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VCE Chemistry ¾
Rate-Yield Conflict [2.9]
Workbook

Outline:

Learning Objectives:

- [ ] **CH34 [2.9.1]** - Explain Effects of Temperature, Inert Gas or Catalyst on Equilibrium System
- [ ] **CH34 [2.9.2]** - Graph Effects of Temperature, Inert Gas Catalyst on Equilibrium System
- [ ] **CH34 [2.9.3]** - Find the Change Made to System From Equilibrium Graph
- [ ] **CH34 [2.9.4]** - Find Equilibrium Constant Changes Due to Temperature
- [ ] **CH34 [2.9.5]** - Find Optimum Operating Conditions in All Circumstances Such as the Rate-Yield Conflict

Section A: Inert Gas

Sub-Section: Le Châtelier's Principle Summary

Let's summarise all the changes so far!

Exploration: Le Châtelier's principle summary

- **Draw an arrow** indicating the direction of the system's response:
  - **System 1**: $2NH_3 \rightleftharpoons N_2 + 3H_2$
  - **System 2**: $N_2 + 2O_2 \rightleftharpoons 2NO_2$
  - **System 3**: $2HI_2 \rightleftharpoons H_2 + I_2$

Change to the System	System 1	System 2	System 3
Addition/Removal of Substances			
Addition of Reactants	→	→	→
Removal of Reactants	←	←	←
Addition of Products	←	←	←
Removal of Products	→	→	→
Change in Volume			
Increase in Volume	→	←	—
Decrease in Volume	←	→	—
Change in Pressure			
Increase in Pressure	←	→	—
Decrease in Pressure	→	←	—

Sub-Section: Inert Gas

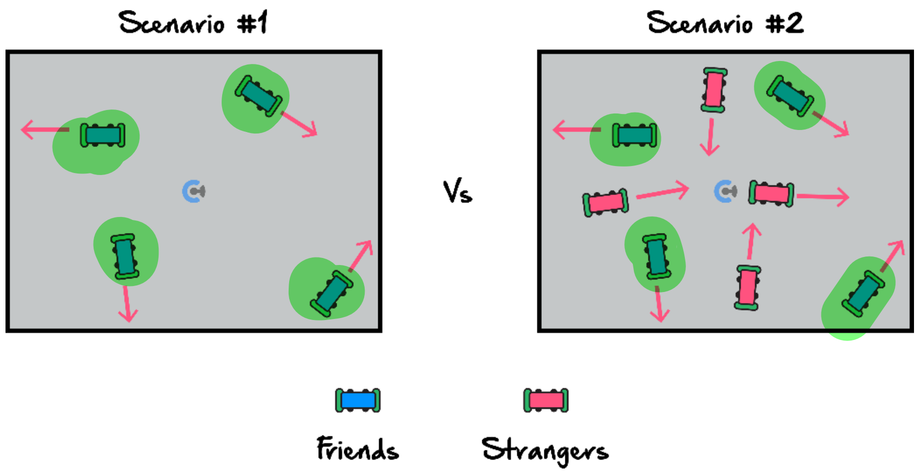
Exploration: Increase in pressure by adding inert gas.

- Consider the following:

$$A + B \rightleftharpoons 2C + 3D$$

- **Reaction quotient value (Q_c):**

- Imagine that your friends are substances A-D.
- Imagine that strangers are like an inert gas.



- Overall pressure when inert gas is added: [increases] / [decreases] / [no change]
- **Concentration of Each Substance:**
  - A and B: [increases] / [decreases] / [no change]
  - C and D: [increases] / [decreases] / [no change]
- Pressure of the reactants and products: [increases] / [decreases] / [no change]
- Reaction quotient (Q_c) value: [increases] / [decreases] / [no change]
- System shift to re-establish equilibrium: [forwards] / [reverse] / [no change]

Definition

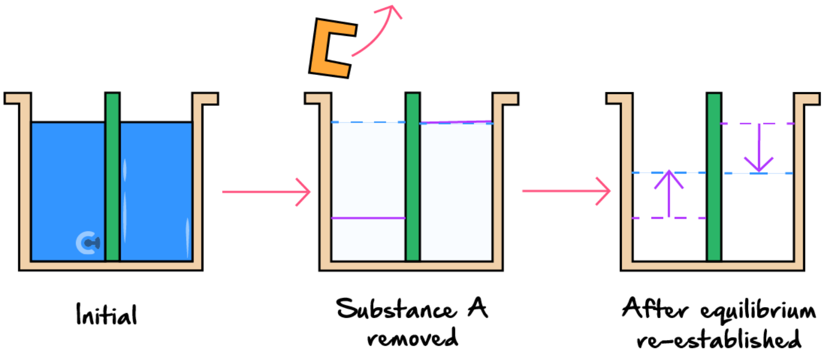
Adding Inert Gas to Equilibrium System

- **Partial pressure** of the **relevant reactants and products** has **not changed**.
- **Result:** No effect on the system.

REMINDER: Water Analogy

- What happens when substance A is removed in the following reaction?

$$A \rightleftharpoons B$$



Question 1

$$CH_3OH(g) \rightleftharpoons CO(g) + 2H_2(g)$$

Draw a forwards or reverse arrow to indicate which direction the equilibrium system will shift if:

a. Volume is increased. ↑V ↓[overall] LCP: ↑[overall] → more particles →	**c.** Carbon monoxide (CO) is removed. →
b. Hydrogen gas (H_2) is added. ←	**d.** An inert gas is added. —

Section B: Effect of Changing Temperature

Sub-Section: System Response

Context

- Whenever the **temperature** of the system is changed.
- According to Le Châtelier's Principle, the system will try to **partially** oppose **this change**.
- Temperature is changed by favouring either the endothermic or exothermic reaction.

Active Recall: What happens in endothermic and exothermic reactions?

Endothermic Reaction	Exothermic Reaction
[absorbs] / [releases] energy	[absorbs] / [releases] energy

Misconception

"As endothermic reactions absorb heat, the substances will get hotter."

TRUTH: While endothermic reactions do absorb heat, they do not get hotter!

- Endothermic reactions **absorb heat** and convert it into:

thermal energy → chemical

- Surrounding temperature becomes: [hotter] / [colder] / [no change]

Space for Personal Notes

Definition

Endothermic v/s Exothermic Reactions

Endothermic Reactions	Exothermic Reactions
Absorb Heat	Release Heat
Surroundings become [hotter] / [colder]	Surroundings become [hotter] / [colder]

Let's consider what happens if the temperature is increased!

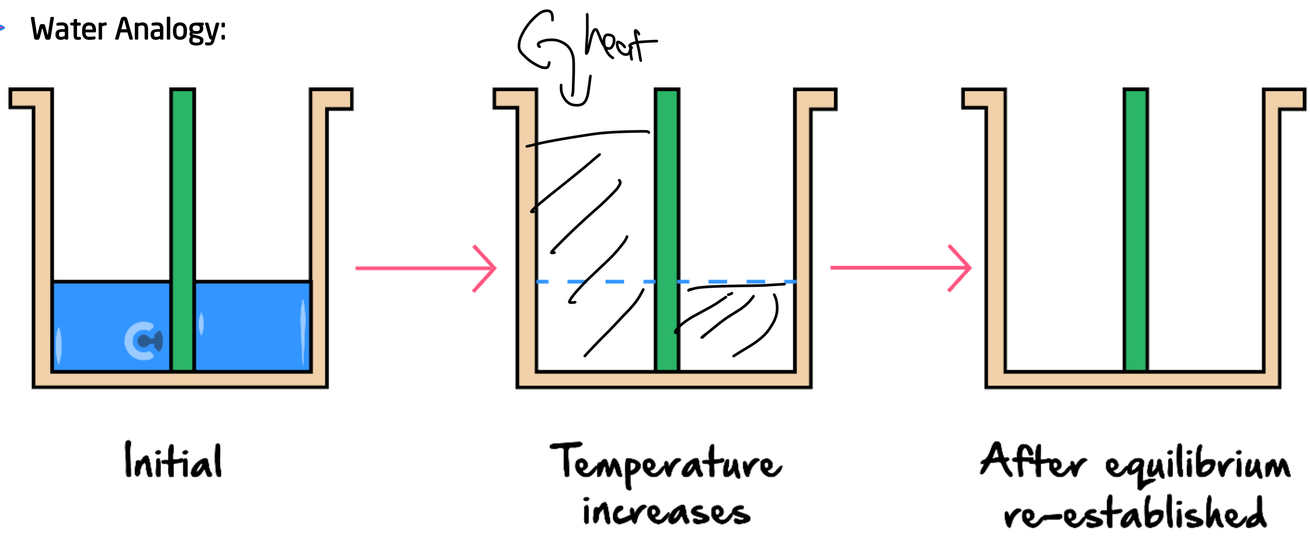
Exploration: Temperature Increase-Endothermic Reaction

Water Analogy:

- Consider an **endothermic** reaction:

$$\uparrow \text{heat} + \mathbf{A + B \rightleftharpoons C + D} \qquad \Delta \mathbf{H > 0}$$

- Endothermic reactions: [absorb] / [release] heat
- Heat in equation: (Label Above)
- Side of the equation heat is on: [left] / [right] side
- If **temperature is increased**, heat is: [added] / [removed]
- **Water Analogy:**



- Direction of shift: [forwards] / [reverse]

Le Châtelier's Principle:

- Direction of **endothermic** and **exothermic** reactions: *(Label Below)*

endo →

$$\mathbf{A + B \rightleftharpoons C + D} \qquad \mathbf{\Delta H > 0}$$

← exo

- **Initial change** made to system: ↑ temp.
- According to Le Châtelier's Principle, the system **partially opposes** the change by decreasing back down.
- Reaction which results in **temperature decrease:** [endothermic] / [exothermic]
- **Direction** of reaction: [forwards] / [reverse]

NOTE: Either method is acceptable, but when writing written responses, **Le Châtelier's Principle** must be used to **explain**, so you must definitely know how to use Le Châtelier's Principle!

Space for Personal Notes

Exploration: Temperature Decrease-Endothermic Reaction

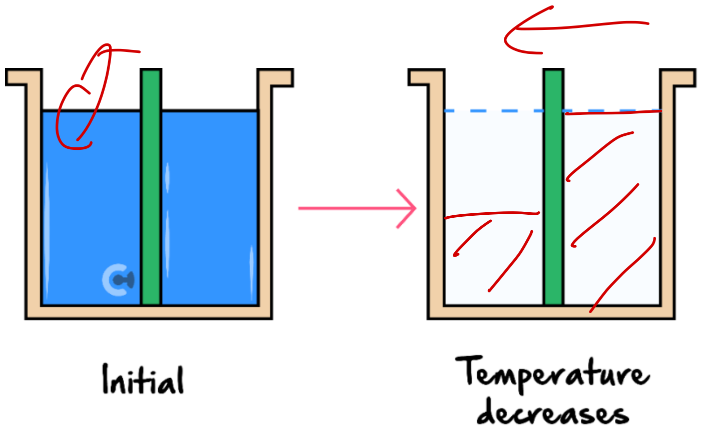
- Consider an **endothermic** reaction, whereby **temperature** is **decreased**.

Water Analogy:

- Heat in equation: (Label Below)

$$\text{heat} + A + B \rightleftharpoons C + D \qquad \Delta H > 0$$

- If **temperature is decreased**, heat is: [added] / [removed]
- Water Analogy:



- Direction of shift: [forwards] / [reverse]

Le Châtelier's Principle:

$$A + B \rightleftharpoons C + D \qquad \Delta H > 0$$

- **Scenario:** Temperature is decreased.
- Le Châtelier's Principle: [increases] / [decreases] temperature back
- Reaction which results in **temperature increase:** [endothermic] / [exothermic]
- **Direction** of reaction: [forwards] / [reverse]

How about exothermic reactions?

Exploration: Temperature Change-Exothermic Reaction

- Consider an **exothermic** reaction, whereby the **temperature is altered.**

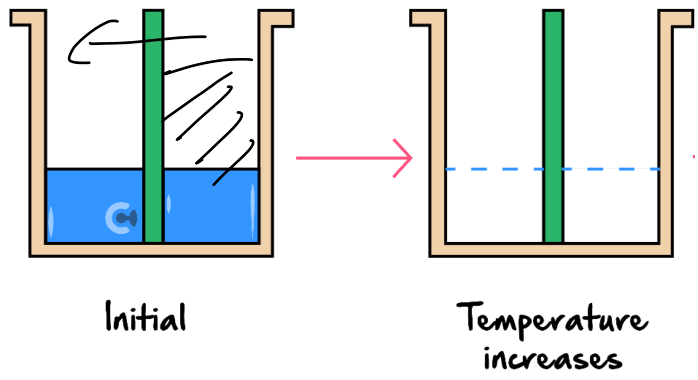
Water Analogy:

- Heat in equation: (Label Below)

$$\mathbf{A + B \rightleftharpoons C + D} \text{ +heat} \quad \mathbf{\Delta H < 0}$$

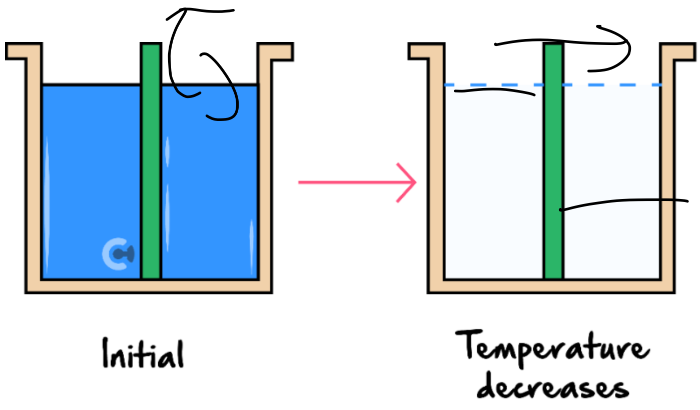
- Side of equation heat is on: [left] / [right] side

- If the temperature increases:
  - Water Analogy:



  - Direction of shift: [forwards] / [reverse]

- If the temperature decreases:
  - Water Analogy:



  - Direction of shift: [forwards] / [reverse]

Le Châtelier's Principle.

- Direction of **endothermic** and **exothermic** reactions: (Label Below)

$\Delta H = -200$

exo →

$$A + B \rightleftharpoons C + D \qquad \Delta H < 0$$

← endo

- If:

Temperature Increases	Temperature Decreases
Le Chatelier's Principle: [increases] / [decreases] temperature back	Le Chatelier's Principle: [increases] / [decreases] temperature back
Type of Reaction Favoured: [endothermic] / [exothermic]	Type of Reaction Favoured: [endothermic] / [exothermic]
Shifts [forwards] / [reverse]	**Shifts** [forwards] / [reverse]

Definition

Effect of Temperature on Equilibrium System

- Use either the water analogy or Le Châtelier's Principle to figure out the direction of shift!
  - Water Analogy – Add (heat) on the appropriate side of the equation.
  - Le Châtelier's Principle – Label forwards/reverse reactions as endothermic or exothermic.

Change to System	System's Respond (Le Châtelier's Effect)	Reaction Favoured
Increase in Temperature	[increase] / [decrease] temp	[endothermic] / [exothermic]
Decrease in Temperature	[increase] / [decrease] temp	[endothermic] / [exothermic]

Space for Personal Notes

Let's look at a question together!

Question 2 (2 marks) **Walkthrough.**

Consider the following reaction as gaseous methanol spontaneously decomposes as follows:

↑ heat + $CH_3OH(g) \rightleftharpoons CO(g) + 2H_2(g) \quad \Delta H = +91\ kJ/mol$

Draw a forwards or reverse arrow to indicate which direction the equilibrium system will shift if:

a. Temperature is increased.

heat →

↑T

→

b. Temperature is decreased.

Initial: ↓T

LCP: ↑T

exo

←

c. Explain your answer to **part a.** (2 marks)

1. Initial change: As temperature increases
2. LCP: Le Châtelier's Principle states system will partially oppose change by decreasing temperature
3. direction: to do so, the forwards endothermic reaction is favoured

<u>Sample Response</u>: **Temperature Change**

1. **Temperature** of the system is **increased/decreased**.
2. According to **Le Châtelier's Principle**, the system **partially opposes** the change by **increasing/decreasing the temperature**.
3. **Favours** the **forwards/reverse endothermic/exothermic** reaction.

Your turn!

Question 3

Consider the following reaction which forms hydrogen chlorine when hydrogen and chlorine gas are mixed:

$$Cl_2(g) + H_2(g) \rightleftharpoons 2HCl(g) \quad \Delta H = -185\ kJ/mol$$

Draw a forwards or reverse arrow to indicate which direction the equilibrium system will shift if:

a. Temperature is increased.

↑T, LCP ↓T – endo ←

b. Temperature is decreased.

→

Question 4

For the reaction:

↑T →

$$\uparrow \text{heat} + PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g) \quad \Delta H = +106\ kJ$$

Predict the effect on the position of equilibrium which results from the following changes by drawing a forward or reverse arrow.

a. Decreasing the volume.

↓V [conc]↑
LCP: ↓[conc] – less particles
←

b. Removing some PCl_5.

←

c. Injecting more Cl_2 gas.

←

d. Increasing the volume of the container.

→

e. Increasing the temperature. →	**f.** Addition of Ne gas. —

Question 5

Consider the following reaction which takes place during the Haber process:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92.2\ kJ/mol$$

Explain how the system would respond if the temperature of the whole system is increased.

~~AS temperatures s increased, Le Chatelier's Principle state that system will partially oppose the change by~~
decreasing temperature back down.

TO do so it favours the reverse endothermic reaction.

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Question 6 Additional Question.

Inspired from VCAA Chemistry Exam 2016
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2016/2016chem-amd-w.pdf#page=15

A team of chemists was investigating the following equilibrium reaction.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H \text{ is negative.}$$

Hydrogen gas, H_2, and iodine gas, I_2, were injected into a sealed container and allowed to reach equilibrium.

The effect of the following changes on the amount of HI was measured:

1. More H_2 gas was injected into the container at a constant temperature and volume.
2. The temperature of the gases was decreased at a constant volume.
3. Some argon gas, Ar, was injected into the container at a constant temperature and volume.
4. The volume of the container was decreased at a constant temperature.

Which change(s) would have resulted in the formation of a greater amount, in mol, of HI?

A. 1 and 2 only.

B. 1, 2 and 4 only.

C. 3 only.

D. 1 and 4 only.

Question 7 Additional Question.

Consider the following equilibrium:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -ve$$

Which of the following will cause this equilibrium to shift to the right?

A. Adding a catalyst.

B. Removing some SO_2.

C. Increasing the volume.

D. Decreasing the temperature.

Sub-Section: Unknown Enthalpy or Number of Particles

Context

- Sometimes, the question deliberately **does not provide** the change in enthalpy (ΔH) of the system, or it does not provide the number of particles in the system.

Unknown Enthalpy or Number of Particles

- For these types of questions, be sure to:

1. Use **Le Châtelier's Principle** to derive how the system **would respond.** (e.g. favouring the endothermic/exothermic reaction, favouring the side with more/less particles.)
2. Figure out the **direction reaction shifted** using **evidence** from the question.
3. **Equate** how the **system would respond** to which **direction** it shifts.

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Let's have a look at a question together!

Question 8 Walkthrough.

The following equilibrium system is shown. However, the sign of the change in enthalpy is unknown. The coefficient of C is also unknown.

$$A(g) + 2B(g) \rightleftharpoons xC(g)$$

a. When temperature is decreased, the concentration of A is seen to increase.

State whether the forward reaction is endothermic or exothermic. Justify your reasoning.

As ↓T, LCP: ↑T exothermic.
As c(A)↑, reverse reaction was favoured.
∴ exothermic is reverse
∴ forwards is endothermic

b. The coefficient, 'x' is known to have a value of either 2, 3, or 4. When the volume of the container is increased at a constant temperature, the amount of B present is seen to decrease.

Identify the value of the coefficient 'x', giving justification for your reasoning.

If V↑, split → favour side w/ more particles.
As n(B)↓, reaction went forward overall.
∴ RHS has more particles. ∴ x=4

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Your turn!

Question 9

The following equilibrium system is shown. ~~However, the sign of the change in enthalpy is unknown.~~ The coefficient of A is also unknown.

$$xA(g) + 2B(g) \rightleftharpoons 4C(g)$$ heat

a. When temperature is increased, the concentration of C is seen to decrease.

State whether the forward reaction is endothermic or exothermic. Justify your reasoning.

exothermic

As concentration of C decreases, C is used up, meaning the reverse reaction was favoured. As temperatures s increased, LCP partially opposes by decreasing temperature, favouring the endothermic reaction.
Therefore, the reverse reaction is endothermic, so forwards reaction is exothermic

b. The coefficient, 'x' is known to have a value of either 1, 2, or 3. When the volume of the container is decreased at a constant temperature, the amount of C present is seen to increase.

Identify the value of the coefficient 'x', giving justification for your reasoning.

As volume is decreased, overall concentration increases, LCP states system partially opposes by decreasing overall concentration back down. To do so, system favours side with less particles.
As n(C) increases, it was being. formed, so forwards reaction was favoured
Therefore, RHS has less particles.
~~So the LHS has more particles, so the value of x is 3.~~

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Question 10 Additional Question.

A reaction at equilibrium is observed, and when the temperature is **decreased**, the concentration of **products decreases**.

What can be inferred about the reaction?

A. The forward reaction is exothermic.

B. The forward reaction is endothermic.

C. The reaction is unaffected by temperature changes.

D. The system remains at equilibrium.

Question 11 Additional Question.

A reaction is at equilibrium in a closed container. When the volume is **increased**, the system shifts to the left to re-establish equilibrium.

What can be inferred about the reaction?

A. The reactants side less more moles of gas.

B. The forward rate of reaction was greater than the reverse rate of reaction as the system re-established equilibrium.

C. From before the change to after the system re-establishes equilibrium, the concentration of the reactants is lower.

D. Temperature was increased.

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Sub-Section: Graphing

Exploration: Graphing Temperature Changes

- Consider the following equilibrium system.

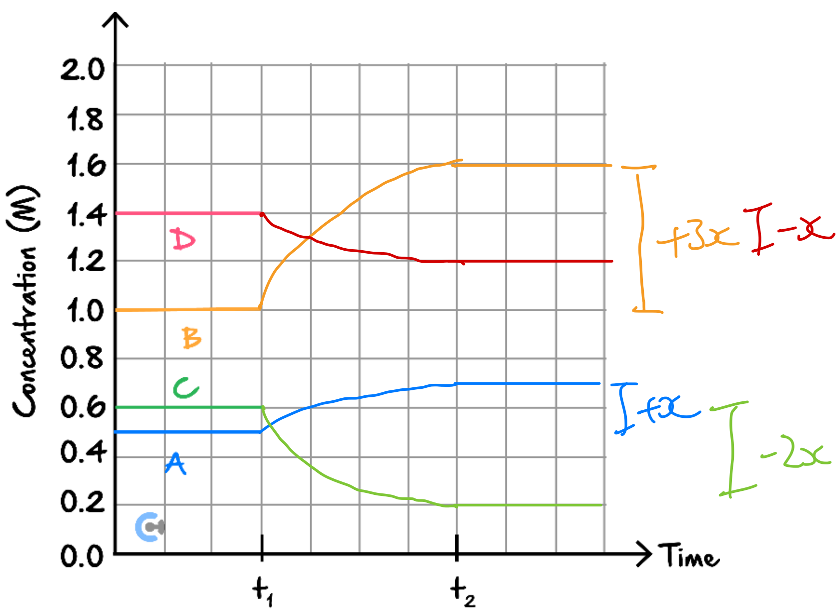
$$A + 3B \rightleftharpoons 2C + D \qquad \Delta H < 0$$

- **Scenario:** Temperature is increased.
- **Le Châtelier's Principle:** system partially opposes by: [increasing] / [decreasing] temperature
- **Favours:** [endothermic] / [exothermic] reaction
- **Direction:** [forwards] / [reverse]

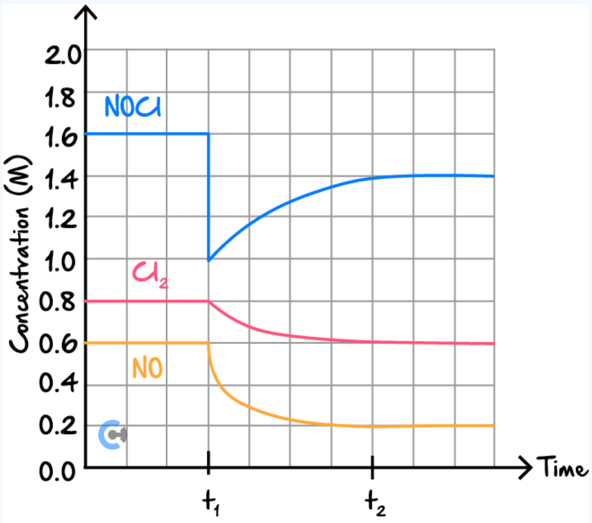
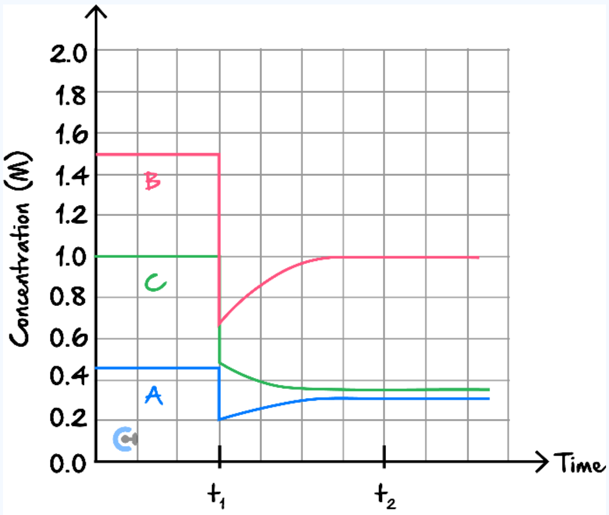
RICE Table

Reaction	A	3B	2C	D
c(initial)	0.500 M	1.000 M	0.600 M	1.400 M
c(change)	+0.200 M	+0.600 M	−0.400 M	−0.200 M
c(final)	0.700 M	1.600 M	0.200 M	1.200 M

Graph



- The temperature change occurs at t_1. Equilibrium is re-established at t_2.
- Do the changes in concentration align with their stoichiometric ratios? [yes] / [no]
- Is there an immediate change in concentration like adding/removing substances? [yes] / [no]

Removing NOCl	Increasing Volume
	

NOTE: A change in temperature has ___no___ immediate effect on the concentrations of any of the species.

What are the implications of no initial spike in concentration of the species?

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Sub-Section: Equilibrium Constant (K_c) and Reaction Quotient (Q_c)

Exploration: Equilibrium Constant (K_c) and Reaction Quotient (Q_c)

- **At the beginning:**
  - System at 25°C.
  - Equilibrium constant (K_c) value is $1.00\ M^{-1}$.

Reaction	A +	3B ⇌	2C +	D	Q_c
c(initial)	$0.500\ M$	$1.00\ M$	$0.600\ M$	$1.40\ M$	$1.00\ M^{-1}$
c(change)	$+0.200\ M$	$+0.600\ M$	$-0.400\ M$	$-0.200\ M$	N/A
c(final)	$0.700\ M$	$1.60\ M$	$0.200\ M$	$1.20\ M$	0.0167 M⁻¹

- **Reaction quotient value (Q_c)** at the end. *(Fill in the table above as well)*

$$Q_c = \frac{[C]^2[D]}{[A][B]^3} = \frac{0.200^2 \times 1.20}{0.700 \times 1.60^3} = 0.0167\ M^{-1}$$

- Is the system at equilibrium at the **beginning**? [yes] / [no]
- Is the system at equilibrium at the **end**? [yes] / [no]
- **Conclusion:** Kc value changes

$$K_c(initial) \rightarrow K_c(end)$$

1.00 M⁻¹ 0.0167 M⁻¹

Definition

Temperature Change

- **Graphing**: There [is] / [is no] initial spike in concentration for everything.
- Temperature is the only change which causes the equilibrium constant to change.

Why does the K_c value change?

Exploration: Why K_c Value Changes?

- **At the beginning:**
  - System at 25°C.
  - Equilibrium constant (K_c) value is $1.00\ M^{-1}$.

$$A + 3B \rightleftharpoons 2C + D \qquad \Delta H > 0$$

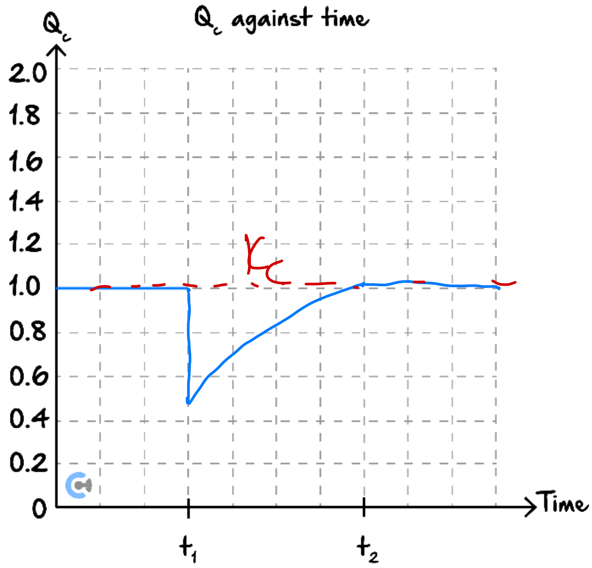
Scenario #1: A is Added

- Q_c **value** when A is added: [increases] / [decreases] / [no change]

$$Q_c = \frac{[C]^2[D]}{[A][B]^3}$$

- System Shift: [forwards] / [reverse]

Beginning	Immediately after change	End
$Q_c = 1.0\ M^{-1}$	$Q_c = 0.5\ M^{-1}$	$Q_c = 1.0\ M^{-1}$



- When **substances are added/removed**, the Q_c **changes suddenly**, and **returns to the same value**!

Scenario #2: Temperature Increases (Heat Added)

$$A + 3B \rightleftharpoons 2C + D \qquad \Delta H > 0$$

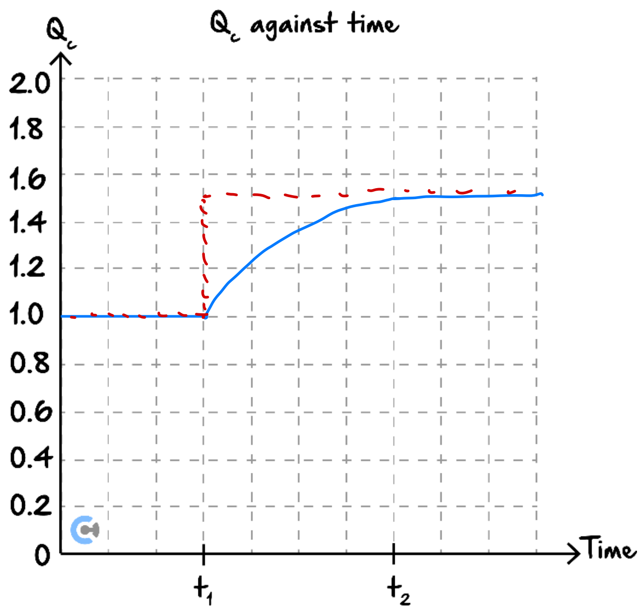
- **Q_c value** when heat is added: (**Hint**: is heat in the Q_c expression?)

$$Q_c = \frac{[C]^2[D]}{[A][B]^3}$$

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

- How does the system shift? [forwards] / [reverse]

Beginning	Immediately after change	End
$Q_c = 1.0\ M^{-1}$	$Q_c = 1.0\ M^{-1}$	$Q_c = 1.5\ M^{-1}$



- When the **temperature is changed**, the **Q_c does not change suddenly, as the expression does not contain heat!**

- This means it **doesn't return** to the same value, but changes to the **new K_c value**!

NOTE: While the reason why K_c value changes are not tested, how the K_c value is tested!

How does the K_c value change?

How K_c Value Changes?

$$A + 3B \rightleftharpoons 2C + D \qquad \Delta H < 0$$

Scenario #1: Reaction shifts forwards

$$K_c = \frac{[C]^2[D]}{[A][B]^3} \text{ or } K_c = \frac{[\text{Products}]}{[\text{Reactants}]}$$

- K_c value [increases] / [decreases].

Scenario #2: Reaction shifts reverse

$$K_c = \frac{[C]^2[D]}{[A][B]^3} \text{ or } K_c = \frac{[\text{Products}]}{[\text{Reactants}]}$$

- K_c value [increases] / [decreases].

TIP: As the reaction goes forward or reverse due to a temperature change, figure out what happens to the amount of **products**!

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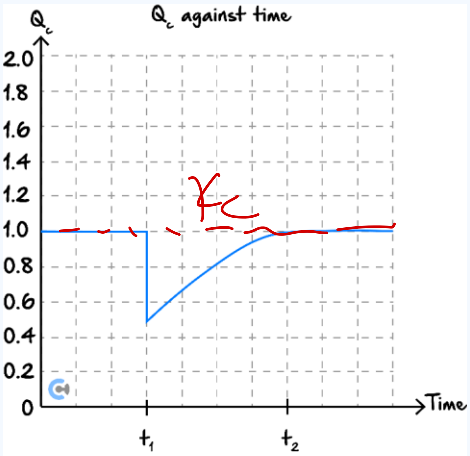
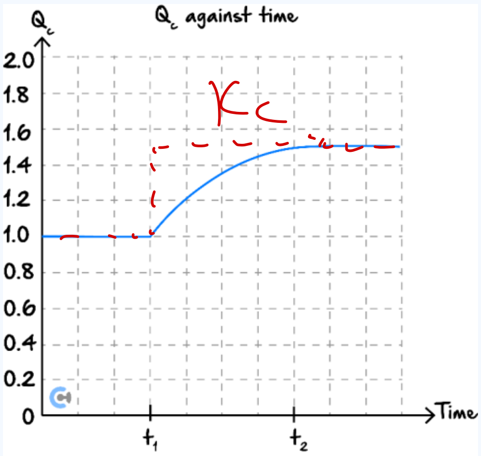
Definition

Temperature on K_c Value Change

- As heat [is] / [is not] in the Q_c expression, temperature change changes the K_c value overall.
- **Example:**

$$A + 3B \rightleftharpoons 2C + D \qquad \Delta H > 0$$

$$Q_c = \frac{[C]^2[D]}{[A][B]^3}$$

Adding A	Increasing Temperature
	
[Does] / [does not] initially spike.	[Does] / [does not] initially spike.
Comes [up] / [down] after.	Comes [up] / [down] after.
Overall: Down → Up	**Overall**: Up

- **Other Reasoning:** Temperature change is also the only change which changes the **energy** of the system, which thus changes the K_c value.
- During temperature change, if reaction shifts:

Forwards Overall	Reverse Overall
K_c value: [increases] / [remains constant] / [decreases]	K_c value: [increases] / [remains constant] / [decreases]

Let's have a look at a question together!

Question 12 Walkthrough.

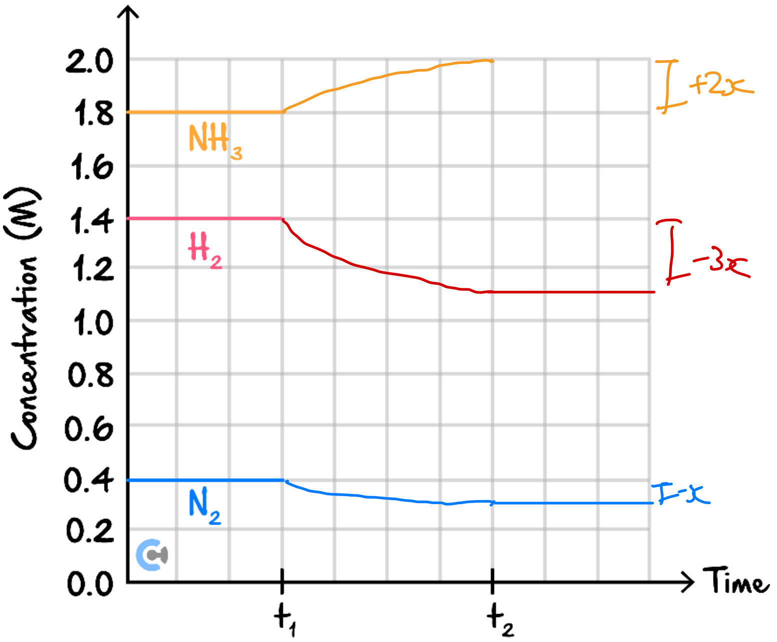
Consider the following reaction with nitrogen and hydrogen gas to form ammonia gas (NH_3):

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -93\ kJ/mol$$

+heat

The initial concentrations of the reactants and products at equilibrium before t_1 are shown in the graph below.

The temperature is then decreased at a constant volume at t_1, before equilibrium is re-established at t_2.



a. State how the system will react to this change.

shifts forwards overall.

b. Complete the graph above to show how the concentrations of each species will change.

$K_c = \frac{P}{R}$

c. Explain whether the equilibrium constant (K_c) is expected to increase, decrease or stay the same.

As temperature has changed, Kc value will change.
As forwards reaction favoured, more products (NH_3) is present at equilibrium, the Kc value will increase.

Your Turn!

Question 13

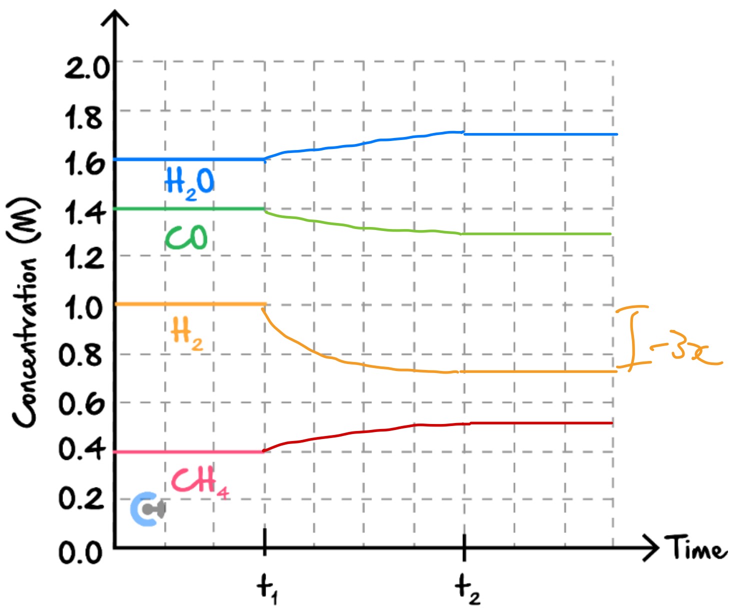
The following reaction takes place during steam reforming, whereby methane can be reacted with water vapour to produce hydrogen gas.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +206\ kJ/mol$$

The initial concentrations of the reactants and products at equilibrium before t_1 are shown in the graph below.

↓T → ↑T exo

The temperature is then decreased at a constant volume at t_1, before equilibrium is re-established at t_2.



a. State how the system will react to this change.

shifts reverse overall

b. Complete the graph above to show how the concentrations of each species will change.

c. Explain whether the equilibrium constant (K_c) is expected to increase, decrease or stay the same.

As temperature change has been made, Kc value will change.

As the reaction shifts reverse overall, amount of products (CO + H2) present at equilibrium is lower.

As ↓ $K_c = \frac{[CO][H_2]^3}{[CH_4][H_2O]}$ ↓, Kc will be lower (so it decreases).

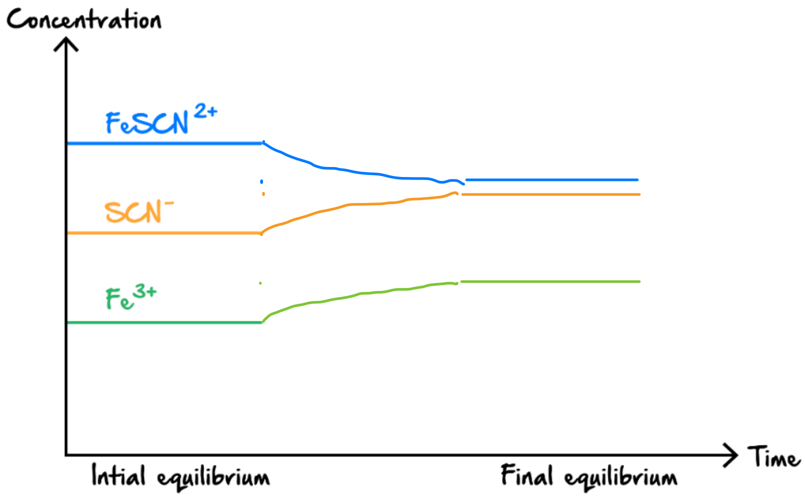
Question 14

In solution, pale yellow-coloured $Fe^{3+}(aq)$ and colourless $SCN^-(aq)$ form an equilibrium with $FeSCN^{2+}(aq)$. $FeSCN^{2+}(aq)$ is red in colour.

$$Fe^{3+}(aq) + SCN^-(aq) \rightleftharpoons FeSCN^{2+}(aq) \qquad \Delta H \text{ negative}$$

red colour

a. The graph below represents the initial concentrations of the ions at equilibrium. Sketch the changes that would be expected to occur to these concentrations if the temperature of the equilibrium mixture was increased to a new, constant value.



b. State what would happen to the red colour of the mixture as this occurs.

less intensely red

NOTE: As there are no gridlines provided, the labels $' + x'$ or $' - x'$ must be shown!

Question 15 Additional Question.

In the following reaction, what will happen to the concentration of H_2 if the temperature is decreased?

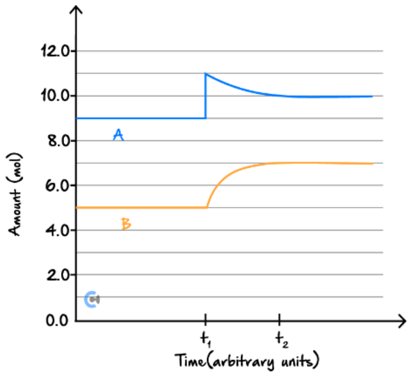
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = +22\ kJ/mol$$

increases

Section C: Graphical Analysis

Context

- What if we are given the equilibrium graph instead, and we need to **derive the change**?



Let's summarise the differences we see in the graphs first!

Exploration: Graphs for Each Change

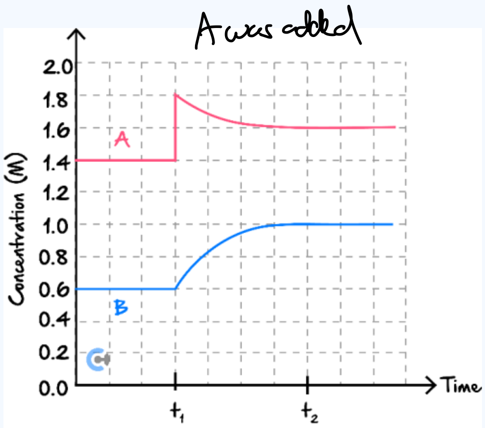
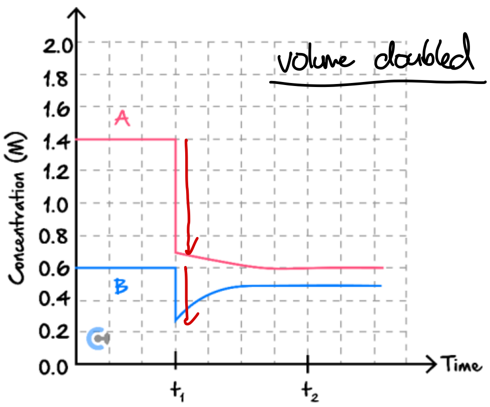
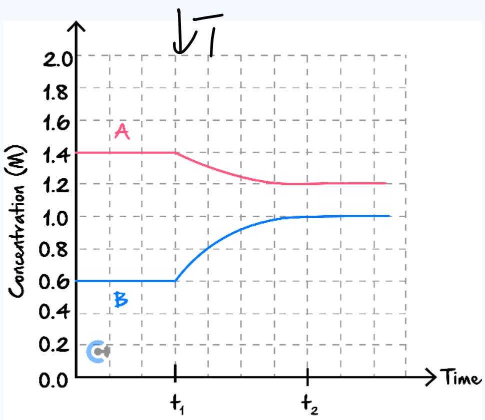
Change to System	Effect of Initial Change on Graph	Le Châtelier's Effect on Graph	K_c Value
Addition/Removal of Species	only one species have a **sudden change** in concentration.	[equilibrium shifts] / [equilibrium stays constant]	[changes]/ [stay constant]
Change in Volume/Pressure	all species have a **sudden change** in concentration.	[equilibrium shifts] / [equilibrium stays constant]	[changes]/ [stay constant]
Change in Volume/Pressure with the same number of reactants and products	all species have a **sudden change** in concentration.	[equilibrium shifts] / [equilibrium stays constant]	[changes]/ [stay constant]
Change in Temperature	no species have a **sudden change** in concentration.	[equilibrium shifts] / [equilibrium stays constant]	[changes]/ [stay constant]

Definition

Graphs for Each Equilibrium Change

- If the following equation is examined:

$$A \rightleftharpoons 2B \text{ + heat } \Delta H < 0$$

Change	Graph
Scenario: Sudden change in the concentration of **only one** of the species **Change Made**: An addition/removal of that species.	
Scenario: Sudden change in the concentration of **only all** of the species **Change Made**: volume change.	
Scenario: Sudden change in the concentration of **none** of the species **Change Made**: A temperature change.	

Let's look at a question together!

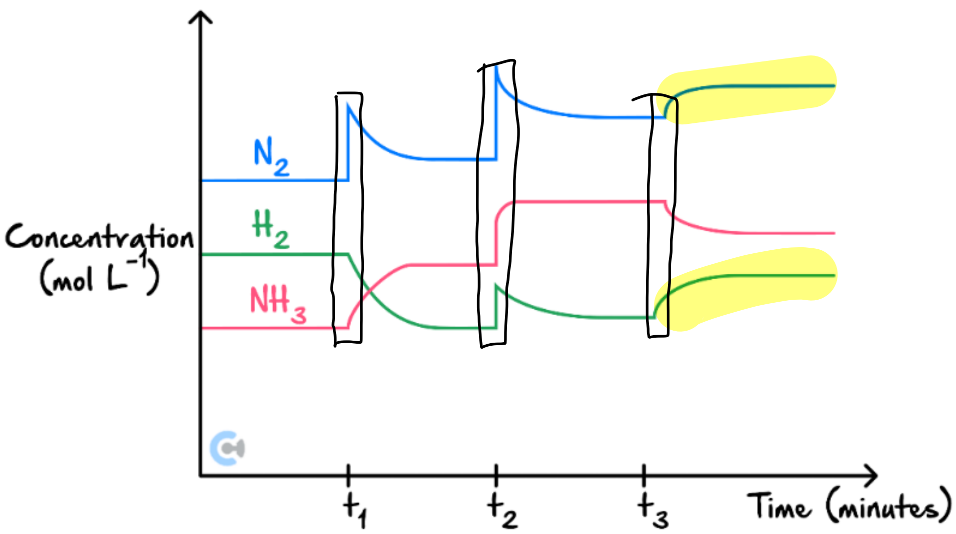
Question 16 Walkthrough.

Ammonia can be formed by the following equation:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92.2\ kJ/mol$$

+heat

The following graph represents the concentration of the reactants and products over time, where changes were made to the system over time.



Identify a change that could've been made to the system at each of the following times.

a. t_1

N₂ was added

b. t_2

Volume decrease

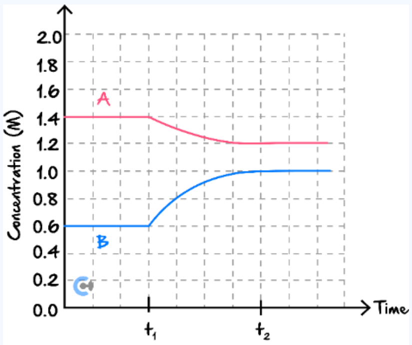
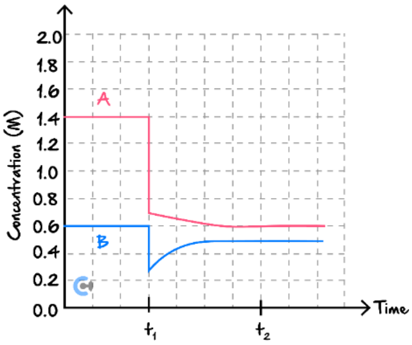
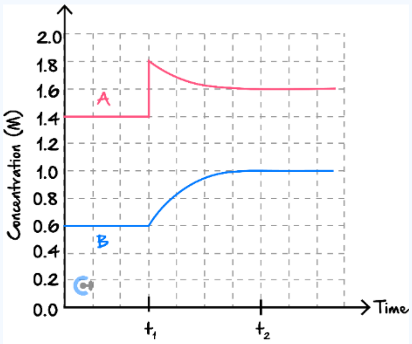
c. t_3

As [reactants] ↑, reverse was favoured (endo), system oppose change by ↓T
∴ original is ↑T.

NOTE: For temperature changes, based on the direction the system shifts, we can derive whether a temperature increase or decrease was made!

Recall!

Active Recall: What change could've been made in each of the following circumstances?

Graph	Change
	[Addition or removal of species] / [volume/pressure change] / [temperature change].
	[Addition or removal of species] / [volume/pressure change] / [temperature change].
	[Addition or removal of species] / [volume/pressure change] / [temperature change].

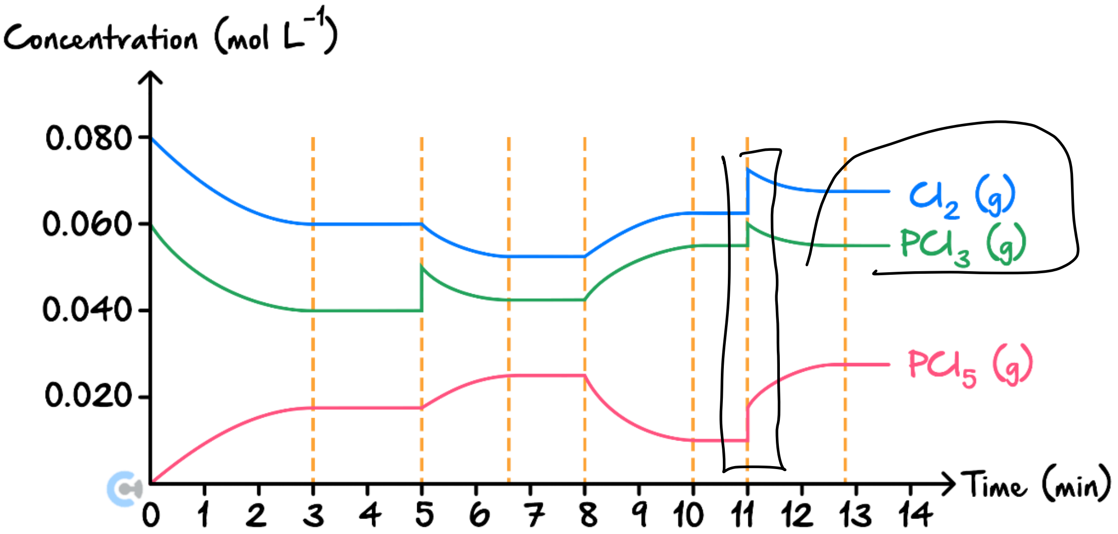
Your Turn!

Question 17

Phosphorous pentachloride, PCl_5, decomposes according to the following equation:

heat + $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g) \qquad \Delta H = +87.9\ kJ/mol$

The following graph represents the concentration of the reactants and products over time, where changes were made to the system over time.



Identify a change that could've been made to the system at each of the following times giving ~~justification for your reasoning with reference to Le Châtelier's Principle.~~

a. $t = 5$

PCl3 was added

b. $t = 8$

T↑

c. $t = 11$

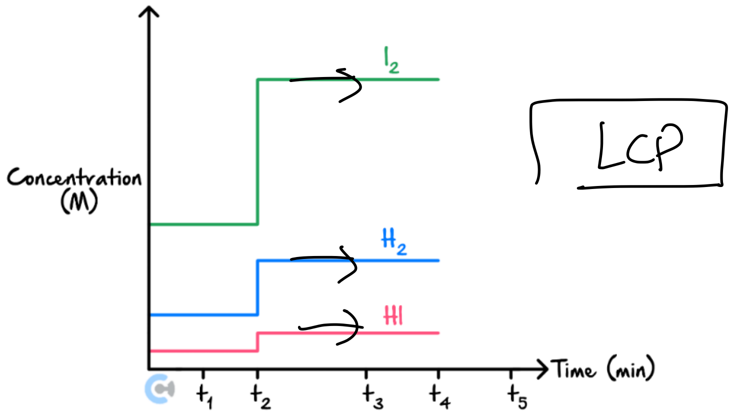
volume decreases.

Question 18

Hydrogen, H_2, and iodine, I_2, react to form hydrogen iodide, HI.

$$\frac{1}{2}H_2(g) + \frac{1}{2}I_2(g) \rightleftharpoons HI(g) \qquad \Delta H = +25.9\ kJ\ mol^{-1}$$

The graph below shows the concentrations of H_2, I_2 and HI in a sealed container. One change was made to the equilibrium system at time t_2 .



a. Identify what change was made to the system.

volume halved

b. A separate change is made to the same system, whereby the equilibrium constant is seen to increase. Explain what change has occurred.

As Kc value has changed, temperature must have been changed. As Kc value increased, there are more products present currently compared to before, meaning the reaction has shifted forwards (endothermic). As such, the system decreased temperature, meaning the original change was an increase in temperature.

NOTE: It is not enough to say 'volume is decreased', if it is clear that it has been doubled or halved, state that! VCAA is strict about this!

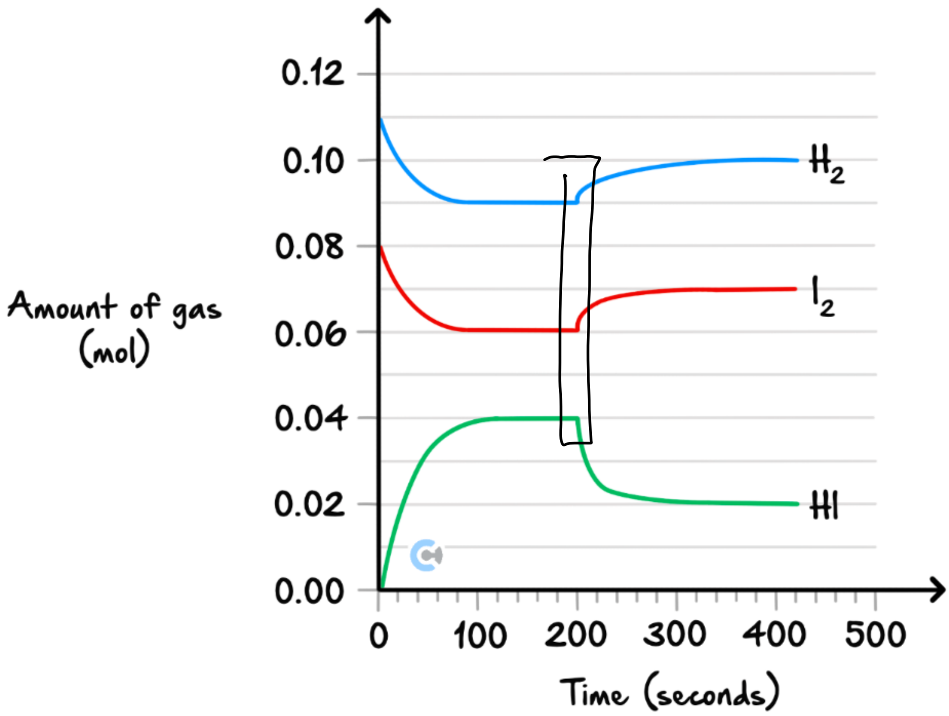
ALSO NOTE: **Temperature** is the **only factor** which changes the K_c value!

Question 19

The gases H_2 and I_2 react according to the following chemical equation:

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

An experiment was conducted by placing set amounts of the reactant gases in a sealed vessel and allowing the system to reach equilibrium, as shown in the graph below.



a. What change was made to the system at 200 seconds? (1 mark)

A. More reactant gases were added.

B. Some HI gas was removed.

C. The temperature was altered.

D. A catalyst for the forward reaction was introduced.

b. How many values of the equilibrium constant for the reaction are evident from 0 to 400 seconds? (1 mark)

A. 1

B. 2

C. 3

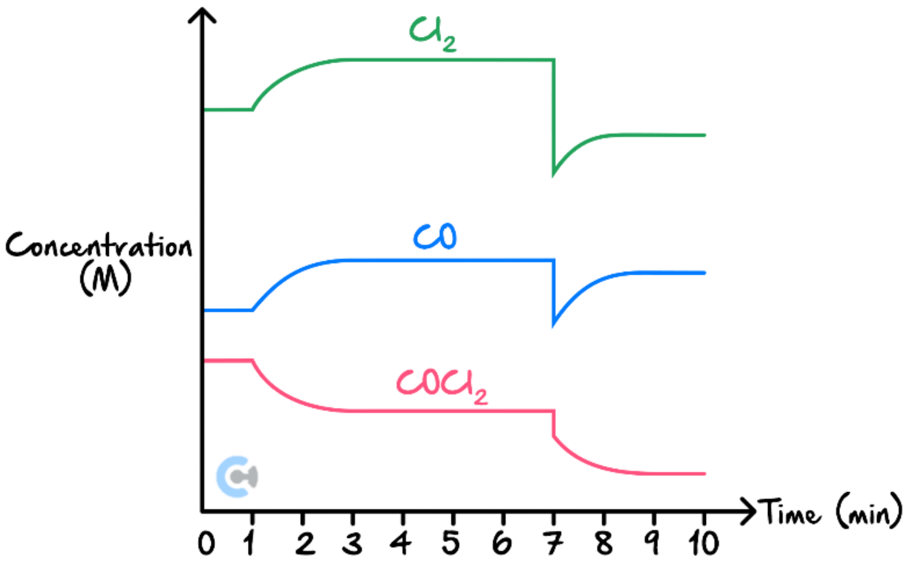
D. More than 3.

Question 20 Additional Question.

The following equation represents the reaction between chlorine gas, Cl_2, and carbon monoxide gas, CO.

$$Cl_2(g) + CO(g) \rightleftharpoons COCl_2(g) \qquad \Delta H = -108\ kJ\ mol^{-1}$$

The concentration-time graph below represents changes to the system.



Which of the following identifies the changes to the system that took place at 1 minute and at 7 minutes?

	1 minute	7 minutes
A.	Increase in temperature.	Increase in volume.
B.	Decrease in temperature.	Decrease in volume.
C.	Decrease in temperature.	Increase in volume.
D.	Increase in temperature.	Decrease in volume.

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Section D: Rate -Time Graphs

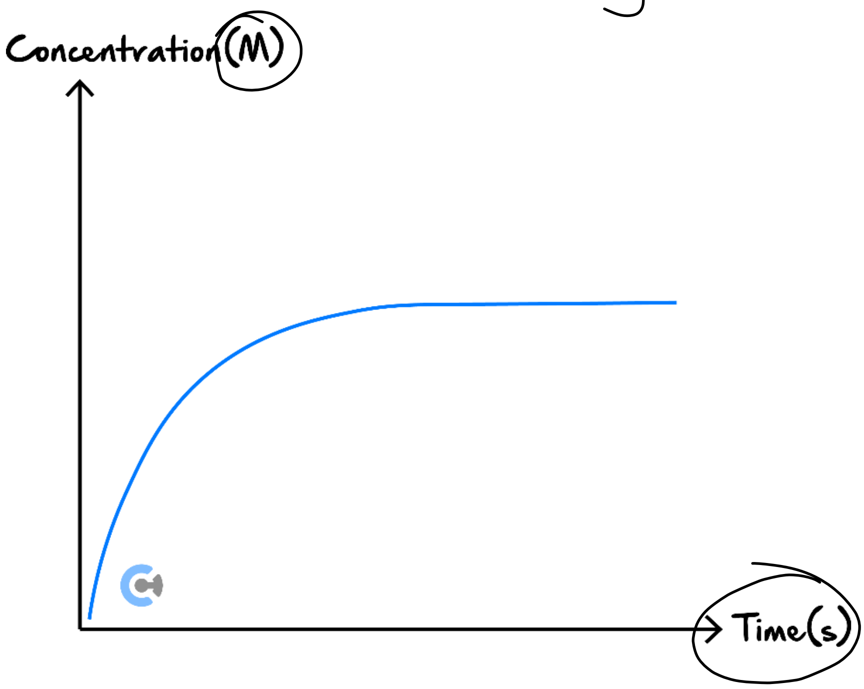
Sub-Section: Rate -Time Graphs

Active Recall: At equilibrium, how do the forward and reverse rates of reaction compare?

Forwards Rate = **Backwards Rate**

Units for Rate of Reaction

- **Rate of reaction** indicated in a concentration-time graph via gradient.



- **Gradient calculated by:** $\frac{rise}{run}$.
- **Units for rate:** $M\,s^{-1}$, $mol\,L^{-1}\,s^{-1}$

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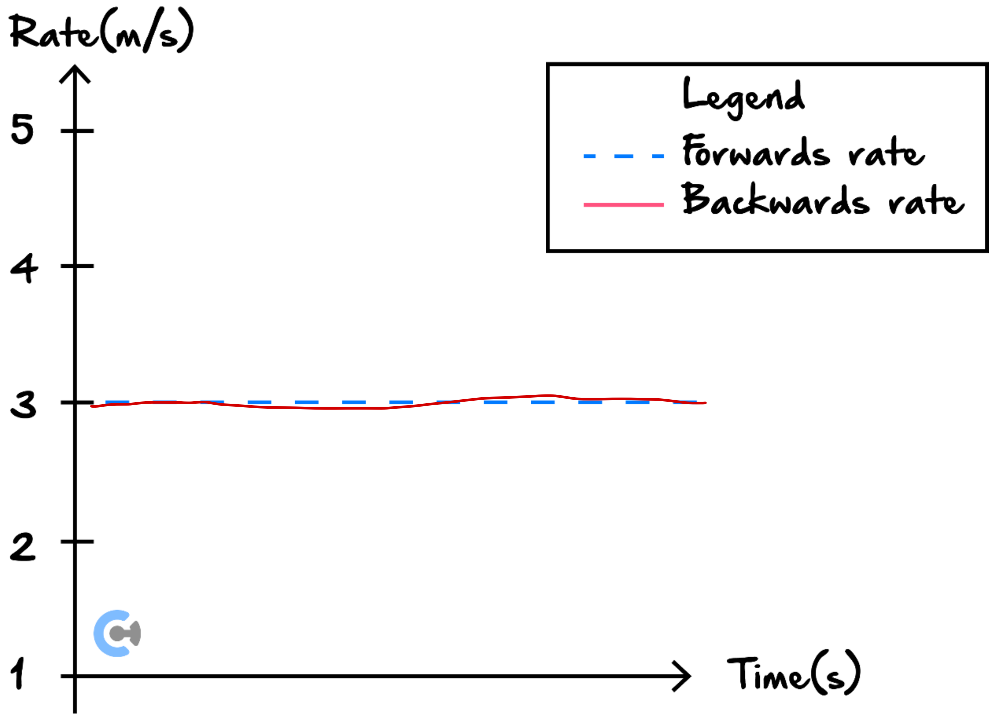
Sub-Section: At Equilibrium

Context

- So far, we've been looking at concentration-time graphs or amount-time graphs, now let's have a look at **rate-time graphs**!

Exploration: Time Graph at Equilibrium

- Consider the following system which is currently at equilibrium:
- Forwards vs Reverse Rate: [Forwards Rate = Reverse Rate] / [Forwards Rate ≠ Reverse Rate]
- **Graph:**



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Sub-Section: Not at Equilibrium

Exploration: Not at equilibrium

- Consider the following equilibrium system which **is not at equilibrium**.

$$\mathbf{A + B \rightleftharpoons C \quad \Delta H < 0}$$

- Forwards vs Reverse Rate: [Forwards Rate = Reverse Rate] / [Forwards Rate ≠ Reverse Rate]

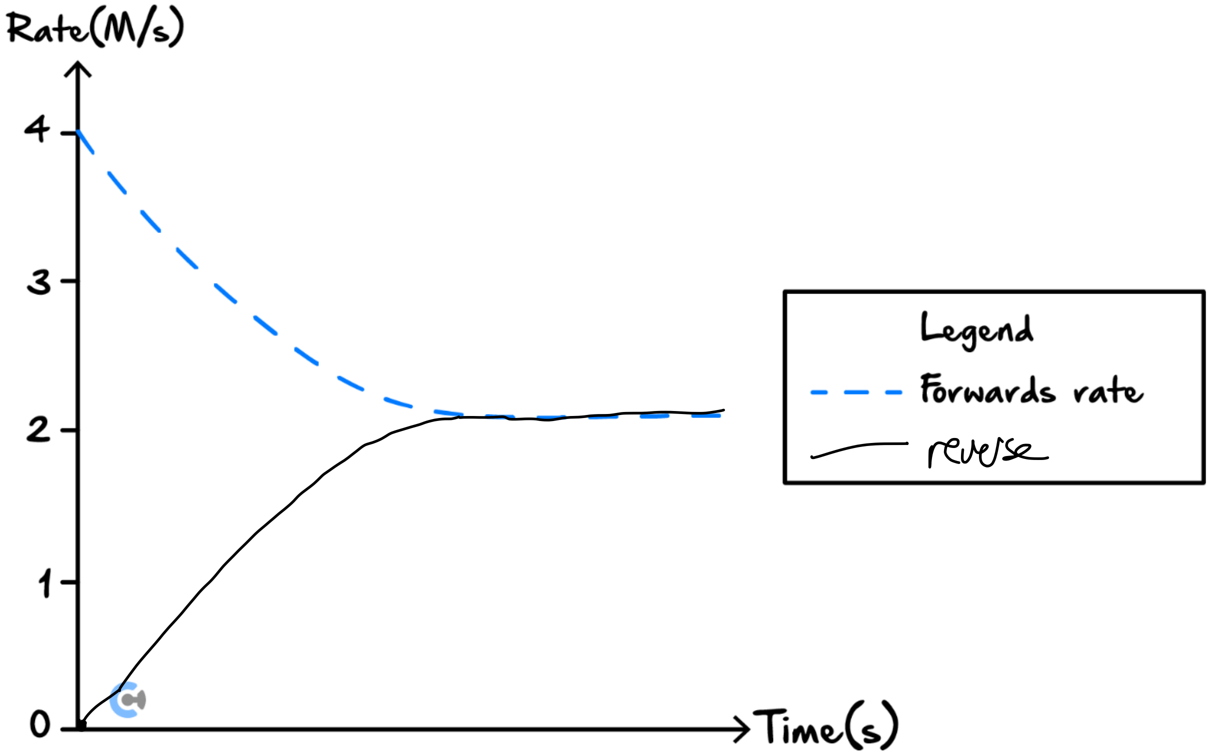
- Consider the following, where A and B are added to an **initially empty vessel**.

Reaction	A +	2B ⇌	C
c(initial)	1.00 M	1.00 M	0.00 M

- Direction to re-establish equilibrium: [forwards] / [reverse]

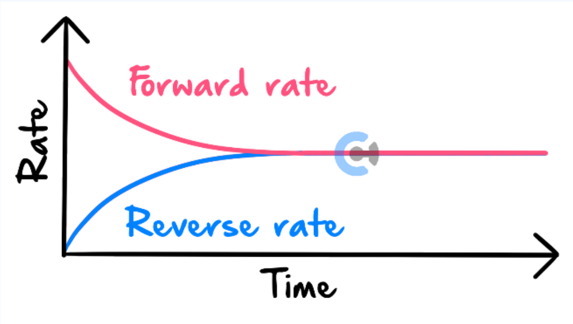
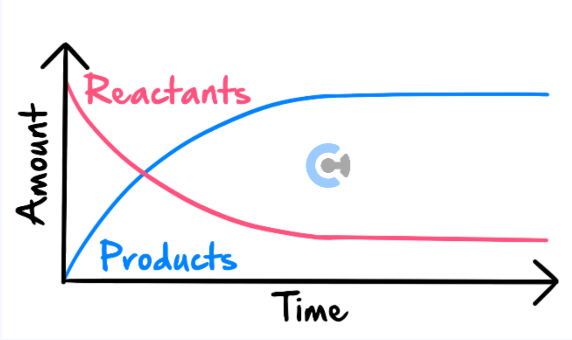
Forwards Rate > Reverse Rate

- Graph:



Definition

Rate-Time vs Concentration-Time Graphs

Rate-Time Graph	Concentration-Time Graph
	
Equilibrium established when: forwards rate $=$ reverse rate.	**Equilibrium established when:** Concentration of everything is constant

NOTE: This stuff is a bit tricky, and will cover if it's on your SAC!

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Sub-Section: Effect of Catalyst

Active Recall: What does a catalyst do to the rate of reaction?

↑ rate

REMINDER: Don't forget a catalyst increases the rate of reaction by providing an alternative reaction pathway with a lower activation energy.

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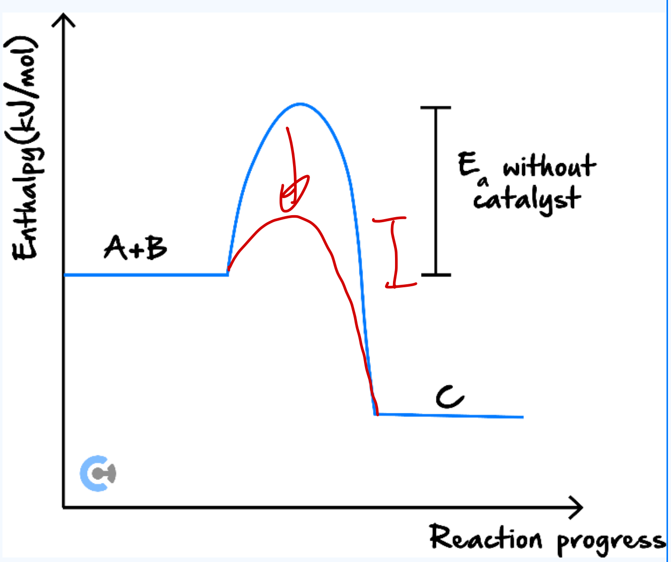
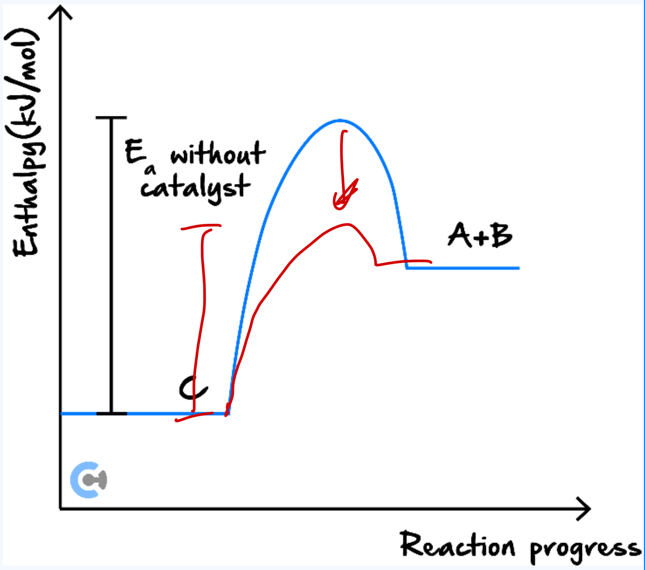
Exploration: Effect of Catalyst on Equilibrium System

$$2A + B \rightleftharpoons C \quad \Delta H < 0$$

- When a catalyst is added:

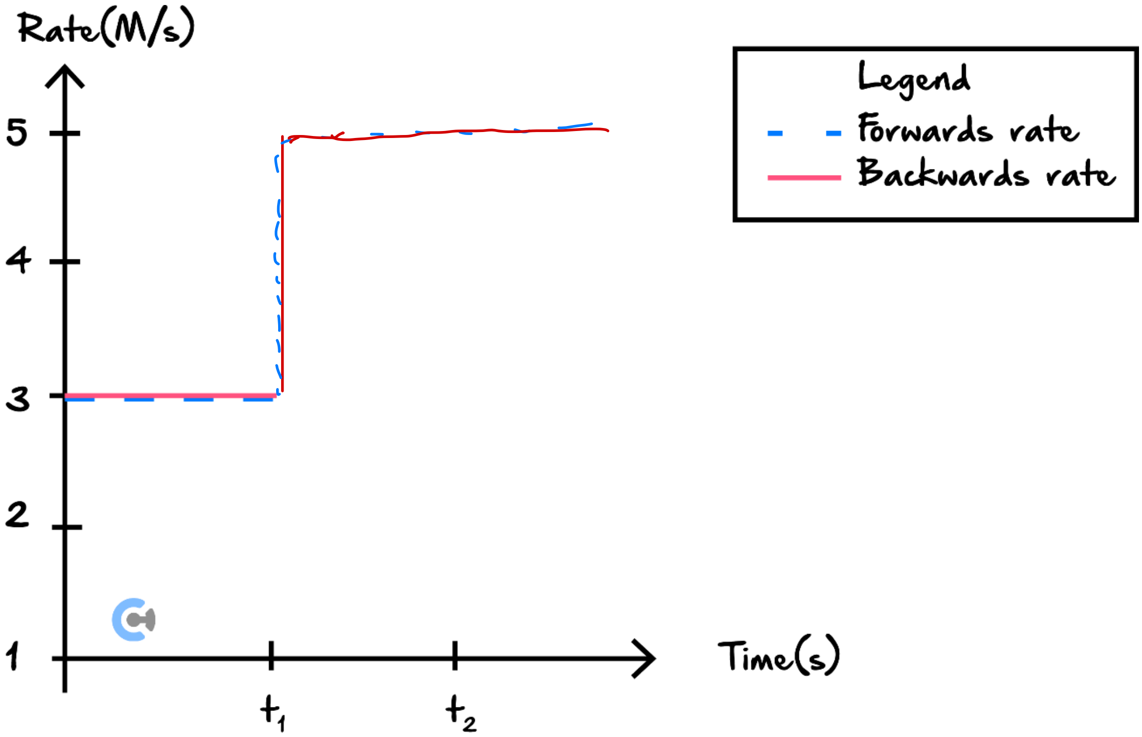
<table>
<tr><th>Forwards Reaction</th><th>Reverse Reaction</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Forwards Activation Energy:
[increases] / [decreases] / [stays same]</td><td>Reverse Activation Energy:
[increases] / [decreases] / [stays same]</td></tr>
<tr><td>Forwards Rate of Reaction:
[increases] / [decreases] / [stays same]</td><td>Reverse Rate of Reaction:
[increases] / [decreases] / [stays same]</td></tr>
</table>

- **Result**: Both the forward and reverse rate of reaction increases by the Same amount
- **Scenario**: System is at equilibrium, and then the catalyst is added:

Initial	End
Forwards rate = reverse rate	Forwards rate = reverse rate

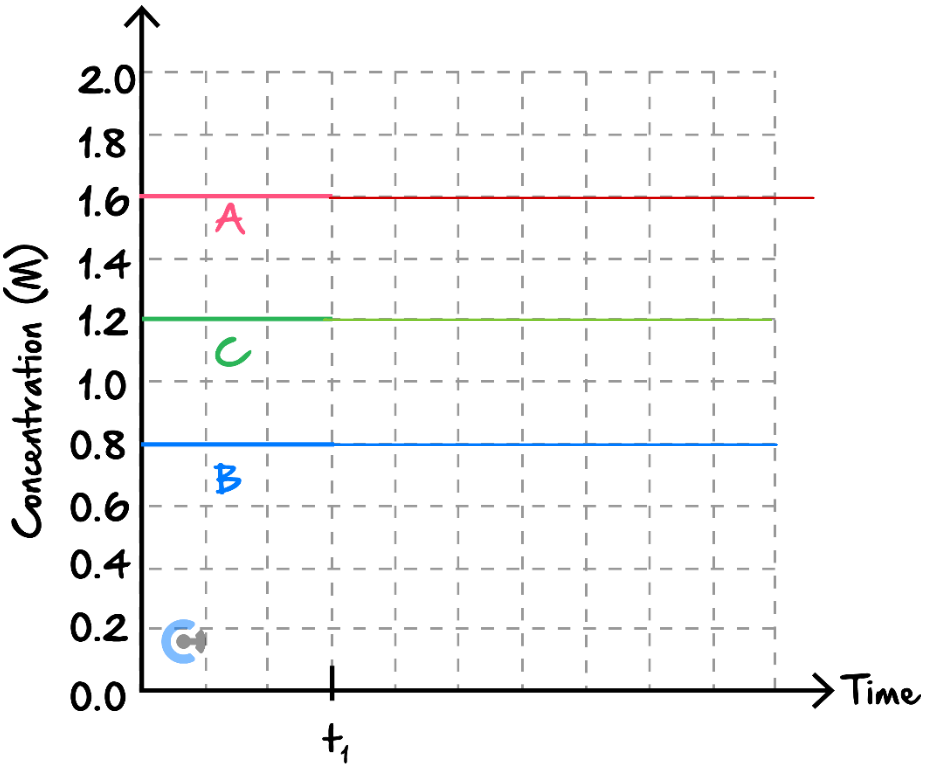
- **Direction Shift**: [forwards] / [reverse] / [no change]

- Rate-Time Graph:



System goes: [forwards] / [reverse] / [no change]

- Concentration-Time Graph:

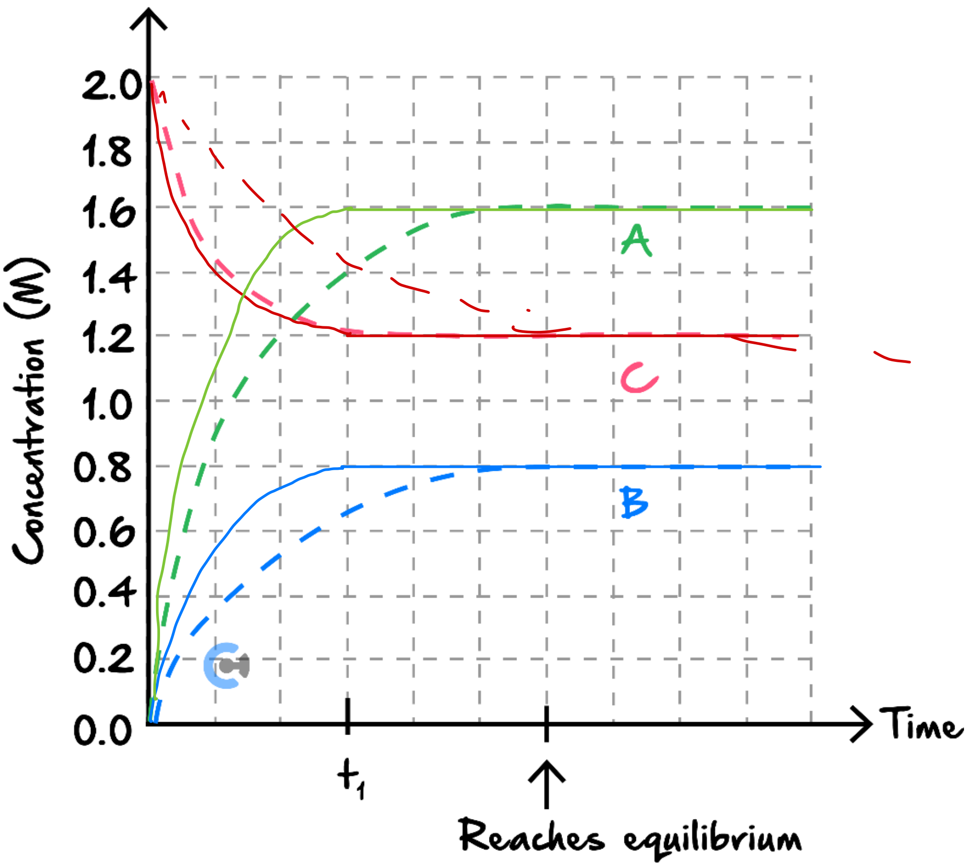


How about systems which are about to reach equilibrium?

Exploration: Effect of Catalyst on a System Reaching Equilibrium

$$2A + B \rightleftharpoons C \quad \Delta H < 0$$

- Consider the following system which is about to reach equilibrium:
  - **Dotted Lines**: Original.
  - **Solid Lines**: With catalyst added at the beginning. *(Label Below)*



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Definition

Effect of Catalyst on Equilibrium System

- **System Shifts**: [forwards] / [reverse] / [no change].
- **Reasoning**: Both forward and reverse rates of reaction are faster by the same amount.
- **If the system is reaching equilibrium,** adding a catalyst results in equilibrium reached quicker.
- **Final Concentration of Species:** Remains same.

Your Turn!

Question 21

How does the addition of a catalyst affect a reversible reaction?

A. It increases the activation energy of the forward reaction only.

B. It decreases the activation energy of the forward reaction only.

C. It increases the activation energy of both the forward and reverse reactions.

D. It decreases the activation energy of both the forward and reverse reactions.

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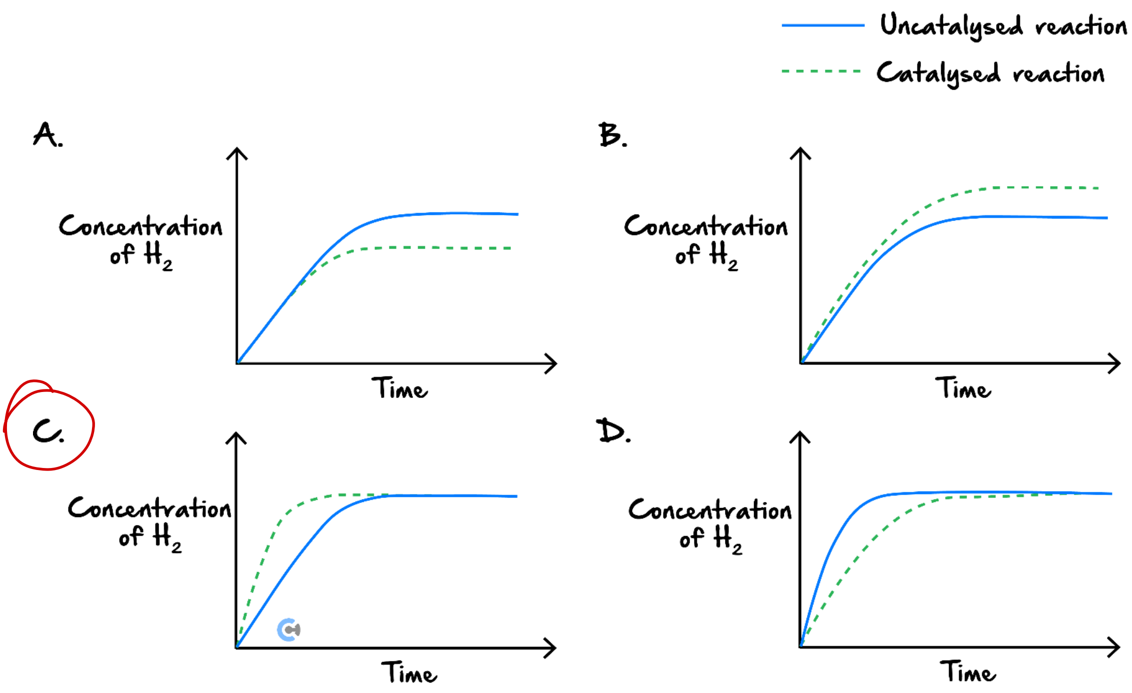
Question 22

Inspired from VCAA Chemistry Exam 2012
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2012/2012chem2-w.pdf#page=7

In trials, the reaction is carried out with and without a catalyst in the sealed container. All other conditions are unchanged. The graph shows the change in hydrogen concentration with time.

Which graph is correct?



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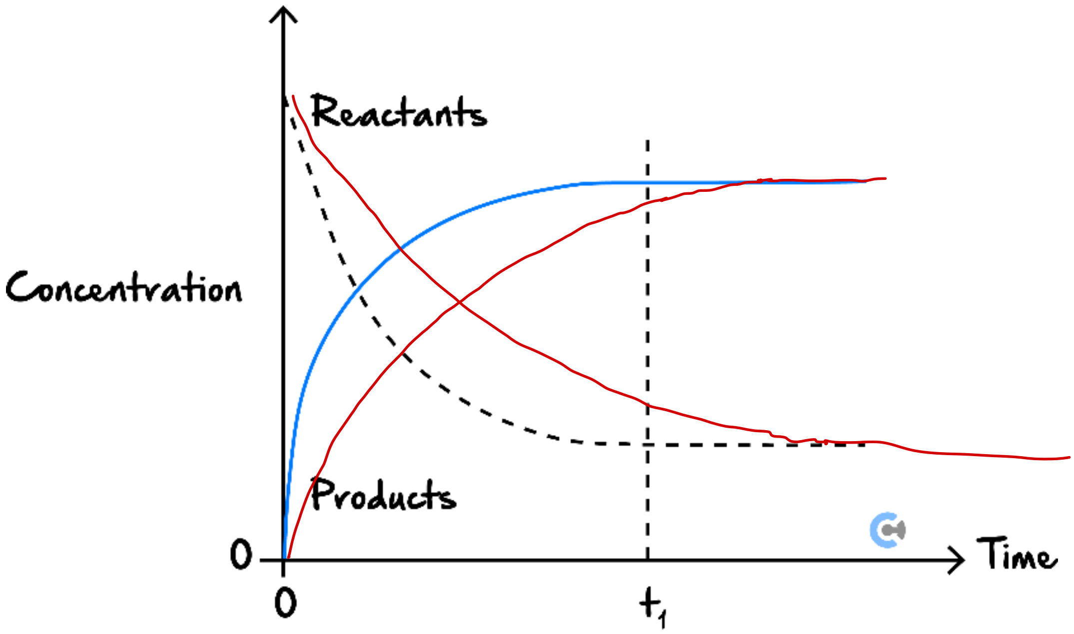
Question 23

Inspired from VCAA Chemistry Exam 2022
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2022/2022chem-w.pdf#page=19

The concentration versus time graph for a different reaction is shown below. This reaction takes place with a catalyst. Equilibrium is reached at the time t_1.



The reaction is repeated without a catalyst.

On the concentration versus time graph above, sketch the expected curve for the products when the reaction is performed without a catalyst.

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Question 24 Additional Question.

Inspired from VCAA Chemistry Exam 1 2005
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/05chem1.pdf#page=2

Sulphur dioxide and oxygen are mixed to form sulphur trioxide according to:

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

Which one of the following best describes the effect of adding the catalyst V_2O_5 to the mixture?

	Equilibrium yield	Reaction rate
A.	Increases	Increases
B.	No change	Increases
C.	No change	No change
D.	Increases	No change

Space for Personal Notes

Section E: Rate-Yield Conflict

Sub-Section: Temperature Rate - Yield Conflict

Context

- Ammonia is produced industrially through the 'Haber Process.'

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92\ kJ/mol$$

- In the industry, NH_3 is produced as quickly and efficiently as possible.
- Main Factors Considered:
  - Rates of reaction.
  - Equilibrium Yield.

How can we improve the rate of reaction?

Discussion: What are some ways in which we can increase the rate of reaction for the production of NH_3?

- catalyst
- ↑ temperature
- ↑ pressure

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How can we improve the equilibrium yield?

Discussion: What are some ways in which we can increase our equilibrium yield of ammonia, NH_3?

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92\ kJ/mol$$

- ↓ temperature
- Add reactants
- Removing products
- ↑ pressure

Let's just look at temperature and pressure!

Exploration: Maximising Rate and Yield

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92\ kJ/mol$$

- Conditions to maximise rate & yield:

Condition	Pressure	Temperature
Maximise Rate	[high] / [low] pressure	[high] / [low] temperature
Maximise Yield	[high] / [low] pressure	[high] / [low] temperature
Overall Conditions Used	[high] / [low] pressure	????

- Temperature dilemma known as: Rate-yield conflict

Discussion: **Which is more important, rate or equilibrium yield?**

[neither] / [rate] / [yield] / [both]

NOTE: A high rate of reaction means products are produced substances faster!

ALSO NOTE: Equilibrium yield means more products are produced for the same amount of reactants.

What conditions are used in real life?

Exploration: Pressure & Temperature Conditions

Pressure

- As **high pressure** maximises both the rate of reaction and yield, a **high pressure** of $2500\ kPa$ is used! ($25 \times$ more than SLC.)

Temperature

- **Temperature conditions used:** [high] / [medium] / [low]
- A temperature of $300\text{-}500°C$ is used, so that neither yield nor temperature is sacrificed.

Other Conditions

- Should a **catalyst** be used to increase the rate of reaction? [yes] / [no]
- Are there any downsides to using a catalyst? [yes] / [no]
- Should **reactants be constantly added** to force equilibrium yield to the right? [yes] / [no]
- Should **products be constantly removed** to force equilibrium yield to the right? [yes] / [no]

Space for Personal Notes

Exploration: Green Chemistry Principles

- When choosing correct operating conditions, which green chemistry principles should be considered?
  - **Atom economy:** [yes] / [no] ____________
  - **Catalysis:** [yes] / [no] ____________
  - **Design for degradation:** [yes] / [no] ____________
  - **Design for energy efficiency:** [yes] / [no] ____________
  - **Designing safer chemicals:** [yes] / [no] ____________
  - **Prevention of wastes:** [yes] / [no] ____________
  - **Use of renewable feedstocks:** [yes] / [no] ____________

Now let's consider the following scenario!

Exploration: Production of Chlorine Gas

- Chlorine gas is produced from NOCl:

$$\text{heat} + 2NOCl(g) \rightleftharpoons Cl_2(g) + 2NO(g) \quad \Delta H = +77\ kJ/mol$$

- **Scenario**: If the **temperature is increased:**

Rate of Reaction	Yield
[increases] / [decreases]	[increases] / [decreases]

- Is there a **rate-yield conflict** for this system? [yes] / [no]
- Why doesn't the rate-yield conflict apply to this system? endothermic

NOTE: The rate-yield conflict doesn't apply to all equilibrium reactions, but rather, it **depends on what type of reaction** it is.

Sub-Section: Pressure Rate-Yield Conflict

Exploration: Pressure Conditions

$$2NOCl(g) \rightleftharpoons Cl_2(g) + 2NO(g) \quad \Delta H = +77\ kJ/mol$$

Condition	Temperature	Pressure
Maximise Rate	[high] / [low] temperature	[high] / [low] pressure
Maximise Yield	[high] / [low] temperature	[high] / [low] pressure
Rate-Yield Conflict	[rate-yield conflict] / [no rate-yield conflict]	[rate-yield conflict] / [no rate-yield conflict]
Overall Conditions Used	[high] / [medium] / [low] temperature	[high] / [medium] / [low] pressure

Rate-Yield Conflict

- **For Temperature:**

Endothermic	Exothermic
Rate-yield conflict [arises] / [does not arise] when increasing temperature.	Rate-yield conflict [arises] / [does not arise] when increasing temperature.

- **Solution to Rate-Yield Conflict:**
  - Use moderate conditions of the factor with rate-yield conflict.
  - Add catalyst to increase rate.
  - Continuously add reactants and remove products to increase equilibrium yield.
- **Relevant Green Chemistry Principles**: "*Catalysis*", "*Design for Energy Efficiency*".
- **When doing Questions**: Treat rate and yield as completely separate things!

Let's have a look at a question together!

Question 25 Walkthrough.

Methanol can be produced from the reaction of carbon monoxide and hydrogen, according to the following equation:

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H = -90\ kJ\ mol^{-1}$$

a. Which set of conditions will produce the maximum yield of methanol?

A. Low pressure and low temperature.

B. Low pressure and high temperature.

C. High pressure and low temperature.

D. High pressure and high temperature.

b. Which set of conditions will result in the greatest rate of production of methanol?

A. Low pressure and low temperature.

B. Low pressure and high temperature.

C. High pressure and low temperature.

D. High pressure and high temperature.

Space for Personal Notes

Your turn!

Use the following information to answer the next two questions.

Steaming reforming is used to create hydrogen gas by reacting methane with water vapour, as shown in the equation below:

heat + $CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ $\Delta H = +206\ kJ\ mol^{-1}$

2 4

Question 26

Which set of conditions will produce the maximum yield of hydrogen gas?

A. Low pressure and low temperature.

B. Low pressure and high temperature.

C. High pressure and low temperature.

D. High pressure and high temperature.

Question 27

Which set of conditions will result in the greatest rate of production of hydrogen gas?

A. Low pressure and low temperature.

B. Low pressure and high temperature.

C. High pressure and low temperature.

D. High pressure and high temperature.

NOTE: High temperature and pressure are always favoured to maximise the rate of reaction!

Space for Personal Notes

Question 28

The following reaction is used to produce chlorine gas and water vapour from hydrogen chlorine.

$$4HCl(g) + O_2(g) \rightleftharpoons 2H_2O(g) + 2Cl_2(g) \quad \Delta H = -202\ kJ/mol$$

+heat

5 4

a. State the pressure conditions which will result in the maximum equilibrium yield of chlorine gas.

high pressure | high

yield rate

b. State the temperature conditions which will result in the maximum equilibrium yield of chlorine gas.

low temperature | high

c. Hence or otherwise, explain what overall temperature and pressure conditions should be used to produce chlorine gas with a high rate of reaction, and with a high equilibrium yield.

high pressure
moderate temperature as ↓T favours yield, but ↑T favours rate
so there is rate-yield conflict for temp.

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Try some more questions!

Question 29

Inspired from VCAA Chemistry Exam 2023
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2023/2023chemistry-w.pdf#page=6

The equation below shows the equilibrium reaction for the conversion of dinitrogen tetroxide, $N_2O_4(g)$, to nitrogen dioxide, $NO_2(g)$.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g) \qquad \Delta H = +58.0\ kJ\ mol^{-1}$$

Temperature is increased from 35°C to 80°C.

a. Identify the direction in which the system shifts overall.

forwards

b. Which of the following occurs to the rates of reactions? (1 mark)

	Rate of forward reaction	Rate of reverse reaction
A.	Increases	Decreases
B.	Decreases	Decreases
C.	Increases	Increases
D.	Decreases	Increases

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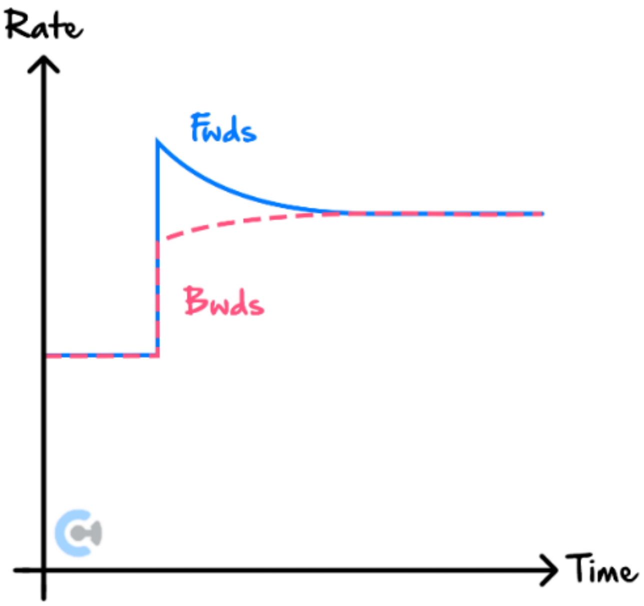
NOTE: Treat the rate of reaction and equilibrium yield separately!

ALSO NOTE: In this scenario, while the forward reaction is favoured, the rate of **both** the forwards and the reverse rate is increased, it's just that the rate of the forward reaction is increased by more!



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Question 30

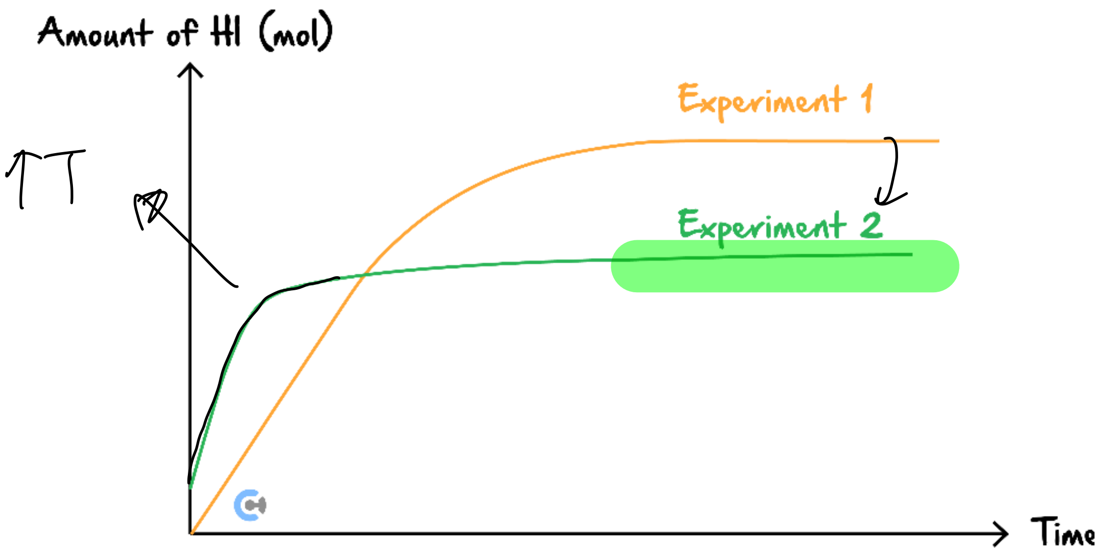
Hydrogen iodide is produced by the reaction between hydrogen and iodine.

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

Two experiments were conducted.

Experiment 1: Quantities of $H_2(g)$ and $I_2(g)$ were placed in a sealed vessel and the reaction was allowed to proceed at a constant temperature.

Experiment 2: Experiment 1 was repeated but at a different temperature.
The graph below shows the amount of hydrogen iodide produced over the course of experiments 1 and 2.



These results show that experiment 2 was conducted at a:

A. Lower temperature than experiment 1 and the reaction is endothermic.

B. Lower temperature than experiment 1 and the reaction is exothermic.

C. Higher temperature than experiment 1 and the reaction is endothermic.

D. Higher temperature than experiment 1 and the reaction is exothermic.

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Question 31 Additional Question.

The four equations below represent different equilibrium systems.

Equation 1	$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$	$\Delta H = -180\ kJ\ mol^{-1}$
Equation 2	$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$	$\Delta H = -46\ kJ\ mol^{-1}$
Equation 3	$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$	$\Delta H = +93\ kJ\ mol^{-1}$
Equation 4	$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$	$\Delta H = +205\ kJ\ mol^{-1}$

After equilibrium was established in each system, the temperature was decreased and the pressure was increased. In which equilibrium system would both changes result in an increase in yield?

A. Equation 1

B. Equation 2

C. Equation 3

D. Equation 4

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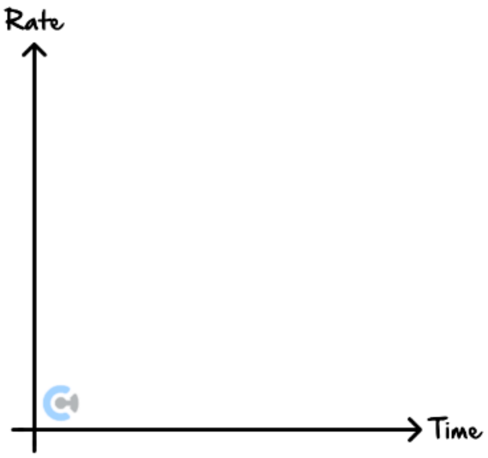
Section F: Rate-Time Graphs for Equilibrium (10 Marks)

This is an extension idea, mainly for schools such as GWSC!

Cheat Sheet

Introduction to Rate-Time Graph

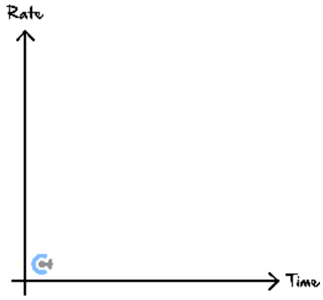
- Blue solid line ( ): Forward Rate of Reaction.
- Red dotted line ( ): Reverse Rate of Reaction.
- Steps:
  - Initial Change → Concentration.
  - Forwards/Reverse Rate Changes.
  - Difference in Rate shifts Fwds/Rvs Overall.
- C is added:



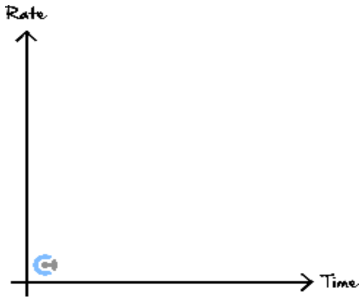
Addition/Removal of Substance

$$A + B \rightleftharpoons C$$

- A is added:



- A is removed:



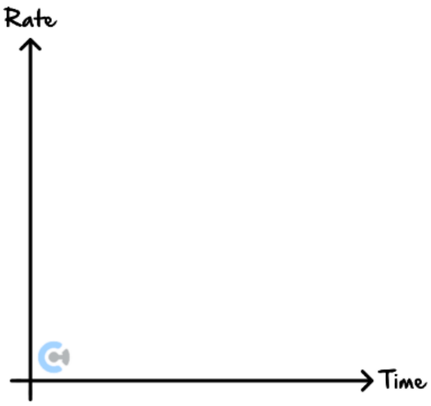
- C is removed:

Cheat Sheet

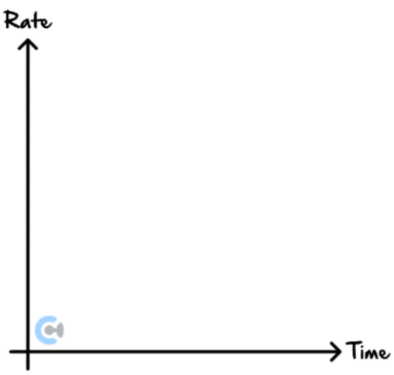
Change in Volume/Pressure

$$A + B \rightleftharpoons C$$

- Decrease Volume:



- Increase Volume:



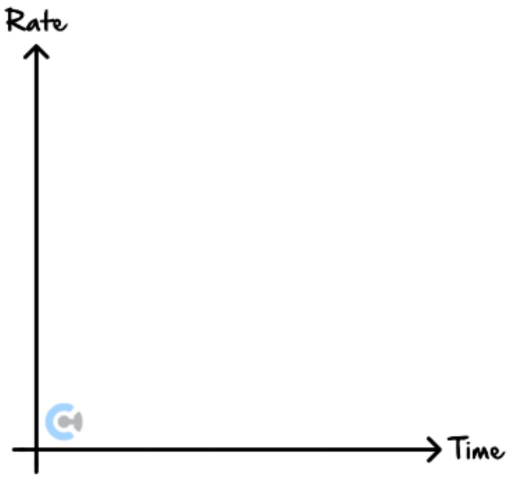
$$A + B \rightleftharpoons 2C$$

- Decrease Volume:

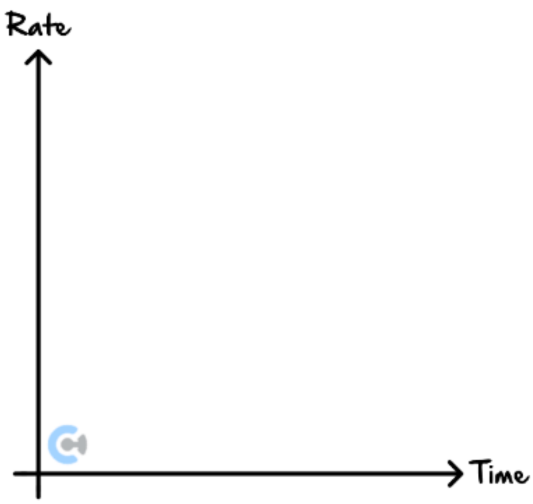
Change in Temperature

$$A + B \rightleftharpoons C \quad \Delta H > 0$$

- Increase Temperature:



- Decrease Temperature:



- **Overall:**
  - If only one rate spikes:

    [substance added or removed] / [volume change] / [temperature change]

  - If both fwds & rvs rate spikes:

    [substance added or removed] / [volume change] / [temperature change]

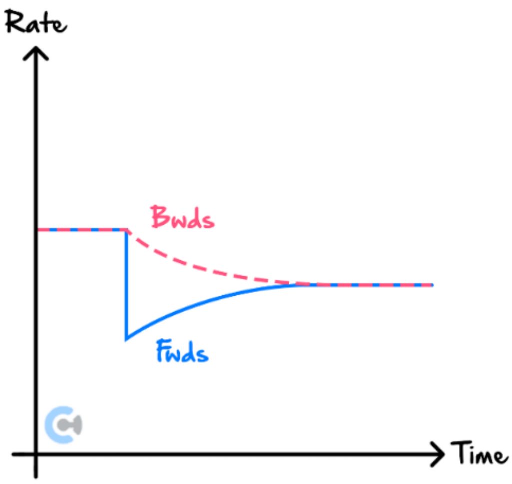
Let's look at a question together!

Question 32 (4 marks) **Walkthrough.**

When placed into an empty reaction vessel, N_2O_4 can reach equilibrium by decomposing into nitrogen dioxide, NO_2, as shown in the equation below.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

After the system reaches equilibrium, a change is made to the system, which is shown in the following graph.



a. State the change that has been made. (1 mark)

---

b. Explain, using collision theory, the direction in which the system will shift to re-establish equilibrium. (3 marks)

Your turn!

Question 33 (1 mark)

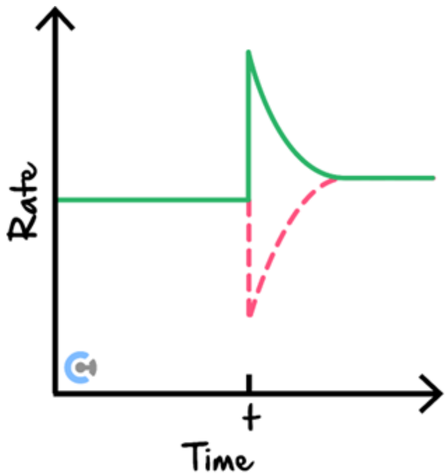
Nitrogen dioxide reacts to form dinitrogen tetroxide in a sealed flask according to the following question:

$$2NO_2(g) \rightleftharpoons N_2O_4(g); \qquad \Delta H = -57.2\ kJ\ mol^{-1}$$

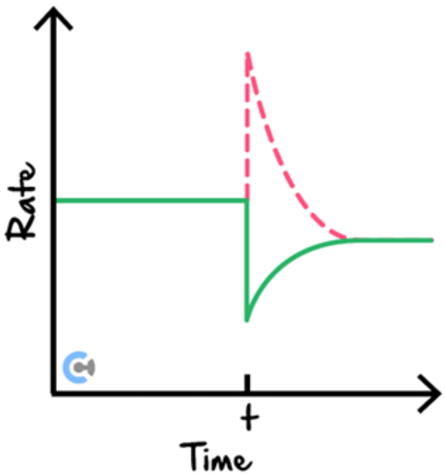
Which graph best represents the rates of both the forward and reverse reactions when an equilibrium system containing these gases is cooled at time t?

The solid green line represents the forward rate of reaction, and the dotted red line represents the reverse rate of reaction.

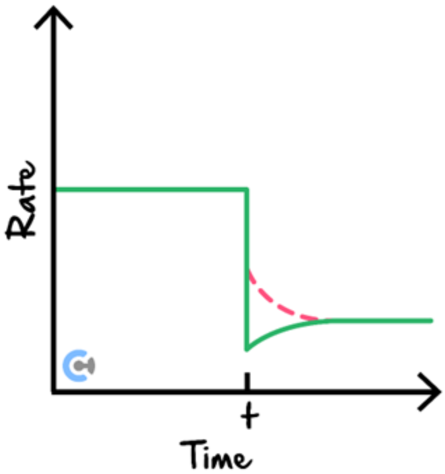
A.



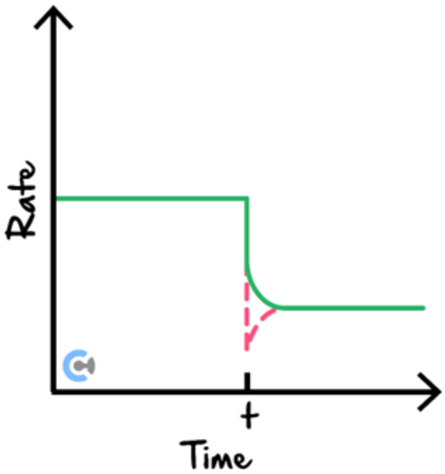
B.



C.



D.



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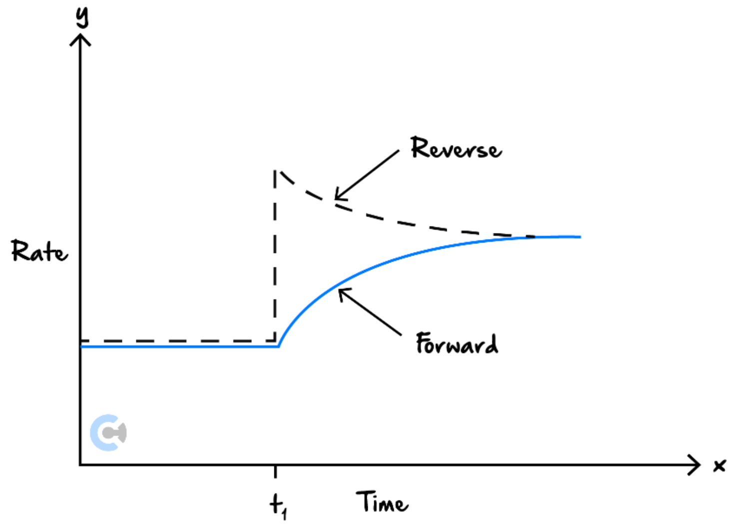
Question 34 (1 mark)

The gases dinitrogen tetroxide and nitrogen dioxide exist in an equilibrium reaction represented by the following equation:

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H < 0$$

The graph below shows the changes to the rates of forward and reverse reactions that occurred when a change was made to the equilibrium system at a time t_1.



Which one of the following changes to the equilibrium mixture would account for the changes shown in the graph?

A. Some N_2O_4 was added to the mixture.

B. A catalyst was added.

C. The volume of the container was increased.

D. The reaction vessel was heated.

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Question 35 (1 mark)

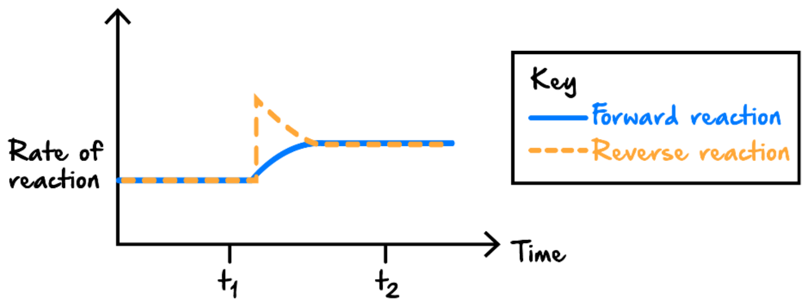
Inspired from Chemistry Exam 2021
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2021/2021chem-w.pdf#page=12

An equilibrium mixture of four gases is represented by the following equation:

$$A(g) + 2B(g) \rightleftharpoons C(g) + D(g); \qquad \Delta H > 0$$

The graph below shows the rate of the forward and reverse reactions versus time.

A single change is made to the equilibrium mixture at a time t_1 and equilibrium is re-established at a time t_2.



Which one of the following is consistent with the information given above?

A. Argon is added to the equilibrium mixture at a time t_1.

B. At time t_1 reactants are removed from the equilibrium mixture.

C. The amount of products is higher at a time t_2 compared to just before time t_1.

D. The change made at a time t_1 results in an increase in the equilibrium constant at a time t_2 .

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Question 36 (1 mark)

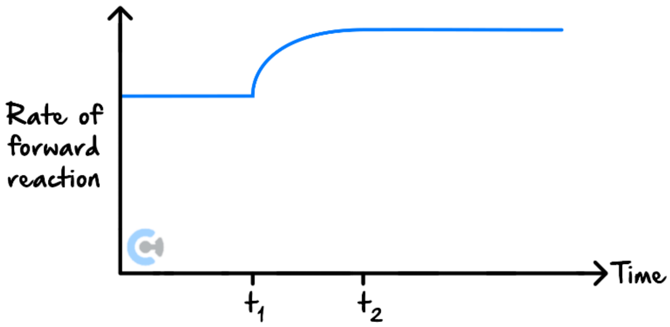
Inspired from VCAA Chemistry Exam 2020
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2020/2020chem-w.pdf#page=11

Nitrogen dioxide, NO_2, and dinitrogen tetroxide, N_2O_4, form an equilibrium mixture represented by the following equation:

$$2NO_2(g) \rightleftharpoons N_2O_4(g); \qquad \Delta H = -57.2\ kJ\ mol^{-1}$$

brown colourless

A change was made at a time t_1 to an equilibrium mixture of NO_2 and N_2O_4, which achieved a new equilibrium at time t_2. A graph showing the rate of the forward reaction is shown below.



Which one of the following describes the change that was made to the initial equilibrium system and the colour change that occurred between t_1 and t_2?

A. The temperature was increased and the colour lightened.

B. The temperature was increased and the colour darkened.

C. The temperature was decreased and the colour lightened.

D. The temperature was decreased and the colour darkened.

NOTE: Temperature change is supposed to spike up the rate, VCAA didn't do it for this question for some reason!

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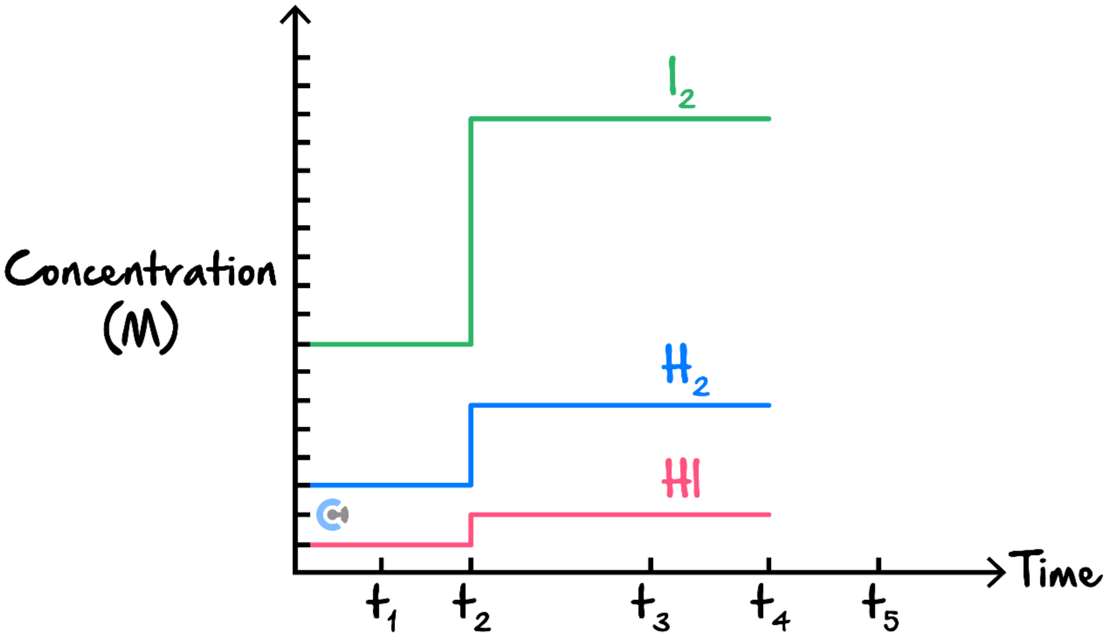
The following information applies to the two questions that follow

Inspired from VCAA CHEMISTRY Exam 2021
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2021/2021chem-w.pdf#page=14

Hydrogen, H_2 , and iodine, I_2 , react to form hydrogen iodide, HI.

$$\frac{1}{2}H_2(g) + \frac{1}{2}I_2(g) \rightleftharpoons HI(g) \qquad \Delta H = +25.9KJ\ mol^{-1}$$

The graph below shows the concentrations of H_2, I_2 and HI in a sealed container. One change was made to the equilibrium system at time t_2.



Question 37 (1 mark)

Which one of the following statements is correct?

A. A catalyst was added at time t_2.

B. The amount of HI is greater at time t_3 compared with time t_1.

C. The rate of reaction producing HI is the same at time t_1 and time t_3.

D. The rate of production of HI at time t_3 is double the rate of production of H_2 at time t_3.

Question 38 (1 mark)

One change was made to the equilibrium system at time t_4, which altered the equilibrium constant. Equilibrium was re-established at time t_5. The rate of the reverse reaction at time t_5 was higher than at time t_3. Which of the following options correctly shows the change in the equilibrium system from time t_3 to time t_5?

	Change from time t_3 to time t_5	
	Equilibrium constant	**Total chemical energy**
A.	Increase	Increase
B.	Increase	Increase
C.	Decrease	Increase
D.	Decrease	Decrease

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Contour Check

Learning Objective: [2.9.1] - Explain the effects of temperature, inert gas or catalyst on an equilibrium system

Study Design

"The application of Le Chatelier's principle to identify factors that favour the yield of a chemical reaction."

Key Takeaways

- Inert Gas on Equilibrium Position:
- Temperature:

Change to System	System's Respond (Le Chatelier's Effect)	Reaction Favoured
Increase in Temperature	[increase] / [decrease] temperature.	[endothermic] / [exothermic]
Decrease in Temperature	[increase] / [decrease] temperature.	[endothermic] / [exothermic]

- Equilibrium Constant (K_c):
- Sample Response:

1. Temp is increased/decreased.
2. According to Le Chatelier's Principle, system ______________________ the change by increasing/decreasing temperature.
3. Favours endothermic/exothermic forwards/backwards reaction.

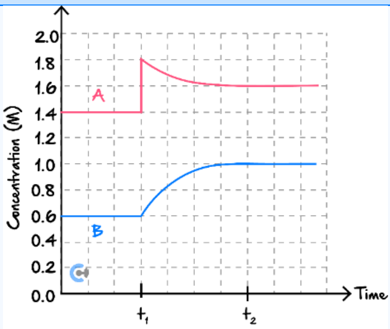
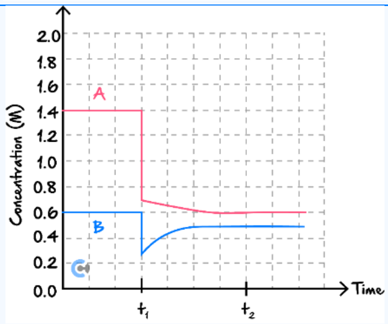
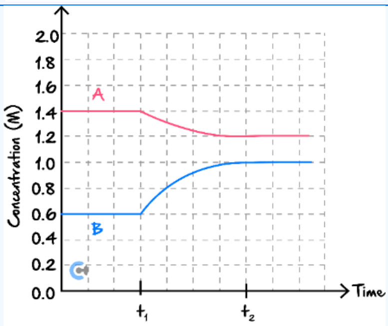
☐ Learning Objective: [2.9.2] - Graph effects of temperature, inert gas catalyst on an equilibrium system

Key Takeaways

- ☐ Temperature: [has]/[doesn't have] initial spike.
- ☐ Inert gas: Has ____________________ on equilibrium graph.
- ☐ In a rate-time graph:
  - If the rate overall has increased, the temperature has [increased] / [decreased].
  - If the rate overall has decreased, the temperature has [increased] / [decreased].

◻ Learning Objective: [2.9.3] - Find the change made to the system from the equilibrium graph

Key Takeaways

Graph	Change
	[addition or removal of species] / [pressure or volume change] / [temperature change]
	[addition or removal of species] / [pressure or volume change] / [temperature change]
	[addition or removal of species] / [pressure or volume change] / [temperature change]

Learning Objective: [2.9.4] - Find equilibrium constant changes due to temperature

Key Takeaways

- During temperature change, if reaction shifts:

Forwards Overall	Reverse Overall
K_c value: [increases] / [remains constant] / [decreases]	K_c value: [increases] / [remains constant] / [decreases]

Learning Objective: [2.9.5] - Find optimum operating conditions in all circumstances such as the rate-yield conflict

Study Design

"Responses to the conflict between optimal rate and temperature considerations in producing equilibrium reaction products, with reference to the green chemistry principles of catalysis and designing for energy efficiency."

Key Takeaways

- Rate-Yield Conflict
  - Example #1: $\mathrm{A + B \rightleftharpoons C} \quad \Delta H = -100\ kJ/mol$

Condition	Pressure	Temperature
Rate	[high] / [low]	[high] / [low]
Equilibrium Yield	[high] / [low]	[high] / [low]
Overall	[high] / [medium] / [low]	[high] / [medium] / [low]

- Example #2: $A + B \rightleftharpoons C + 2D \quad \Delta H = +100\ kJ/mol$

Condition	Pressure	Temperature
Rate	[high] / [low]	[high] / [low]
Equilibrium Yield	[high] / [low]	[high] / [low]
Overall	[high] / [medium] / [low]	[high] / [medium] / [low]

- To maximise rate, always ______________________________.
- To maximise yield, always ____.
- Green Chemistry Principles: ____.

difficult

4 AOS 1 : fuels & energy, spon redox

1 AOS 2 : electrolysis + equilibrium

3 AOS 3 : organic & food

2 AOS 4 : instrumental analysis + medicinal

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