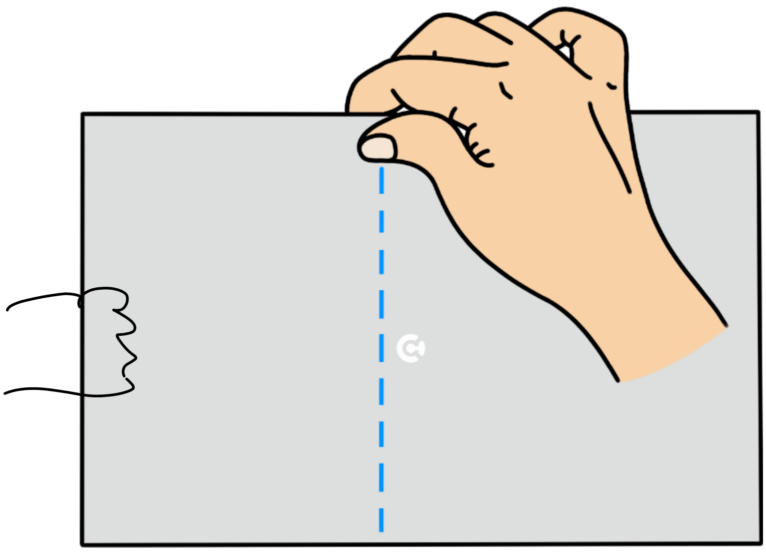
Catalyst

- **Definition**: A substance that increases the rate of a chemical reaction without itself being consumed.
- **How**: Catalysts alter the rate of reaction by providing an alternative reaction pathway with a lower activation energy.

How does a catalyst do this? What does this even mean?

Analogy: Paper

- Imagine trying to tear a piece of paper with one hand...

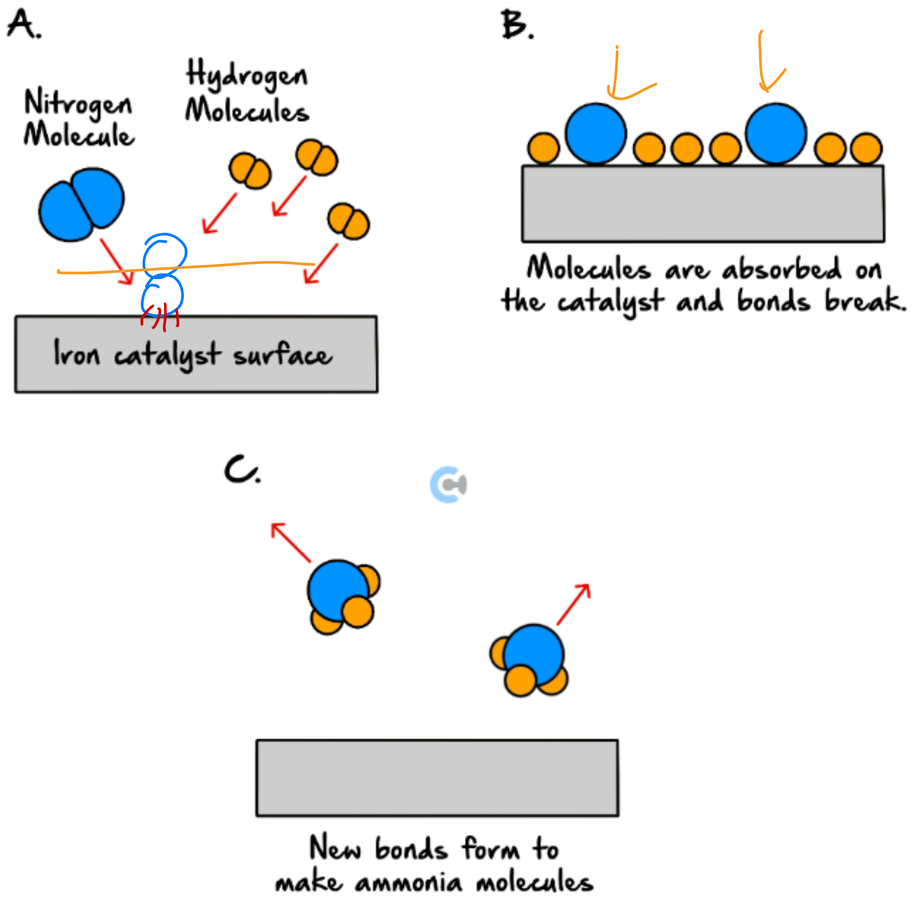


- This is how a reaction takes place normally.
- **Catalyst is present:** It simply acts as another hand.
- **Catalyst Purpose:** Helps to hold the other end of the paper, allowing us to tear the paper much more easily.

Exploration: How a Catalyst Works

- Consider the following reaction:

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g) \qquad \Delta H = -91\ kJ/mol$$



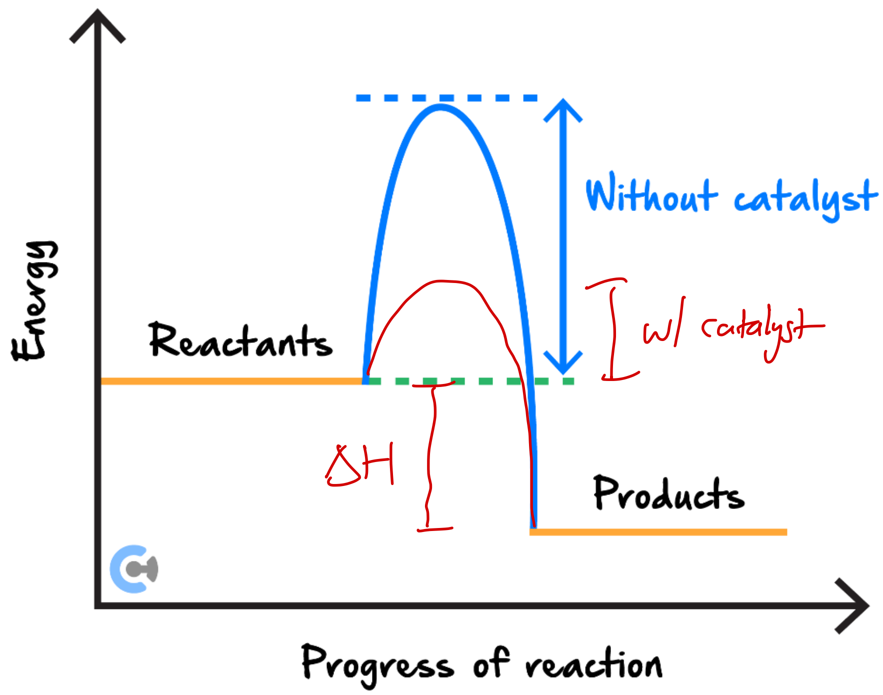
- Reactants **adsorb** onto the iron surface. They form **temporary** and **partial** intermolecular bonds with the catalyst.
- **As reactants attach:** Covalent bonds within their molecules weaken.
- **Activation Energy:** [increases] / [decreases] / [stays same]
- **Rate of Reaction:** [increases] / [decreases] / [stays same]

Space for Personal Notes

Catalysts

- A catalyst provides an alternative reaction pathway with lower activation energy by forming **temporary** and **partial intermolecular bonds** with the reacting particles.
- **Activation Energy:** [increases] / [decreases] / [stays same]
- **Rate of Reaction:** [increases] / [decreases] / [stays same]
- Catalyst Before vs After: no change.

Exploration: Catalysts - Energy Profile Diagram



- Overall change in enthalpy (ΔH) with catalyst: [increases] / [decreases] / [no change]

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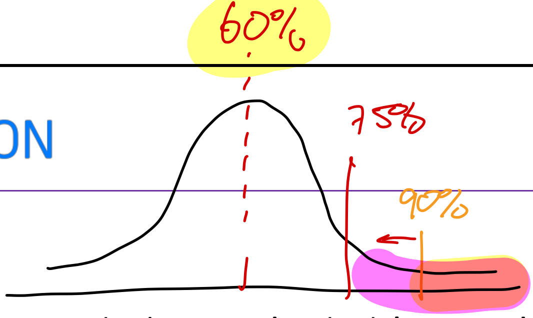

Analogy: Math Test

- We see that **increasing temperature** and using a **catalyst** both **increase the proportion of particles** with sufficient energy to overcome the activation energy.

- **Setup**: Imagine a math test with an average score of 60% and a high distinction being 90%.

  - Do a lot of people get a high distinction? **[yes]/[no]**

Scenario #1: Increasing Temperature	Scenario #2: Using Catalyst
Increases Average Kinetic Energy.	Lowers Activation Energy.
Average Test Score: 60% → 75%	**Average Test Score:** 60%
High Distinction Requirement: 90%	**High Distinction Requirement:** 90% → 75%
Proportion of People with High Distinction: [increases] / [decreases] / [same]	**Proportion of People with High Distinction:** [increases] / [decreases] / [same]

- Temperature and adding a catalyst both increase the proportion of successful reactions, just in **different ways**!

Sample Response: Effect of the Addition of a Catalyst

- The addition of a catalyst **lowers the activation energy** by providing an **alternative reaction pathway**.
- **Proportion** of particles with **sufficient energy** to overcome this **new activation energy is increased**.
- **Probability/proportion** of **fruitful/successful collisions** is **increased**, **increasing** the **overall rate of reaction**.

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Try some questions!

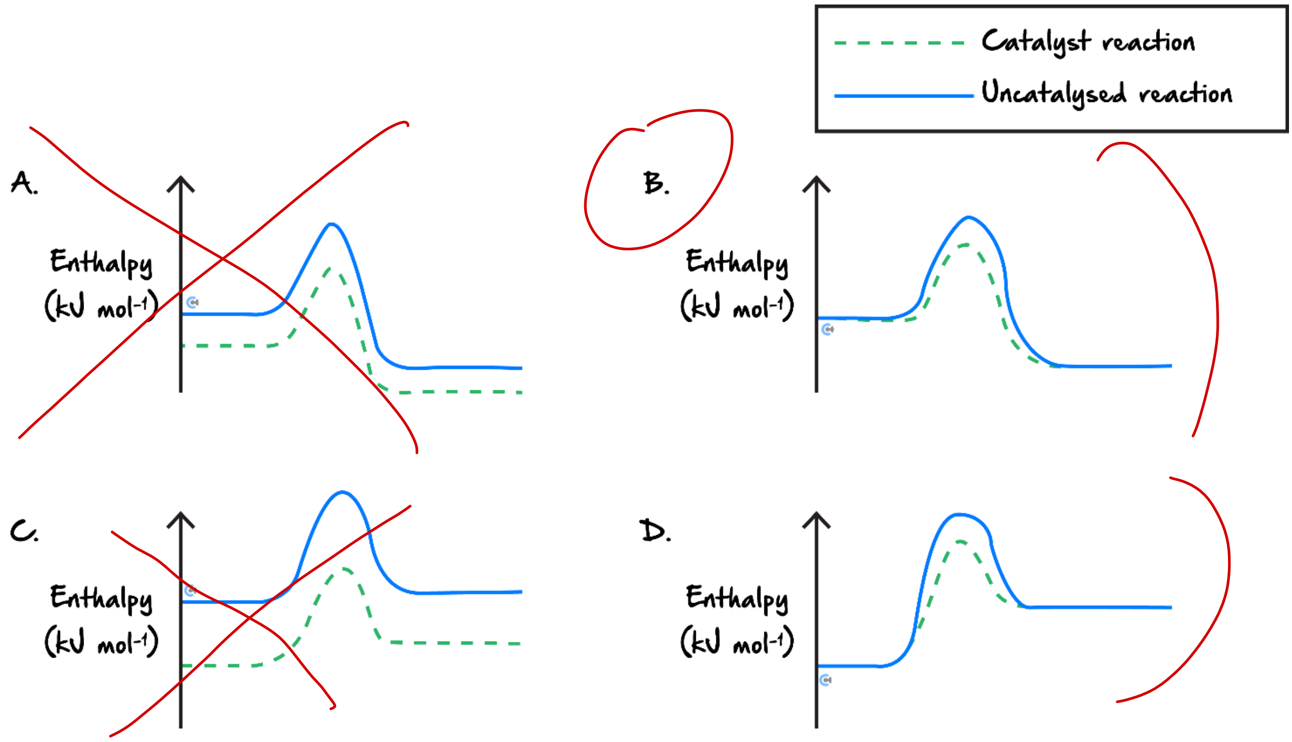
Question 15 (1 mark)

Inspired from VCAA Chemistry Exam 2015
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2015/2015chem-w.pdf#page=6

The oxidation of Sulfur dioxide is an exothermic reaction. The reaction is catalysed by Vanadium(V) Oxide.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

Which one of the following energy profile diagrams correctly represents both the catalysed and the uncatalysed reaction?



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Question 16 (1 mark)

Inspired from VCAA Chemistry Exam 2017
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2017/2017chem-w.pdf#page=2

A catalyst:

A. Slows the rate of reaction.

B. Ensures the reaction is exothermic.

C. Increases frequency of collisions between reacting particles.

D. Provides an alternative pathway for the reaction with lower activation energy.

NOTE: A catalyst merely increases the proportion of particles that can successfully react – it does not affect the frequency of collisions!

Question 17

An experiment is done twice – once with a catalyst and once without a catalyst. When the experiment is run with a catalyst, the rate of reaction is seen to be greater. Explain why this is the case.

With a catalyst, rate of reaction is greater as a catalyst provides alternative reaction pathway with a lower actiavation energy. This increases the proportion of particles with sufficient energy to overcome the new, lower activation energy, increasing proportion of successful collisions, thereby increasing rate.

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Question 18 (1 mark) **Additional Question.**

Inspired from VCAA Chemistry Exam 2019
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2019/2019chem-w.pdf#page=5

5 mL of Ethanol, CH_3CH_2OH, undergoes combustion in a test tube with a diameter of 1 cm. This experiment is performed in a fume cupboard. The temperature in the fume cupboard is 20°C. Which one of the following actions will reduce the rate of reaction?

A. Perform the experiment in a test tube with a diameter of 2 cm.

B. Increase the temperature in the fume cupboard to 25°C.

C. Increase the volume of the Ethanol to 7 mL.

D. Mix 2 mL of a dilute solution of Sodium hydroxide, NaOH, with the Ethanol.

NOTE: Sodium hydroxide doesn't do anything, and thus is effectively the same as adding water!

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Section D: Measuring Rates of Reaction

Sub-Section: Measuring Rates of Reaction

Context

- Generally, rates of reaction are measured by monitoring changes which can be observed.

- In total, there are 4 main methods we use to measure the rate of reaction. They include observing the change over a period of time:
  - mass
  - volume
  - pH
  - temperature

  colour

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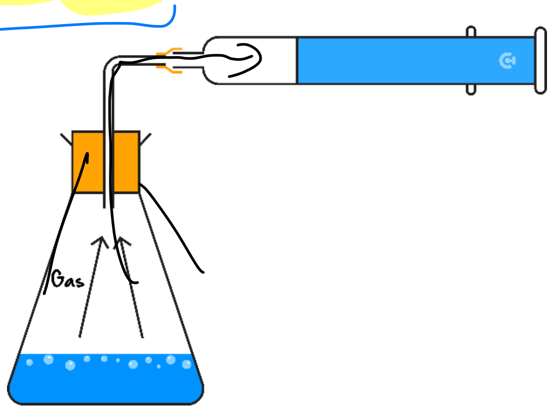
Let's have a look at each of the methods in depth!

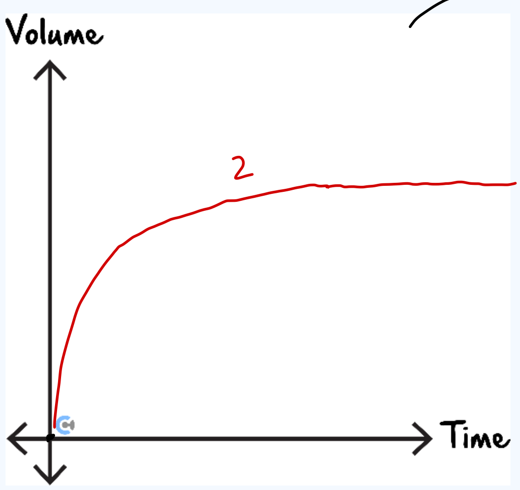
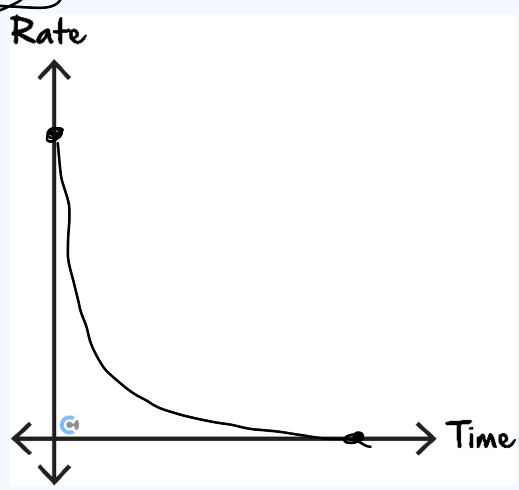
Exploration: Method 1 – Volume of Gas Evolved

- **Conditions**: Reaction produces a gas.
- **Setup**: Attach a **gas syringe** to capture the gaseous products.
- **Consider the reaction:**

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



What does the graph look like?

Volume against Time	Rate Against Time
	

dV/dt

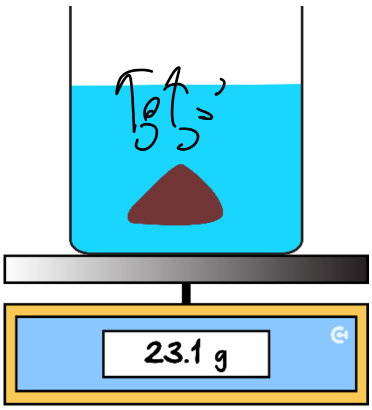
NOTE: The rate of reaction is indicated by the gradient of the graph!

ALSO NOTE: The **rate vs time graph** is simply just the derivative of the volume vs time graph!

Exploration: Method 2 – Change in Mass

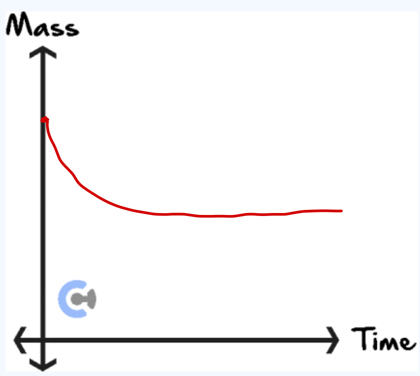
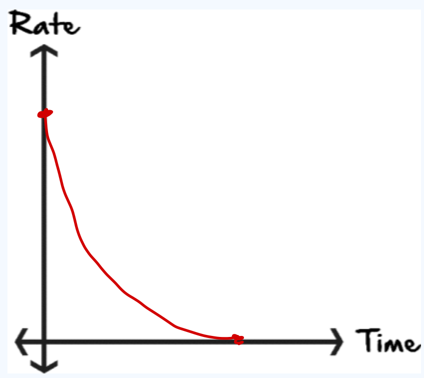
- **Conditions**: Reaction produces a **gas.**
- In the following acid-carbonate reaction, there are **gaseous products:**

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



- **Mass of the reaction vessel over time:** [increases] / [decreases] / [no change]
- **Reasoning**: gas escapes

What does the graph look like?

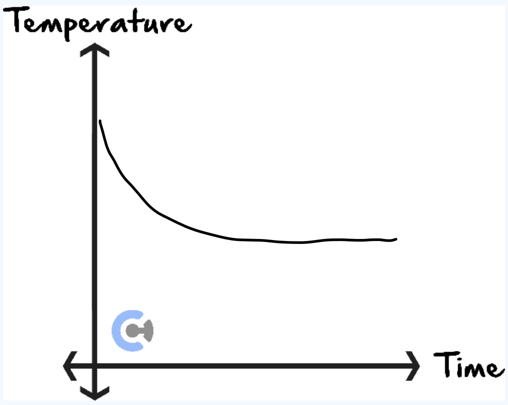
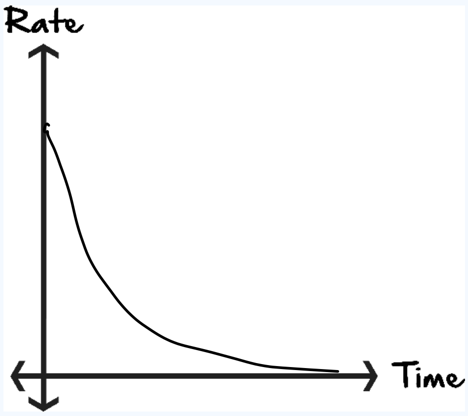
Mass Against Time	Rate Against Time
	

Exploration: Method 3 – Change in Temperature

- Almost every single reaction has a change in temp, whether it be exothermic or endothermic!
- Consider the following reaction:

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g) \quad \Delta H = +210\ kJ/mol$$

- **Type of Reaction:** [endothermic] / [exothermic]
- **Temperature Change:** [increases] / [decreases] / [no change]

Temperature Against Time	Rate Against Time
	

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Exploration: Method 4 – Change in pH

- Most reactions which involve acids or bases will have a change in pH over time.
- Consider the following reaction:

$$MgO(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l)$$

- **Acidity/Basic Changes:** [more] / [less] – [acidic] / [basic]
- **pH Change:** [increases] / [decreases] / [no change]
- As the pH scale is **logarithmic**, you will not be asked to plot the graph for pH!

Method to Measure Rate of Reaction

Definition

Method Of Measuring Rate	Conditions
Change in Volume (Gas Syringe)	Gaseous Products
Change in Mass (Weighing Scale)	Gaseous Products
Change in pH (pH metre/indicator)	H^+ or OH^- used/formed
Change in Temperature (thermometer)	Reaction is endothermic/exothermic

Space for Personal Notes

Sub-Section: In-Depth Graphical Analysis

Active Recall: How is the rate of reaction indicated in a graph?

gradient

Let's look at a question together!

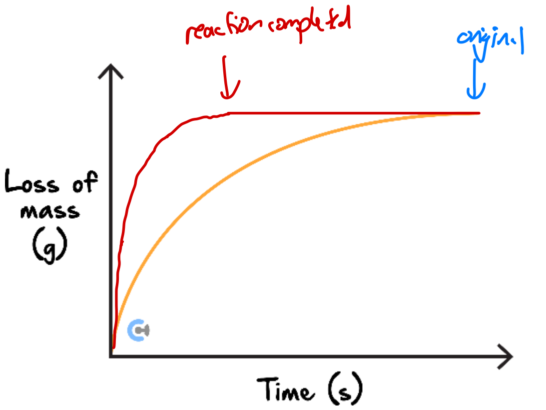
Question 19 Walkthrough.

Nitric acid is added to a 10 g granular zinc, which reacts according to the following equation:

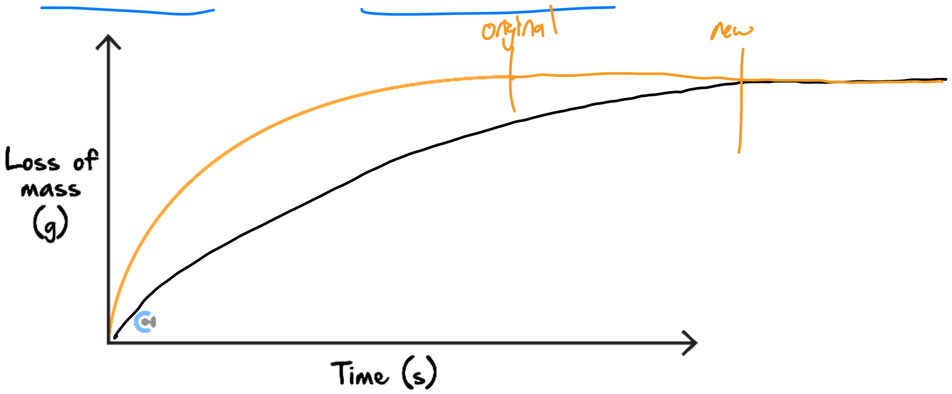
$$Zn(s) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + H_2(g)$$

On the axes provided below, draw the new graph observed if:

a. A catalyst was added.



b. The zinc metal was used in large chunks rather than broken down into granular pieces.



NOTE: As both scenarios result in the same amount of product forming, the graph ________________ at the same point!

Your turn!

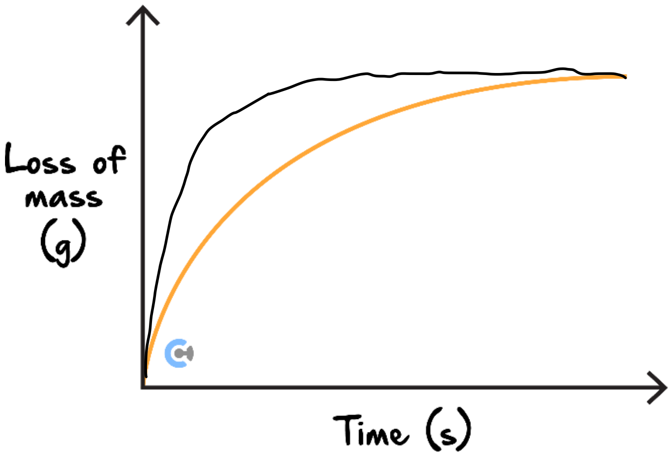
Question 20

Now consider the following reaction, which occurs at SLC in the presence of a manganese dioxide catalyst.

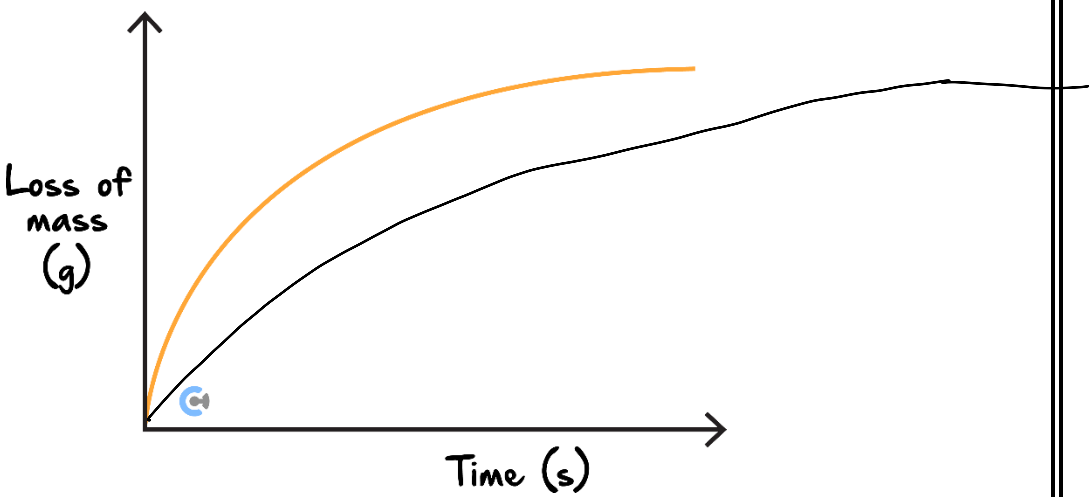
$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

On the axes provided below, draw the new graph observed if:

a. The reaction is carried out at 40°C.



b. The manganese dioxide catalyst is removed.



Now, let's consider a scenario where the amount of acid is changed as well!

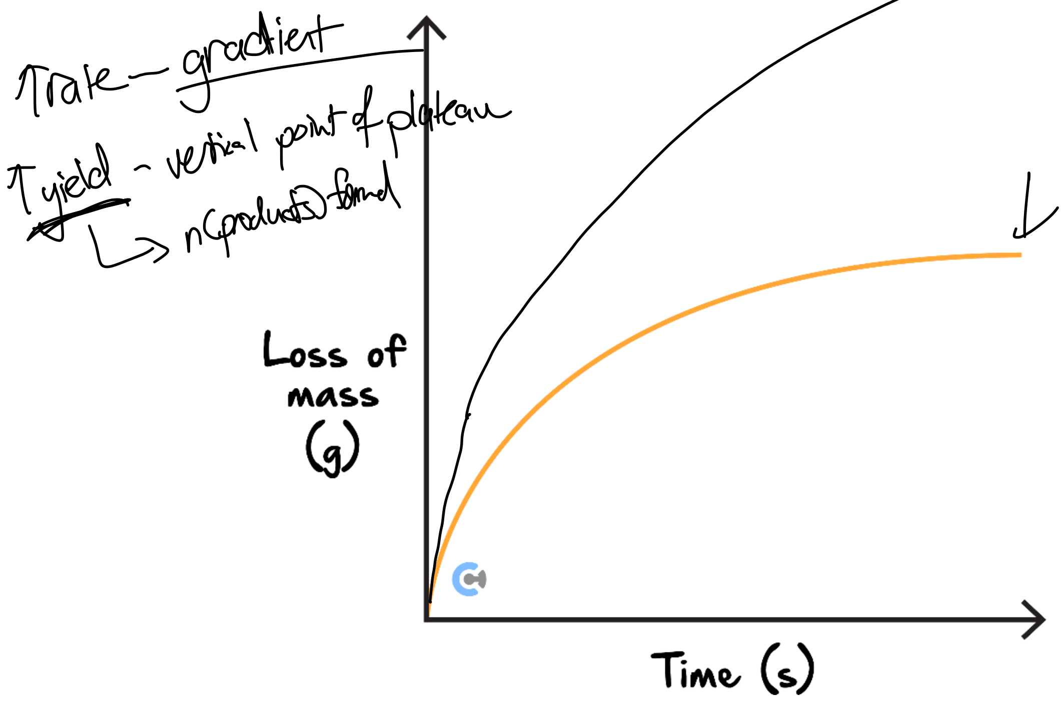
Exploration: $1.0\ M$ vs $2.0\ M$ HCl as the Limiting Reagent

- Consider a solution where there is $10.0\ mL$ of $1.0\ M$ and $2.0\ M$ of HCl and an excess amount of zinc metal.

$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

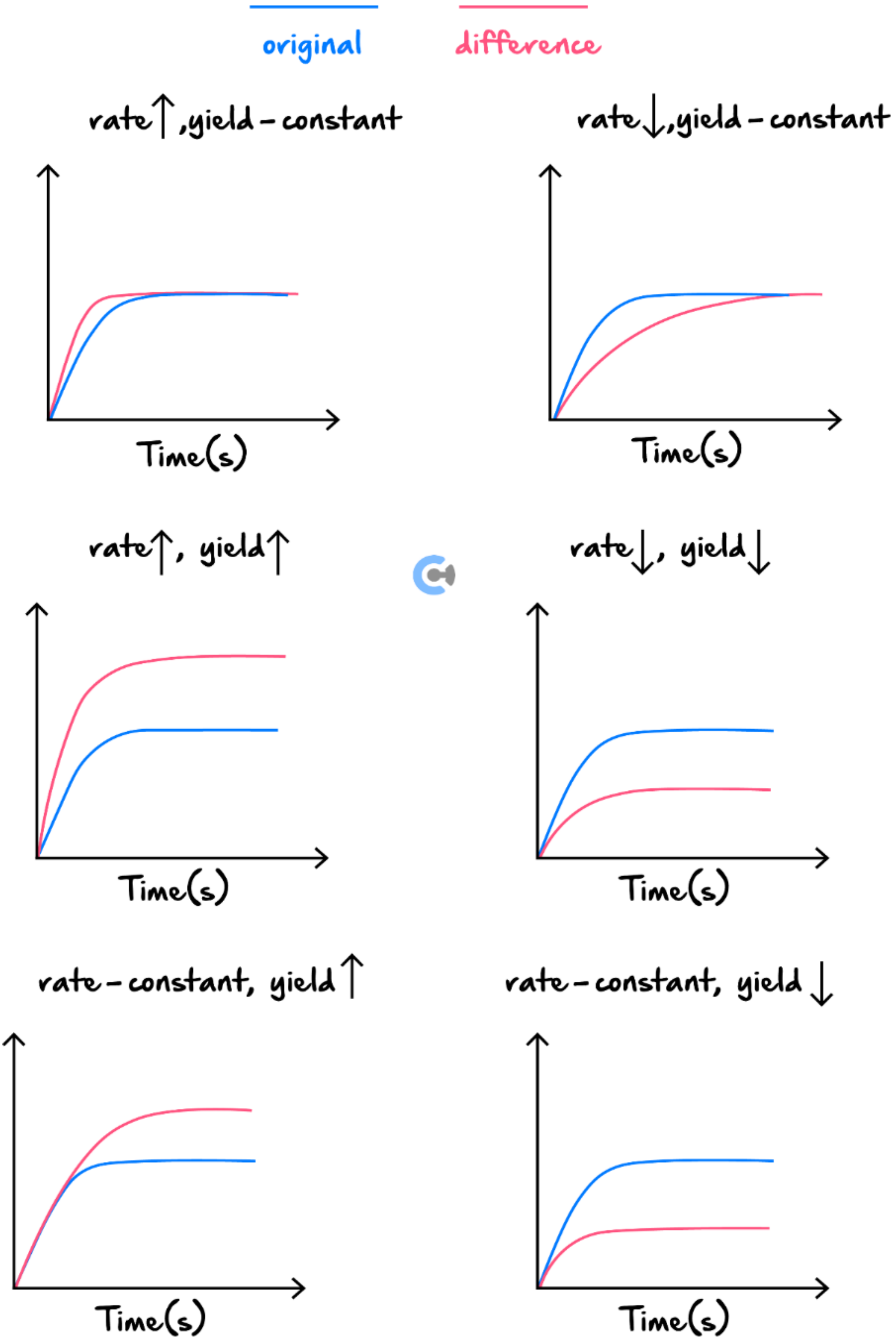
Setup	$10\ mL$ of $1.0\ M$ HCl	$10\ mL$ of $2.0\ M$ HCl
Rate of reaction	[slower] / [quicker]	[slower] / [quicker]
$n(HCl)$	lower	increase
Mass of hydrogen gas (H_2) produced	[greater] / [lesser]	[greater] / [lesser]
Change in the mass of the mixture	[greater] / [lesser]	[greater] / [lesser]

There is a difference in the rate of reaction and the amount of $H_2(g)$ produced! What does this look like on the graph?



Definition

Rate vs Yield in Graphs



Your turn!

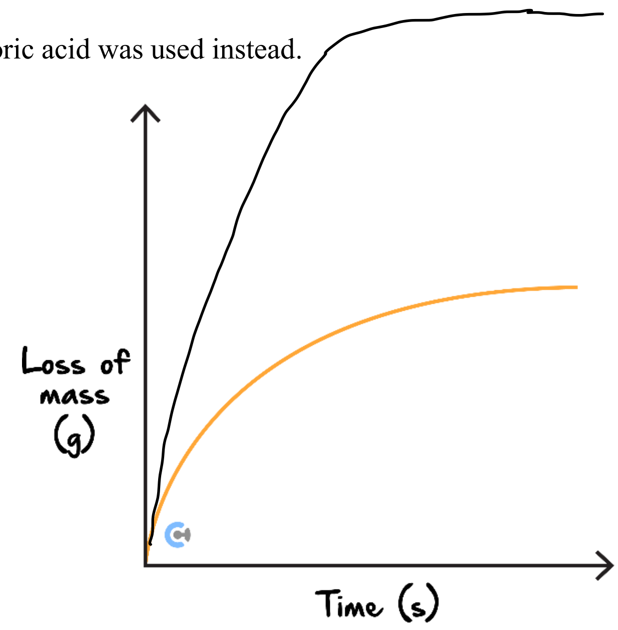
Question 21

Now consider a similar situation but now hydrochloric acid is now the **limiting reagent**.

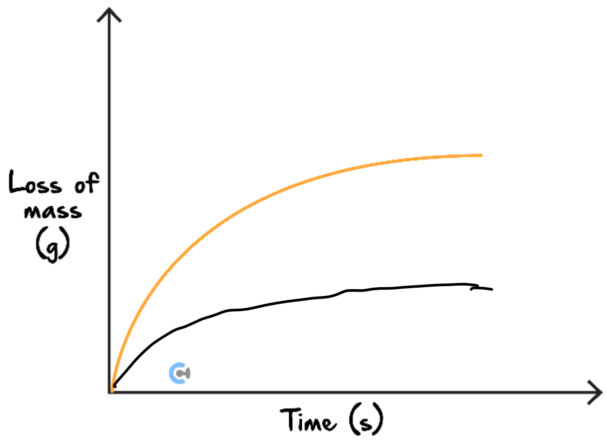
$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

Assuming the 'original' reaction used 10 mL of 1.0 M hydrochloric acid, compared to the 'original' graph, how would the new graph look like if:

a. 10 mL of 2.0 M hydrochloric acid was used instead.



b. 10 mL of 0.5 M hydrochloric acid was used instead.



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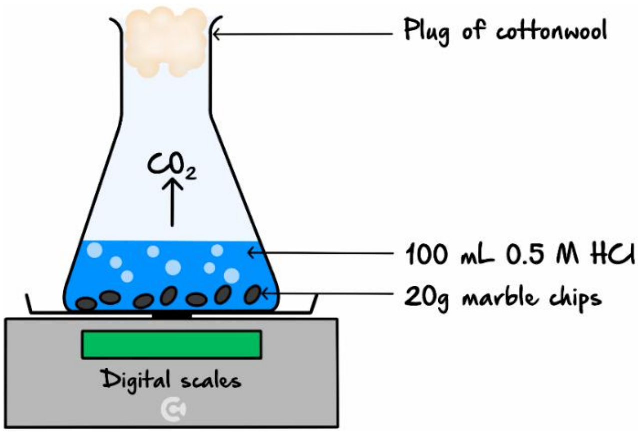
Question 22 (1 mark)

Inspired from VCAA Chemistry Exam 2016
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2016/2016chem-amd-w.pdf#page=14

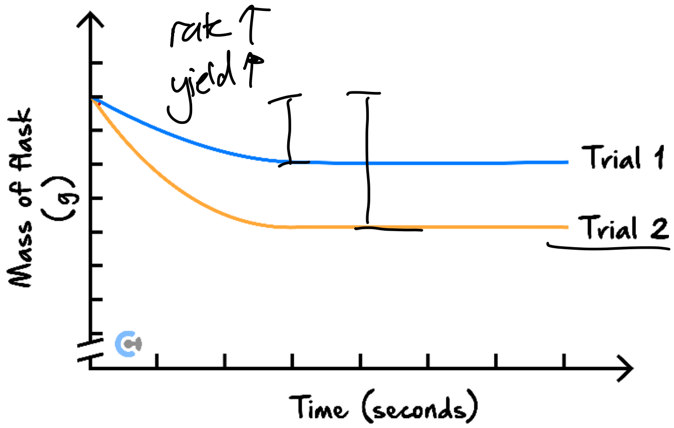
A student set up an experiment to test the effect of different factors on the rate and extent of the reaction between a strong acid and marble chips (Calcium carbonate, $CaCO_3$). In each trial, the mass of the flask and its contents were measured every 30 seconds from the instant the reactants were mixed.

The strong acid used was Hydrochloric acid, HCl. The equation for the reaction is as follows.

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



The results of the two trials were graphed on the same axes and are shown below.



In Trial 2, the student must have:

A. Heated the 0.5 *M* HCl before adding it to the flask.

B. Doubled the volume of 0.5 *M* HCl added to the flask.

C. Used 100 *mL* of 0.5 *M* H_2SO_4 instead of 100 *mL* of 0.5 *M* HCl.

D. Used the same mass of marble but crushed it into a powder.

Contour Checklist

- [ ] **Learning Objective: [2.6.1] - Explain how factors increase the frequency of collisions**

Key Takeaways

Concentration	Pressure
Used for [aqueous (aq)] / [gaseous (g)] mixtures.	Used for [aqueous (aq)] / [gaseous (g)] mixtures.

- [ ] To increase the frequency of **successful** collisions with **correct orientation**, the frequency __total__ collisions must be [increased] / [decreased].

- [ ] **Concentration/Pressure** can be **increased** by:

Amount (n)	Volume (V)
[increase] / [decrease] amount of particles.	[increase] / [decrease] volume of container.

- [ ] **Increase in Concentration or Pressure**
  - When concentration/pressure is increased, **particles move**: [closer together] / [further apart]
  - **Frequency of total collisions:** [increases] / [decreases]
  - **Frequency** of **fruitful/successful collisions** with **correct orientation** collisions: [increases] / [decreases]
  - **Overall rate of reaction:** [increases] / [decreases]

- [ ] Increase in Concentration or Pressure Flow Chart

Key Feature → __total__ Freq. Collisions → Frequency of __successful__ Collisions with Correct Orientation → Rate of Reaction

- Effect of Inert Gas on Rate of Reaction
  - When an inert gas is added, the **overall pressure:** [increases] / [decreases] / [stays same]
  - Partial pressure of reactants: [increases] / [decreases] / [stays same]
  - Frequency of collisions between reactants: [increases] / [decreases] / [stays same]
  - Rate of reaction: [increases] / [decreases] / [stays same]
- Surface Area
  - Cutting/dividing substance into thin powder [increases] / [decreases] surface area.
  - **Contact between reactants:** [increases] / [decreases]
  - **Total frequency of collisions:** [increases] / [decreases]
  - **Frequency** of **fruitful/successful collisions** with **correct orientation** collisions: [increases] / [decreases]
  - **Overall rate of reaction:** [increases] / [decreases]

Learning Objective: [2.6.2] - Explain how temperature & catalyst affect the proportion of successful collisions

Key Takeaways

- Greatest effect on the rate of reaction: [frequency of collisions] / [energy upon collision]
- Effect of Temperature on Rate (Sample Response)
  - **Overall**: Increasing temperature [increases] / [decreases] average kinetic energy.

Energy Upon Collision	Frequency of Collision
Reacting particles collide with [greater] / [lesser] force	Average moving speed of particles: [increases] / [decreases] / [same]
Probability of colliding with sufficient energy to overcome the activation energy [increases] / [decreases] / [same]	Total frequency of collisions: [increases] / [decreases] / [same]
Proportion/probability of successful/fruitful collisions [increases] / [decreases] / [same]	Frequency of successful collisions: [increases] / [decreases] / [same]

- Energy Upon Collision Flow Chart:

avg. K Energy → Greater force upon collision → Greater proportion/probability for Collisions with suff energy to overcome E_a. ____ → Greater Rate

- **Catalysts are** substances that increase the rate of a chemical reaction without itself being consumed.

- Catalysts alter the rate of reaction by providing an alternative reaction pathway with a lower activation energy.

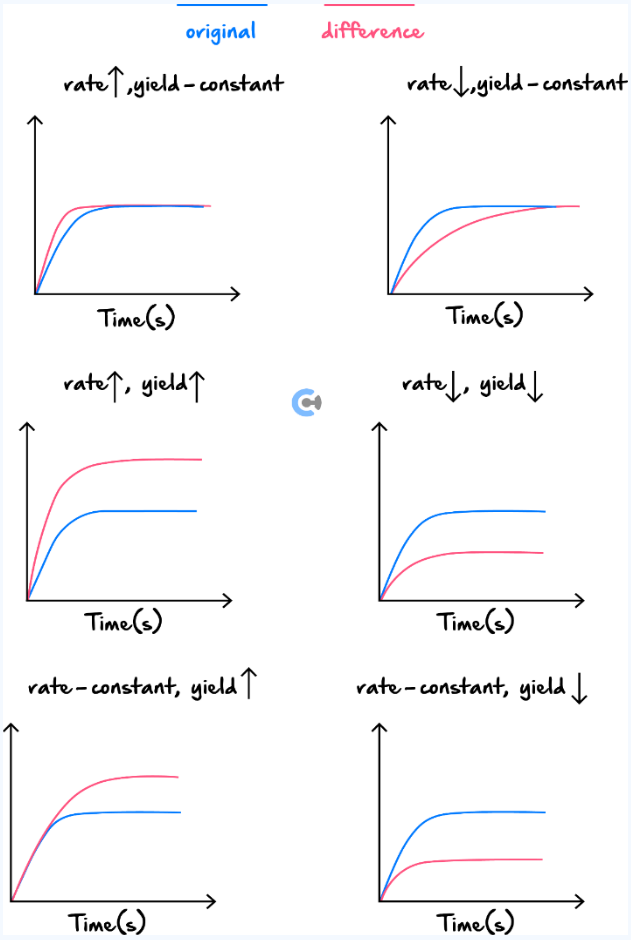
- Catalyst Sample Response:
  - A catalyst provides an alternative reaction pathway with lower activation energy by forming **temporary** and **partial intermolecular bonds** with the reacting particles.
  - **Activation Energy:** [increases] / [decreases] / [stays same]
  - **Rate of Reaction:** [increases] / [decreases] / [stays same]
  - Catalyst Before vs After: unchanged.

Learning Objective: [2.6.3] - Graph differences in rate & yield

Key Takeaways

Method Of Measuring Rate	Conditions
Change in Volume (Gas Syringe)	Gaseous Products
Change in Mass (Weighing Scale)	Gaseous Products
Change in pH (pH meter/indicator)	H^+ or OH^- used/formed
Change in Temperature (thermometer)	Reaction is endothermic/exothermic

- Rate vs Yield in Graphs



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