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VCE Chemistry ¾
AOS 2 Revision II [2.10]
Workbook Solutions

Outline:

Section A: [2.6] - Rates of Reaction (17 Marks)

Sub-Section: Recap

Cheat Sheet

[2.6.1] - Explain how factors increase the frequency of collisions

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].

Cheat Sheet

[2.6.2] – Explain how temperature & catalyst affect the proportion of successful collisions

- 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 Kinetic Energy → Greater Force Upon Collision → Greater Probability for Collisions with Sufficient Energy to Overcome E_a → Greater Rate

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

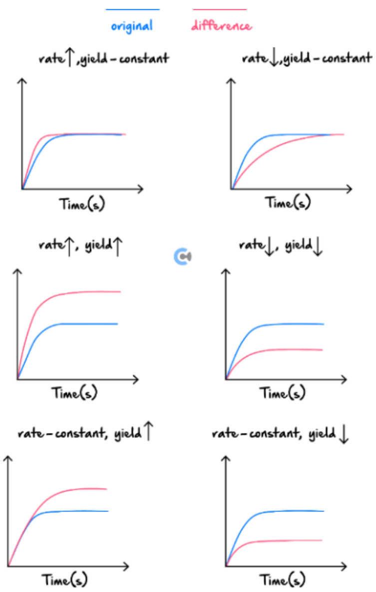
- Catalysts alter the rate of reaction by providing an alternative reaction pathway with a lower activation energy.

- 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.

[2.6.3] – Graph differences in rate & yield

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**



Sub-Section: Questions

INSTRUCTION: 12 Marks. 12 Minutes Writing.

Question 1 (3 marks)

Ethan is studying the reaction that occurs between 1.0 M sulphuric acid and 17.90 g of solid copper oxide in a 500 mL beaker according to the reaction:

$$CuO(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(l)$$

State what effect each of the following would have on the rate of reaction observed when compared to the original set-up shown above.

a. Using 2.0 M sulphuric acid solution. (0.5 marks) **[2.6.1] [2.6.2]**

Increase

b. Using 0.5 M sulphuric acid. (0.5 marks) **[2.6.1] [2.6.2]**

Decrease

c. Using powdered copper oxide. (0.5 marks) **[2.6.1] [2.6.2]**

Increase

d. The same reaction took place, but this time a 1 L beaker was used instead. (0.5 marks) **[2.6.1] [2.6.2]**

No change

e. A catalyst is added. (0.5 marks) **[2.6.1] [2.6.2]**

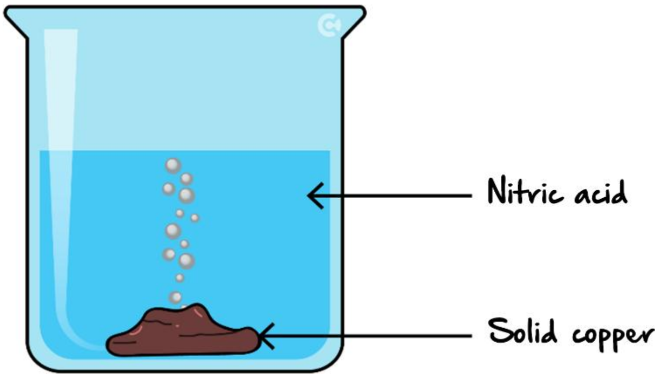
Increase

f. 100 mL of water is added. (0.5 marks) **[2.6.1] [2.6.2]**

Decrease

The following information applies to the two questions that follow

$$Cu(s) + 4HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2NO_2(g) + 2H_2O(l)$$



Question 2 (1 mark) **[2.6.1] [2.6.2]**

Which one of the following will **not** increase the rate of the above reaction?

A. Decreasing the size of the solid copper particles.

B. Increasing the temperature of HNO_3 by 20°C.

C. Increasing the concentration of HNO_3.

D. Allowing NO_2 gas to escape.

Question 3 (1 mark) **[2.6.2]**

In the above reaction, the number of successful collisions per second is a small fraction of the total number of collisions.

The **major** reason for this is that:

A. The nitric acid is ionised in solution.

B. Some reactant particles have too much kinetic energy.

C. The kinetic energy of the particles is reduced when they collide with the container's walls.

D. Not all reactant particles have the minimum kinetic energy required to initiate the reaction.

Space for Personal Notes

Question 4 (1 mark) **[2.6.2]**

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.

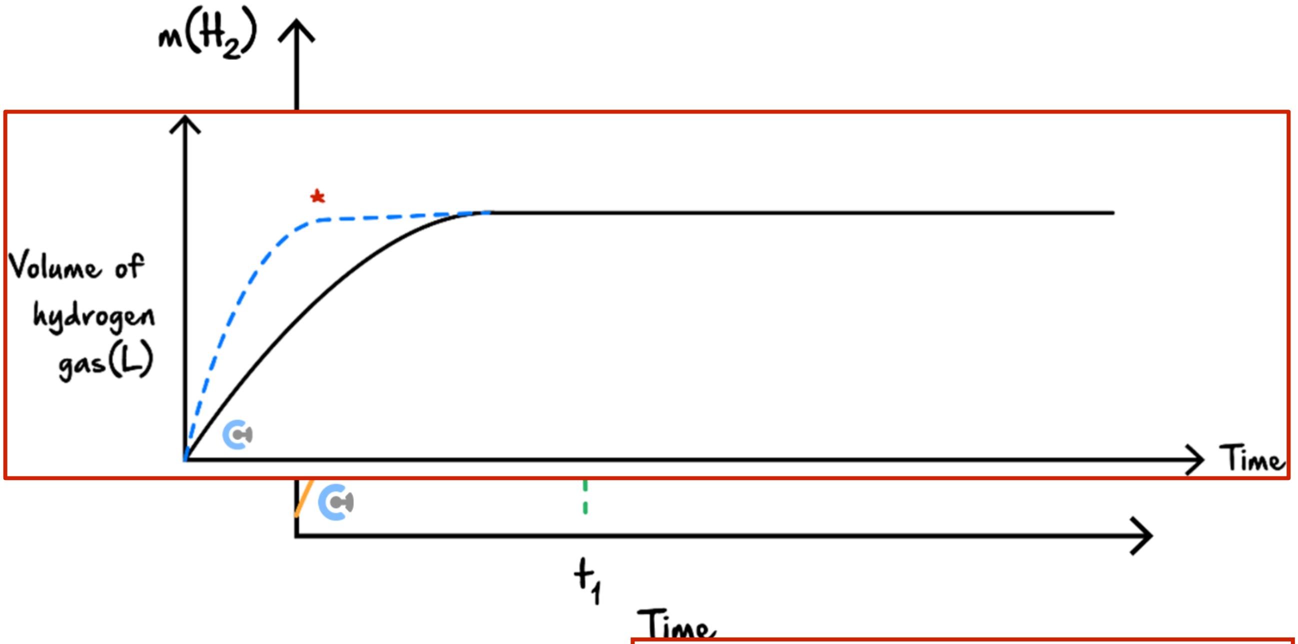
C. It increases the activation energy of both the forward and reverse reactions.

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

Question 5 (6 marks)

A 2.0 *g* piece of magnesium ribbon was added to a known volume of 2.0 *M* hydrochloric acid.

The mass of hydrogen gas produced during the reaction was measured and recorded. The graph below shows the result of this experiment.



a. Write an equation for the reaction between magnesi

$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$*

or

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

* One mark was awarded on this equation for 'all' states being correct.

Marks	0	1	2	Average
%	18	29	54	1.4

b. What event occurs at the time t_1? (1 mark) **[2.6.3]**

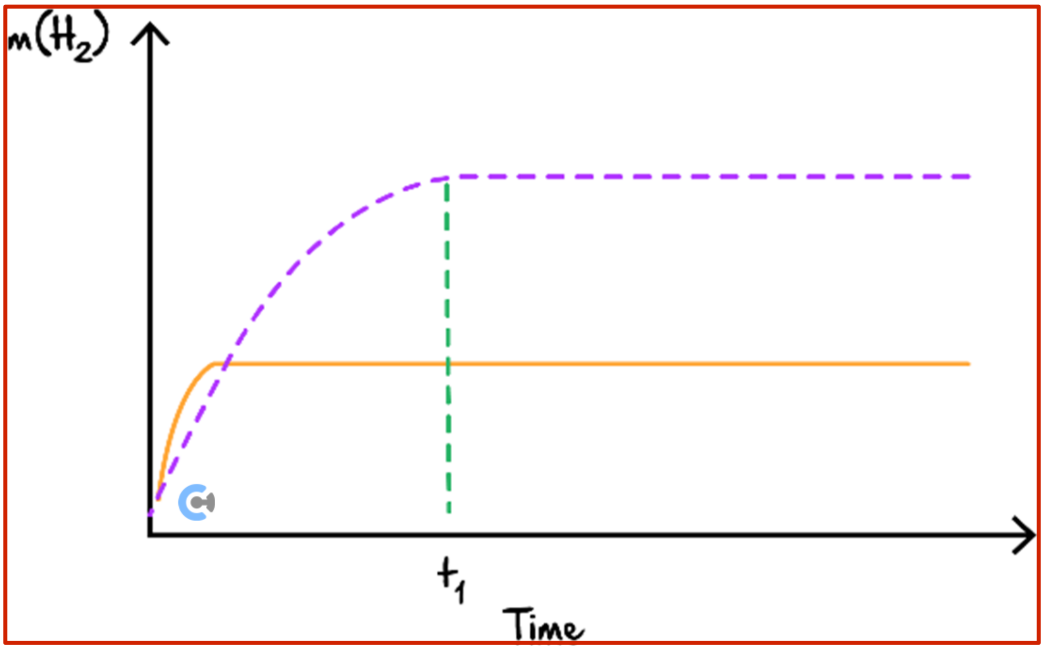
The reaction reached completion (cannot say reached equilibrium).

c. In a second experiment, 2.0 g of magnesium ribbon was added to the same volume of 2.0 M hydrochloric acid, but a catalyst was added as well.

On the axes above, sketch the expected graph of the volume of hydrogen against time for this second experiment. Give an explanation for the shape of your graph. (2 marks) **[2.6.3]**

Rate is quicker (steeper gradient).
Still plateaus at the same point (same amount of products produced).

d. In a third experiment, 1.0 g of powdered magnesium and the results are recorded. On the axes below, sketch the results of the third experiment compared to the first experiment. (2 marks) **[2.6.3]**



Check off any learning objectives obtained full marks from the "Contour Check" booklet!

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Sub-Section: Additional Questions

Question 6 (3 marks) **[2.6.2]**

Explain the effect of decreasing the temperature of a system using collision theory.

A decrease in temperature decreases the average kinetic energy of the reactants
Reactants will collide with smaller force, thereby decreased proportion of collisions with sufficient energy to overcome the activation energy. Thereby, decreasing the proportion of collisions, hence of successful collisions.
Decrease in temperature reduces frequency of collisions, hence of successful collisions with correct orientation, reducing rate of reaction.

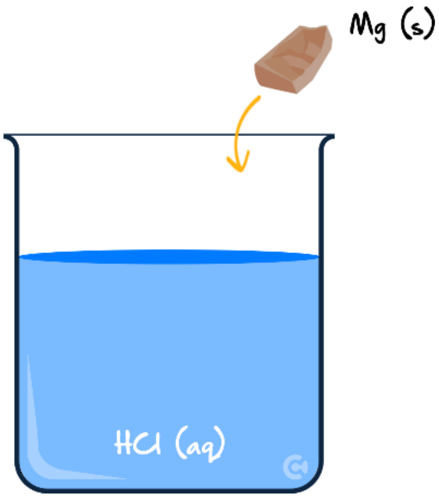
Space for Personal Notes

Question 7 (2 marks)

It is known that magnesium and hydrochloric acid react via the reaction:

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

The original magnesium blocks are thoroughly sanded prior to use and 50 g of Mg(s) blocks are dropped into the HCl solution.



For the following questions, consider that there were two beakers with similar setups but one changed different conditions for the reactants.

a. If a 2.0 M HCl solution is compared to a 1.0 M HCl solution (all other conditions remain the same), which beaker would produce the most bubbles in 1 second? (1 mark) **[2.6.1]**

A. The beaker with 1.0 M HCl, because lower concentration speeds up the reaction.

B. The beaker with 2.0 M HCl, because higher concentration increases the rate of reaction.

C. Both beakers would produce the same amount of bubbles because concentration does not affect the rate.

D. The beaker with 1.0 M HCl, because it has fewer hydrogen ions to react with magnesium.

b. If for one beaker, the magnesium block is broken into 10 smaller pieces but left on a bench for 2 weeks, how would the rate of bubble production compare to the original block of sanded magnesium? (1 mark) **[2.6.1]**

A. The beaker with smaller pieces would produce more bubbles because of the increased surface area.

B. The beaker with the original block would produce more bubbles because the surface is freshly sanded.

C. Both beakers would produce the same amount of bubbles because the amount of magnesium is the same.

D. The beaker with smaller pieces would produce fewer bubbles because exposure to air for 2 weeks would cause oxidation.

Section B: [2.7] - Equilibrium (24 Marks)

Sub-Section: Recap

Cheat Sheet

[2.7.1] - Write equilibrium constant expression & find its value (including units)

- K_c Expression:

$$aA + bB + ... \rightleftharpoons cC + dD + ...$$

$$K_c = \frac{[C]^c \times [D]^d \times ...}{[A]^a \times [B]^b \times ...}$$

- **K_c value key property:** always has the __same__ at a certain temperature, irrespective of the amounts of the reactants/products which we start off with!

- K_c units need to be calculated separately each time.

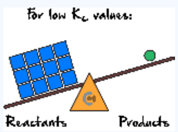
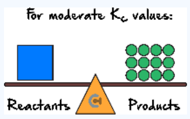
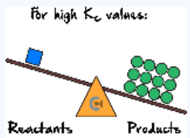
Homogenous Equilibrium	Heterogenous Equilibrium
[Only one] / [Multiple] state(s) of matter present in equation.	[Only one] / [Multiple] state(s) of matter present in equation.

Aqueous (aq) or Gaseous (g) Substances	Solid (s) or Liquid (l) Substances
[Have] / [Don't have] concentration.	[Have] / [Don't have] concentration.
Concentration is as stated.	Concentration is _one_.

- When plugging values into K_c expression, [amount (mol)] / [concentration (M)] should be plugged in.

- Calculate units by.

[2.7.2] - Identify the extent of reaction

$K_c < 10^{-4}$	$10^{-4} < K_c < 10^4$	$K_c > 10^4$
[Small] / [Medium] / [Large] extent of reaction.	[Small] / [Medium] / [Large] extent of reaction.	[Small] / [Medium] / [Large] extent of reaction.
[Reactants] / [Both] / [Products] favoured at equilibrium.	[Reactants] / [Both] / [Products] favoured at equilibrium.	[Reactants] / [Both] / [Products] favoured at equilibrium.
		

[2.7.3] - Find equilibrium constant when equation is changed

- When **reversing equations**, take the __reciprocal__.

- When **multiplying by a coefficient**, take the _power_ of that coefficient.

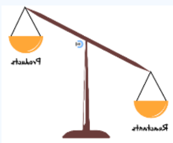
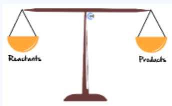
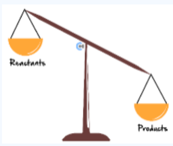
- **Units:** _Follow_ how equation has been changed!

Cheat Sheet

[2.7.4] - Apply Q_c to find direction of equilibrium shift

Equilibrium Constant (K_c)	Reaction Quotient (Q_c)
$K_c = \frac{[C]^c \times [D]^d \times ...}{[A]^a \times [B]^b \times ...}$	$Q_c = \frac{[C]^c \times [D]^d \times ...}{[A]^a \times [B]^b \times ...}$
Is found by using concentrations **at equilibrium**!	Is found at **any point in time** (could be at equilibrium, could not be at equilibrium!).

- If $Q_c = K_c$, the system [is] / [is not] at equilibrium.
- If $Q_c \neq K_c$, the system [is] / [is not] at equilibrium.

$Q_c < K_c$	$Q_c = K_c$	$Q_c > K_c$
[undershot] / [perfect shot] / [overshot]	[undershot] / [perfect shot] / [overshot]	[undershot] / [perfect shot] / [overshot]
[forwards] / [neither] / [reverse] reaction favoured.	[forwards] / [neither] / [reverse] reaction favoured.	[forwards] / [neither] / [reverse] reaction favoured.
		

[2.7.5] - Apply RICE tables to find K_c

- Stands for
  - Reaction
  - Initial
  - Change
  - Equilibrium
- **Good idea to add a fifth row**: concentration.
- **Key Terms**: "Empty" or "evacuated" means there are no other substances present at the beginning.
- **Steps:**
  1. Fill out knowns.
  2. Find n_c (use stoichiometric ratios & +/− signs).
  3. Find n_e.

Let's walkthrough together!

Question 8 (4 marks) **Walkthrough.**

The following equation is used to show what occurs when nitrogen and hydrogen gas are mixed.

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

In a 9.00 L container, there is 8.00 mol of nitrogen gas and 1.29 mol of hydrogen gas.

The K_c value is found to be 0.00469 M^{-2}.

a. Determine the extent of the reaction. (1 mark) **[2.7.2]**

Medium extent.

b. Find the amount of ammonia gas present at equilibrium. (3 marks) **[2.7.1]**

$$K_C = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{\left[\frac{0.852}{9}\right]^2}{\left[\frac{4}{9}\right]\left[\frac{1.29}{9}\right]^3} = 0.00469\ M^{-2}$$

$$n(NH_3) = 0.852\ mol$$

Space for Personal Notes

Question 9 (4 marks) **Walkthrough. [2.7.5]**

At a particular temperature, 5.20 mol of CS_2 and 14.50 mol of hydrogen gas is placed into an initially evacuated 3.0 L rigid container. The equation describing the system is shown below.

$$CH_4(g) + 2H_2S(g) \rightleftharpoons CS_2(g) + 4H_2(g)$$

At equilibrium, 3.5 mol of H_2S is present. Calculate the K_c value for this reaction.

R	CH_4	+ $2H_2S$	⇌ CS_2	+ $4H_2$
n_i	0	0	5.20	14.50
n_c	+1.75	+3.5	−1.75	−7.00
n_e	1.75	3.5	3.45	7.5
c_e	0.583	1.167	1.15	2.5

$$K_c = \frac{[CS_2][H_2]^4}{[CH_4][H_2S]^2} = \frac{1.15 \times 2.5^4}{0.583 \times 1.167^2} = 56.6\,M^2$$

$$= 57\,M^2$$

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Sub-Section: Questions

INSTRUCTION: 13 Marks. 13 Minutes Writing.

Question 10 (1 mark) **[2.7.2]**

Which pair of components must be equal for a chemical system to be at equilibrium?

A. The rate of the forward reaction and the rate of the reverse reaction.

B. The concentrations of the reactants and the concentrations of the products.

C. The enthalpy of the forward reaction and the enthalpy of the reverse reaction.

D. The time that an atom exists in a reactant molecule and in a product molecule.

Question 11 (1 mark) **[2.7.2]**

The value of the equilibrium constant, K_c, for a reaction is 1.0×10^{10}. Which statement about the extent of the reaction is correct?

A. The reaction hardly proceeds.

B. The reaction goes almost to completion.

C. The products have a higher concentration than the reactants.

D. The concentrations of reactants and products are the same.

Space for Personal Notes

Question 12 (2 marks) **[2.7.1]**

For the following equation:

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

Given the K_c value is 0.593 M at 25°C, and at equilibrium, the concentration of PCl_3 is 2.18 M and the concentration of Cl_2 is also 8.11 M, find the concentration of PCl_5 at equilibrium.

$$K_c = \frac{[Cl_2][PCl_3]}{[PCl_5]}$$

$$[PCl_5] = \frac{[Cl_2][PCl_3]}{K_c} = \frac{8.11 \times 2.18}{0.593} = 29.81\ M$$

Question 13 (4 marks) **[2.7.5]**

At a particular temperature, 20.0 moles of SO_3 is placed into an initially evacuated 3.0 L rigid container, and the SO_3 dissociates by the reaction below.

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

At equilibrium, 3.5 moles of SO_2 is present. Calculate the K_c value for this reaction.

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

n_i	20	0	0
n_c	↓ 3.5	↑ 3.5	↑ 1.75
n_e	16.5	3.5	1.75
c	5.5	1.167	0.583

$$K_c = \frac{[SO_2]^2[O_2]}{[SO_3]^2} = \frac{1.167^2 \times 0.583}{5.5^2}$$
$$= 0.02625\ M = 0.026\ M$$

Question 14 (5 marks)

Consider the reaction shown in the following equation:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = -\frac{9.4\ kJ}{mol}, \qquad K_c = 54.8 \text{ at } 700\text{ K}$$

a. Write the expression for the equilibrium constant for this reaction. (1 mark) **[2.7.1]**

$$K_c = \frac{[HI]^2}{[I_2][H_2]}$$

b. 10.00 mol of HI, 10.00 mol H_2 and 2.00 mol I_2 are placed in a 1.5 L container at 700 K. Predict in which direction the reaction will proceed. Justify your answer. (3 marks) **[2.7.4]**

$$Q_c = \frac{[HI]^2}{[I_2][H_2]} = \frac{\left(\frac{10}{1.5}\right)^2}{\left(\frac{2}{1.5}\right)\left(\frac{10}{1.5}\right)} = 5.0$$

$Q_c < K_c$ shifts right

c. For each of the following equations determine the K_c value and its subsequent units.

i. $2H_2(g) + 2I_2(g) \rightleftharpoons 4HI(g)$. (0.5 marks) **[2.7.3]**

$3.00 \times 10^3, 3sf$

ii. $5HI(g) \rightleftharpoons \frac{5}{2}H_2(g) + \frac{5}{2}I_2(g)$. (0.5 marks) **[2.7.3]**

$4.50 \times 10^{-5}, 3sf$

Check off any learning objectives obtained full marks from the "Contour Check" booklet!

Space for Personal Notes

Sub-Section: Additional Questions

Question 15 (1 mark) **[2.7.5]**

Nitrosyl chloride (NOCl) is a highly toxic gas that decomposes according to the equation:

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$$

To investigate the reaction, 1.2 *mol* of NOCl(g) is placed in an empty 1.0 *L* flask and allowed to reach equilibrium. The flask and its contents are kept at a constant temperature.

If $[Cl_2] = 0.20\ M$ at equilibrium, what is the equilibrium concentration of NOCl(g)?

A. 0.80 *M*

B. 1.00 *M*

C. 1.10 *M*

D. 1.40 *M*

	$2NOCl(g)$	$\rightleftharpoons$	$2NO(g)$	$+ Cl_2(g)$
Initially	1.2 M		-	-
Reacting	0.40 M	→	0.40 M	0.20 M
Equilibrium	0.80 M		0.40 M	0.20 M

The 0.20 mol Cl_2 present in the 1.0 L flask at equilibrium was produced by the reaction of 0.40 mol NOCl, leaving 0.80 mol NOCl at equilibrium.

Question 16 (1 mark) **[2.7.3]**

The equilibrium constant for the reaction: $N_2O_4(g) \rightleftharpoons 2NO_2\ (g)$ is 0.212 *M* at 373 K. For the reaction:

$$NO_2(g) \rightleftharpoons \frac{1}{2}N_2O_4(g)$$

The value of the equilibrium constant at the same temperature would be:

A. 4.72

B. 2.17

C. 0.460

D. 0.212

The reaction: $NO_2(g) \rightleftharpoons \frac{1}{2}N_2O_4(g)$ is the reverse of the given reaction and with half the coefficients. Hence, the constant for this equation is $\frac{1}{(0.212)^{\frac{1}{2}}} = 2.17$

Correct Answer: B

Space for Personal Notes

Question 17 (1 mark) **[2.7.5]**

A mixture of 0.40 mol of $CO(g)$ and 0.40 mol of $H_2(g)$ was placed in a 1.00 dm^3 vessel. The following equilibrium was established.

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

At equilibrium, the mixture contained 0.25 mol of $CO(g)$. How many moles of $H_2(g)$ and $CH_3OH(g)$ were present at equilibrium?

	Equilibrium mol of H_2	**Equilibrium mol of CH_3OH**
A.	0.25	0.15
B.	0.50	0.25
C.	0.30	0.25
D.	0.10	0.15

Space for Personal Notes

Section C: [2.8] - Le Chatelier's Principle (27 Marks)

Sub-Section: Recap

Cheat Sheet

[2.8.1] - Explain effects of addition/removal of substances or pressure/volume changes on equilibrium system

- Principle:

  "If a system is at equilibrium, and is subjected to a change, the equilibrium will shift to partially oppose the change."

- Explanation Response:

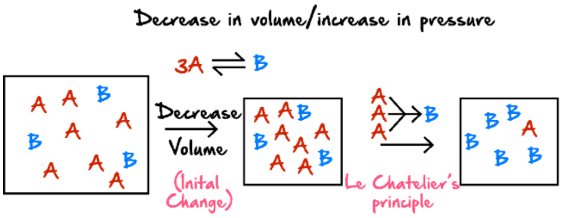
  1. Initial change.
  2. According to LCP, system partially opposes x change.
  3. Forwards/Backwards Reaction favoured.

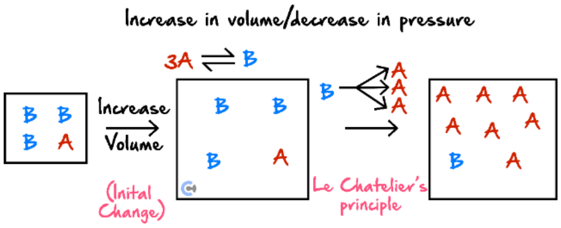
- Adding/Removing Substances:

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

  - Adding Reactants: shifts [left] / [right]
  - Adding Products: shifts [left] / [right]
  - Removing Reactants: shifts [left] / [right]
  - Removing Products: shifts [left] / [right]
  - Reacting Substances out: Effectively removes it.

- Change Volume/Pressure:





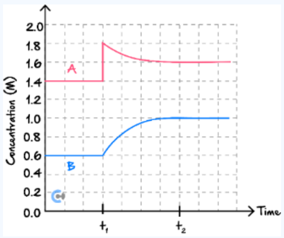
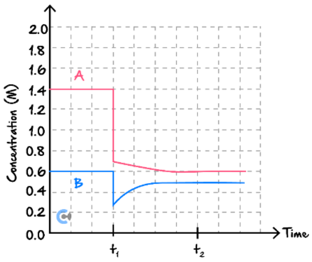
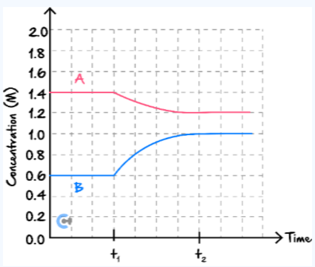
Volume Increase	Volume Decreased
Particles [squash together] / [pull apart].	Particles [squash together] / [pull apart].
Particles [merge] / [split apart].	Particles [merge] / [split apart].
Amount of particles [increase] / [decrease].	Amount of particles [increase] / [decrease].

- Volume/Pressure change when same number of particles on both sides: No change.

Cheat Sheet

[2.8.2] - Graph effects of addition/removal of substances or pressure/volume changes on equilibrium system

- **Steps for Graphing Le Chatelier's Principle**
  1. Initial change (spike).
  2. System response (gradual).
     - Stoich ratios.
     - Partial opposition.

Change	Graph
Addition/removal species	
Pressure/volume change	
Temperature change	

- **For Volume:**
  - Initial Changes: concentration of everything changes based on the starting concentration of everything, not stoichiometric ratios.
  - Equilibrium Changes: Substances increase/decrease based on stoichiometric ratios.

- **Volume Change on Concentration vs Amount:**

Volume Change	Overall Concentration	Overall Amount
Initial → immediately after volume decrease	[increases] / [decreases] / [stays same]	[increases] / [decreases] / [stays same]
As system re-establishes equilibrium:	[increases] / [decreases] / [stays same]	[increases] / [decreases] / [stays same]
Overall Change	[increases] / [decreases] / [stays same]	[increases] / [decreases] / [stays same]

- **Main Trick**: For amount, **volume change** does not affect the amount of particles!
- When graphing Q_c ,value overall [changes] / [stays same].
- K_c value never changes (unless temperature is changed).

[2.8.3] – Apply partial opposition during equilibrium to the effects on amount, concentration & colour of substance

- Change in Colour is based on the [amount] / [concentration] of substances.
- Le Chatelier's Principle only: Partially opposes change.

Let's walkthrough together!

Question 18 (3 marks) **Walkthrough. [2.8.1]**

Iron (III) ions can react with thiocyanate (SCN^-) in the following manner:

$$Fe^{3+}(aq) + SCN^-(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

It is known that Silver ions ($Ag^+(aq)$) react with the thiocyanate ($SCN^-(aq)$) to form a precipitate, $AgSCN(s)$.

Explain the direction in which the equilibrium system will shift when silver ions are added.

1. Silver ions react with the SCN^- effectively removing SCN^-,
2. According to Le Chatelier's Principle, the system partially opposes the change by increasing the $c(SCN^-)$ backup.
3. System shifts backwards overall.

Question 19 (2 marks) **Walkthrough.**

Sulphur dioxide (SO_2) can react with chlorine gas (Cl_2) in the following manner:

$$SO_2(g) + Cl_2(g) \rightleftharpoons SO_2Cl_2(g)$$

Draw an arrow, indicate the direction in which the system will shift in response if:

a. Sulphur dioxide is removed. (1 mark) **[2.8.1]**

backwards

b. Volume is increased. (1 mark) **[2.8.1]**

backwards

Question 20 (5 marks) **Walkthrough.**

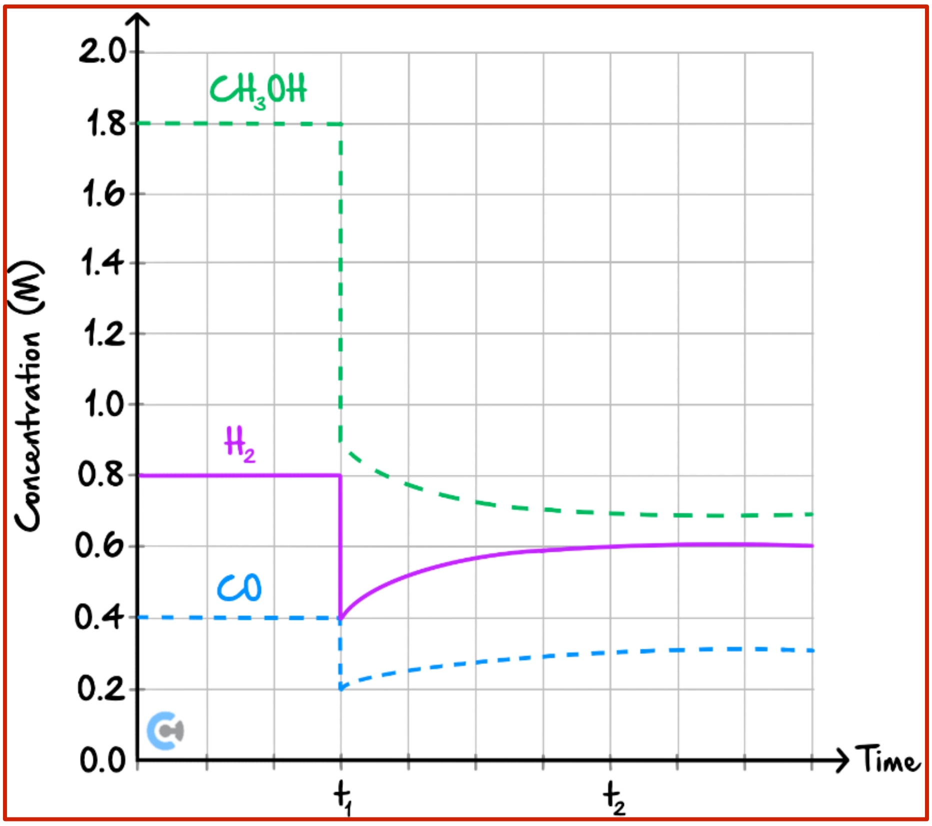
Consider the following reaction, which is initially at equilibrium, before the volume is doubled.

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

a. State the direction in which the equilibrium system will shift overall in response. (1 mark) **[2.8.1]**

Backwards

b. Show how the concentrations of each substance will change as a result on the graph provided below, assuming that the change is made at t_1, and equilibrium is re-established at t_2. (2 marks) **[2.8.2]**



c. The equilibrium yield of hydrogen gas is to be investigated.

i. Identify how the **concentration** of hydrogen gas changes overall. (1 mark) **[2.8.3]**

Decreases – concentration decreases at the beginning; the system shifts to only partially increase it back up.

ii. Identify how the **amount** of hydrogen gas changes overall. (1 mark) **[2.8.3]**

Increases – reaction goes backwards.

Sub-Section: Questions

INSTRUCTION: 12 Marks. 12 Minutes Writing.

Question 21 (2 marks)

For the following equilibrium reaction determine the direction in which the system will shift to re-establish equilibrium.

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

a. The volume is decreased. (0.5 marks) **[2.8.1]**

Forward

b. The pressure is decreased. (0.5 marks) **[2.8.1]**

Backwards

c. Ammonia gas is added. (0.5 marks) **[2.8.1]**

Backwards

d. Nitrogen gas is removed. (0.5 marks) **[2.8.1]**

Backwards

Space for Personal Notes

Question 22 (2 marks)

For the following reaction, B is yellow whilst the other species is colourless.

$$2A(aq) + B(aq) \rightleftharpoons 3C(aq)$$

a. Determine the direction the system would shift if the volume is halved. (1 mark) **[2.8.1]**

Neither Direction

b. Determine the overall change in colour. (1 mark) **[2.8.3]**

More intensely yellow

Question 23 (7 marks)

The equation of the system:

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$$

The system was allowed to reach equilibrium before the volume was halved.

a. Using Le Chatelier's Principle, explain how the system will react to this change. (3 marks) **[2.8.1]**

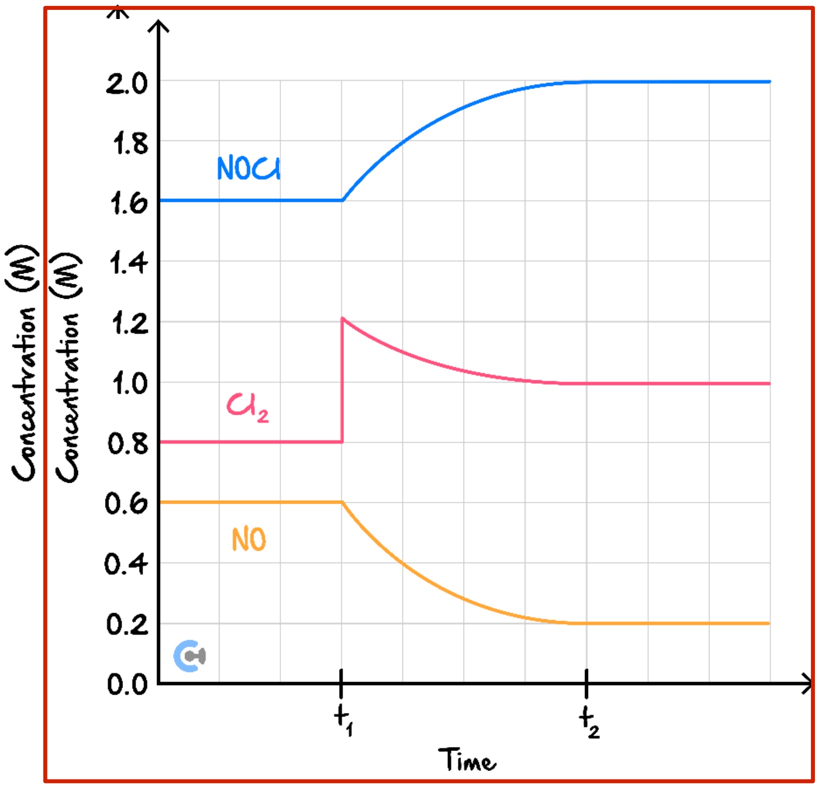
As reaction vessel volume is halved, overall concentration is doubled. As per Le Chatelier's Principle, system partially opposes the increase in overall concentration by decreasing the concentration via favouring the reaction producing the lesser number of particles. Hence, backwards reaction is favoured.

b. A different change is then made, which comprised of adding 0.200 mol of chlorine gas ($Cl_2(g)$) into the 0.500 L reaction vessel.

i. Identify how the system will react to the change. (1 mark) **[2.8.1]**

Backwards

ii. Complete the concentration-time graph for the reaction, using the initial concentrations provided, where t_1 is the time of increasing reaction vessel volume while t_2 is the time of re-establishing equilibrium. (2 marks) **[2.8.2]**



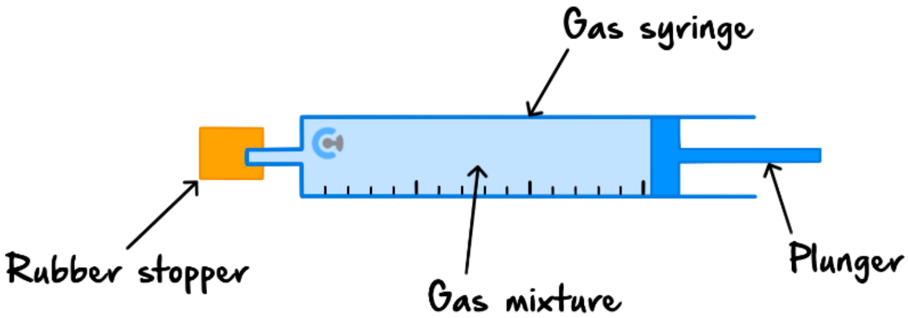
iii. It is found that chlorine gas has a greenish-yellow colour. Compare the intensity of this greenish-yellow colour from before t_1 to at t_2. (1 mark) **[2.8.3]**

More intense

Space for Personal Notes

Question 24 (1 mark) **[2.8.2]**

A sealed gas syringe contains an equilibrium mixture of brown nitrogen dioxide gas NO_2, and colourless dinitrogen tetroxide gas N_2O_4. This is shown in the diagram below.

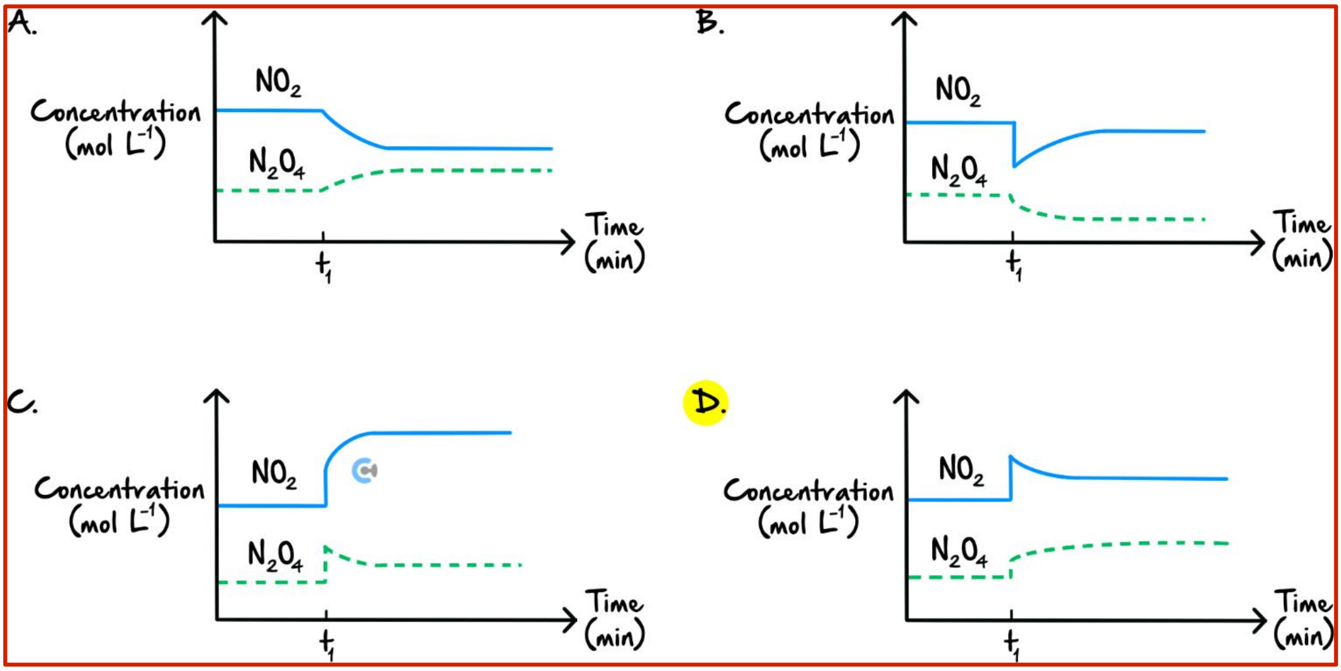


The equation for this equilibrium reaction is:

$$N_2O_4(g) \rightleftharpoons 2NO_2(g) \qquad \Delta H = +57.20\ kJ\ mol^{-1}$$

The plunger is suddenly pushed in at the time t_1, thus decreasing the total volume of the gas mixture. The temperature of the gas mixture is kept constant.

Which one of the following concentration-time graphs represents the change that occurs?



Check off any learning objectives obtained full marks from the "Contour Check" booklet!

Sub-Section: Additional Questions

Question 25 (5 marks)

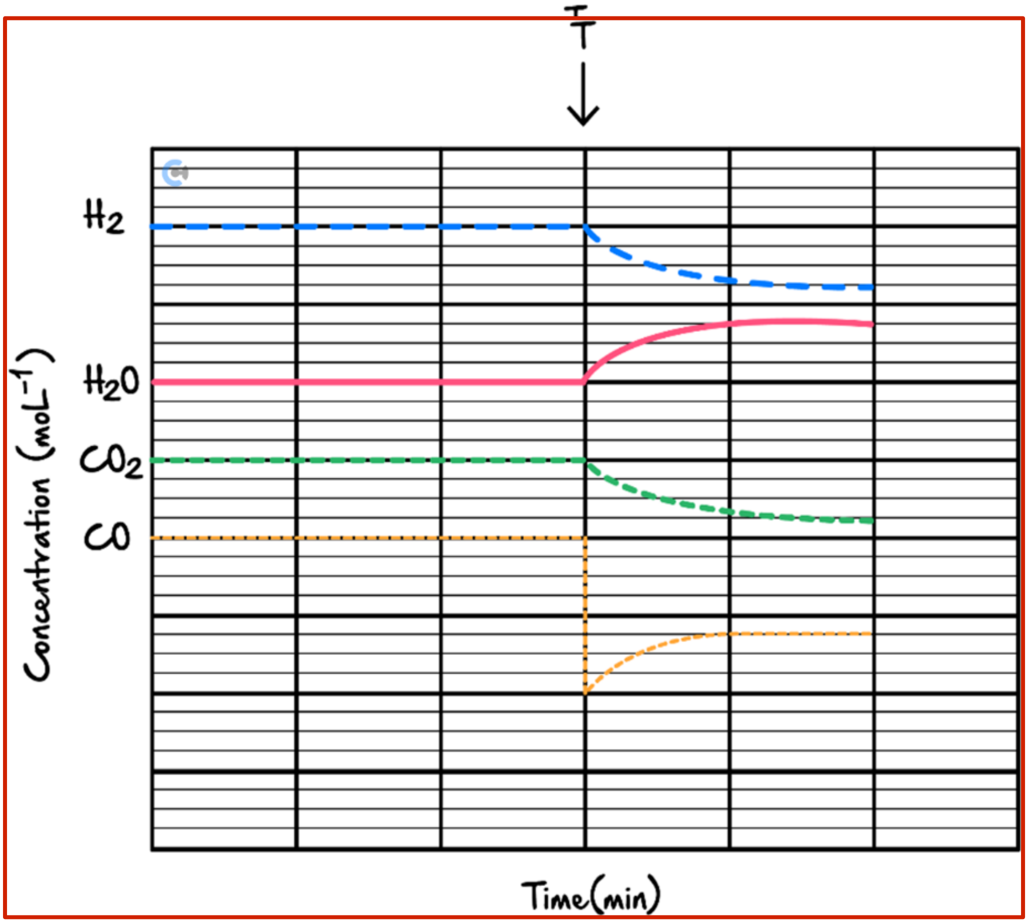
The concentrations of reactants and products as a function of time for the following system were determined.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

At time T, some $CO(g)$ was removed from the system.

a. The concentration of CO after time T is shown.

Sketch the concentrations after time T for the remaining species. (2 marks)



Criteria	Marks
• Sketches the concentrations correctly	2
• Provides some correct features	1

b. Using collision theory, explain the change in the concentration of CO after time T. (3 marks)

Criteria	Marks
• Provides a thorough explanation of the change in the concentration of CO	3
• Provides some explanation of the change in the concentration of CO	2
• Provides some relevant information	1

At time T, the concentration of CO was decreased.
A decrease in the concentration of CO results in a decrease in the rate of the forward reaction due to fewer collisions between CO and H_2O molecules.
The rate of the reverse reaction is now greater than the forward reaction so the concentrations of $H_2(g)$ and $CO_2(g)$ decrease. As this occurs, the concentrations of $CO(g)$ and $H_2O(g)$ gradually increase.
The rate of the forward reaction subsequently increases until at some point the rate of the reverse reaction will be the same as the rate of the forward reaction as equilibrium is established.

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Section D: [2.9] - Rate Yield Conflict (29 Marks)

Sub-Section: Recap

Cheat Sheet

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

- Inert Gas on Equilibrium Position: ____ No effect ____
- Temperature:

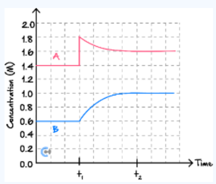
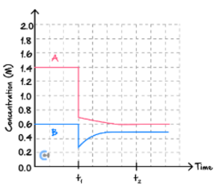
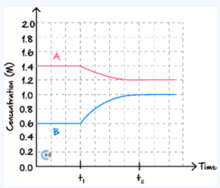
Change to System	System's Respond (Le Chatelier's Effect)	Reaction Favoured
Increase in Temperature	[increase] / [decrease] temperature.	[endothermic] / [exothermic]
Decrease in Temperature	[increase] / [decrease] temperature.	[endothermic] / [exothermic]

- Equilibrium Constant (K_c): ____ changes ____
- Sample Response:
  1. Temp is increased/decreased.
  2. According to Le Chatelier's Principle, system ____ partially opposes ____ the change by increasing/decreasing temperature.
  3. Favours endothermic/exothermic forwards/backwards reaction.

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

- Temperature: [has] / [doesn't have] initial spike.
- Inert gas: Has ____ no effect ____ 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].

[2.9.3] - Find the change made to the system from the equilibrium graph

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]

Cheat Sheet

[2.9.4] - Find equilibrium constant changes due to temperature

- During temperature change, if reaction shifts:

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

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

- **Rate-Yield Conflict:**

Example #1: $A + B \rightleftharpoons C \quad \Delta H = -100\ kJ/mol$

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 add a catalyst.
- To maximise yield, always add reactants, remove products.
- Green Chemistry Principles: design for energy efficiency, catalysis.

Let's walkthrough together!

Question 26 (4 marks) **Walkthrough.**

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

$$3A(g) \rightleftharpoons xB(g) + C(g)$$

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. (2 marks) **[2.9.1] [2.9.3]**

Exothermic. As temperature is increased, the system partially opposes the change by decreasing temperature, favouring the endothermic reaction. As the concentration of C is seen to decrease, the backwards reaction must have been favoured. As such, the backwards reaction must be endothermic, meaning that the 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 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. (2 marks) **[2.9.1] [2.9.3]**

2 - As volume is increased, the overall pressure is decreased. According to LCP, the system partially opposes the change by increasing overall pressure back down, favouring the side with more particles. As the amount of B present has decreased, the backwards reaction was favoured, meaning the left side of the equation has less particles (3). This means the right hand side of the equation has more particles, and as such, the coefficient of x must be 3.

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Sub-Section: Question Set *A*

INSTRUCTION: 10 Marks. 10 Minutes Writing.

Question 27 (1 mark) **[2.9.1]**

What happens when the temperature of the following equilibrium system is increased?

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -91\ kJ$$

	Position of equilibrium	Reaction rates of forward and reverse reactions
A.	Shifts to the left	Increase
B.	Shifts to the left	Decrease
C.	Shifts to the right	Decrease
D.	Shifts to the right	Increase

Question 28 (1 mark) **[2.9.1]**

Sulphur dioxide and oxygen are mixed to form sulphur trioxide according to the equation below. Which one of the following best describes the effect of adding the catalyst V_2O_5 to the mixture?

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

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

Question 29 (4 marks)

When the colourless ions $Fe^{3+}(aq)$ and $SCN^{-}(aq)$ react together, the complex ion $Fe(SCN)^{2+}(aq)$ forms in an equilibrium reaction. The complex ion is a deep red colour. At room temperature the equilibrium constant favours the product side of the reaction.

The reaction is shown below.

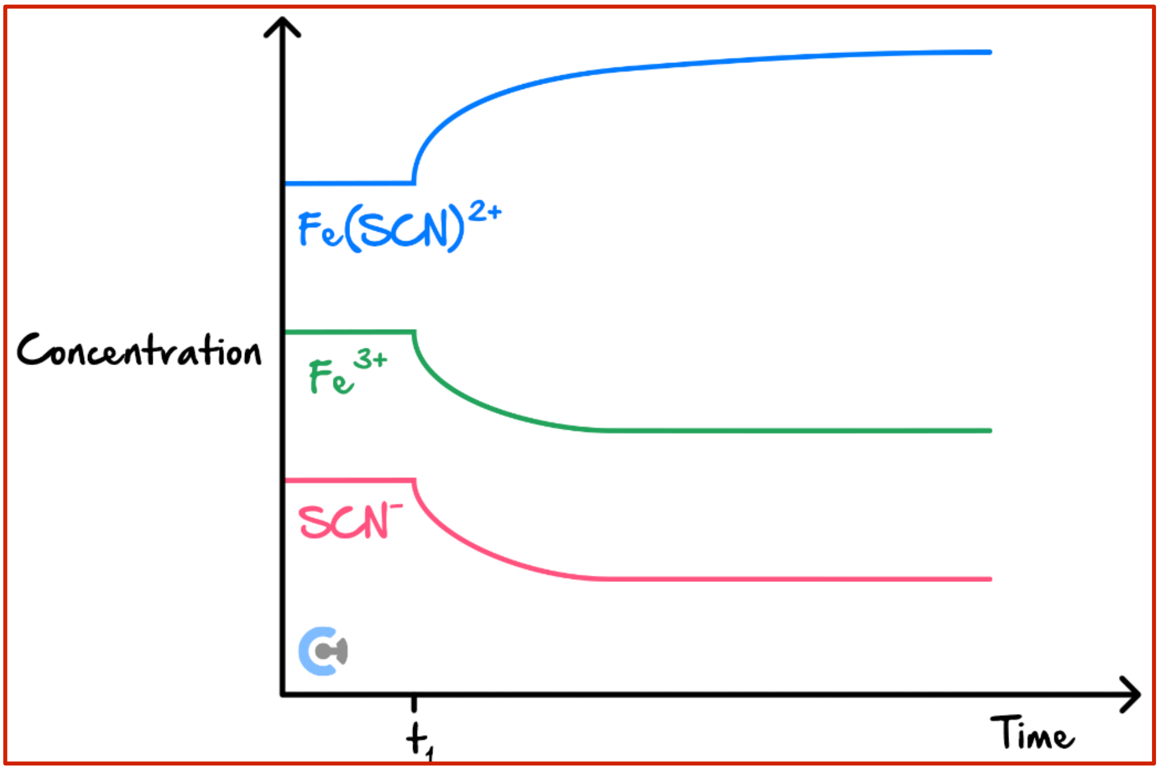
$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

a. 50 mL of 1.0 M $Fe^{3+}(aq)$ and 50 mL of 1.0 M $SCN^{-}(aq)$ are mixed in a beaker and allowed to reach equilibrium.

Tick the correct statement/s for the equilibrium system in the table below. (1 mark)

The contents of the beaker will be coloured red.	✓
The concentration of Fe^{3+} ions in the beaker is 1.0 M.	
The formation of $FeSCN^{2+}(aq)$ ceases at equilibrium.	
The $[SCN^{-}]$ remains constant at equilibrium.	✓

b. Another sample of an equilibrium mixture was cooled at a time t_1.The graph below shows the initial concentrations of ions in the mixture and how the concentration of SCN^- ions changed after the **cooling** at the time t_1.



i. Complete the graph by showing the changes in concentrations in Fe^{3+} and $Fe(SCN)^{2+}$ until equilibrium is reached again. (1 mark) **[2.9.2]**

ii. Based on the information given, is the formation of $Fe(SCN)^{2+}$ an endothermic or exothermic reaction? Explain your choice. (2 marks) **[2.9.1]**

exothermic

The mixture was cooled at t_1, which caused more product to be generated and reactants to be used up. When an equilibrium mixture is cooled, the change will be opposed and so more heat will be generated; that is, the forward reaction is exothermic.

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Question 30 (4 marks)

A solution is prepared for the following equilibrium. The value of the equilibrium constant at 20°C is 50.

$$A(aq) + 2B(aq) \rightleftharpoons 2C(aq) + D(aq) \qquad \Delta H = +100\ kJ\ mol^{-1}$$

A(aq) is a dark blue colour but all of the other species present are colourless. The following tests are carried out on separate samples of the solution.

Test 1	A few mL of a concentrated solution of A are mixed into the solution.
Test 2	A few mL of a concentrated solution that reacts readily with B **only** are mixed into the solution.
Test 3	The solution is heated from 20°C to 40°C.
Test 4	A catalyst is added to the solution.

a. For each of the tests, predict whether the mixture would be darker, lighter or unchanged. Place a tick (✓) in the column of your choice. (2 marks) **[2.8.3] [2.9.1]**

	Test result: Solution colour		
	Darker	**Lighter**	**No change**
Test 1	✓		
Test 2	✓		
Test 3		✓	
Test 4			✓

b. For each of the tests, predict whether the value of the equilibrium constant would be greater than, less than or equal to 50. For each of your predictions give an explanation. (2 marks) **[2.9.4]**

	Test result: Value of K_c		
	> 50	**= 50**	**< 50**
Test 1		✓	
Test 2		✓	
Test 3	✓		
Test 4		✓	

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Sub-Section: Question Set B

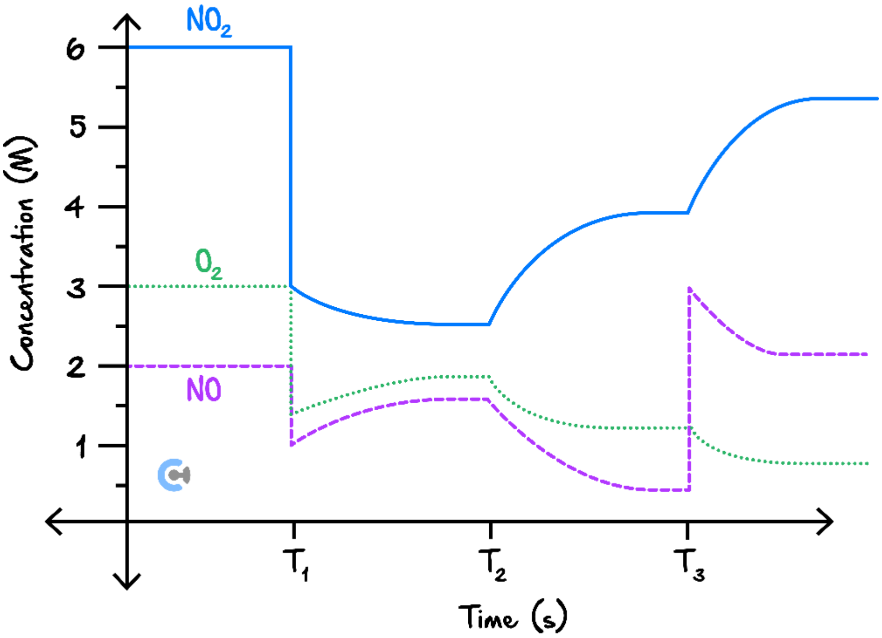
INSTRUCTION: 12 Marks. 12 Minutes Writing.

Question 31 (7 marks)

For the reaction:

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g), \qquad \Delta H < 0$$

a. The system has some changes made at three different times, as shown in the graph below.



i. Identify a change that could have been made to the system at T_1. (1 mark) **[2.9.3]**

Volume increased/pressure decreased.

ii. At T_2. (1 mark) **[2.9.3] [2.9.1]**

A. The rate of the reverse reaction has increased.

B. The rate of the forward reaction has decreased.

C. Temperature was increased.

D. The equilibrium constant value decreased.

iii. At T_3. (1 mark) **[2.9.3]**

A. The equilibrium constant changed value.

B. More of both reactants were added to the reaction vessel.

C. Some of the products were removed.

D. Nitrogen dioxide gas is formed at a faster rate of reaction.

b. Determine the pressure and temperature conditions required to maximise the:

i. Rate of reaction. (1 mark) **[2.9.5]**

High temperature and high pressure for maximising rate.

ii. Equilibrium yield of NO_2. (1 mark) **[2.9.5]**

Low temperature and High pressure for maximising yield.

c. Determine the pressure and temperature conditions that should be used to maximise the rate and equilibrium yield of nitrogen dioxide gas. Justify your answer. (2 marks) **[2.9.5]**

High pressure – maximises both rate and yield.
Moderate temperature – there is a rate yield conflict!

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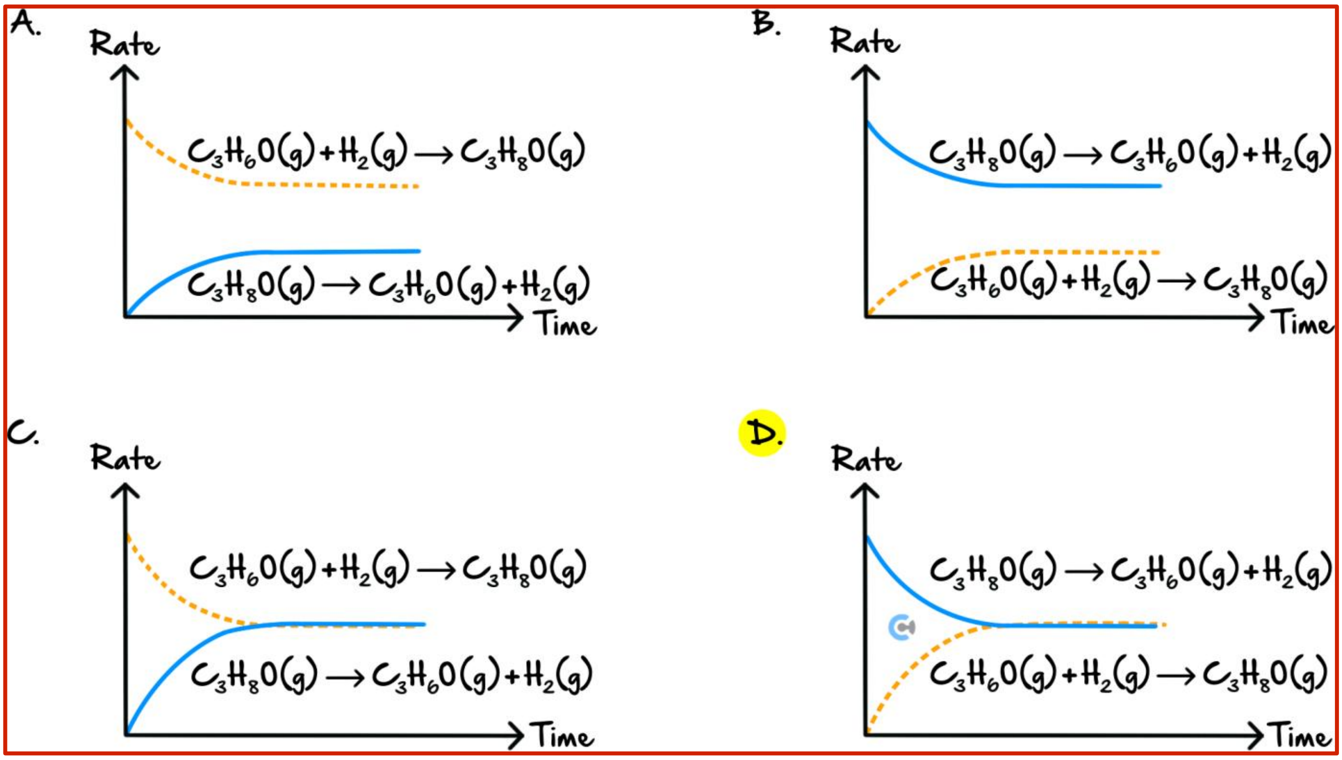
Question 32 (1 mark) **[2.8.3]**

When 2-propanol (C_3H_8O) reacts to form an equilibrium mixture with propanone (C_3H_6O) and hydrogen gas, which one of the following best represents how the **rates** of the forward and back reactions change over time?



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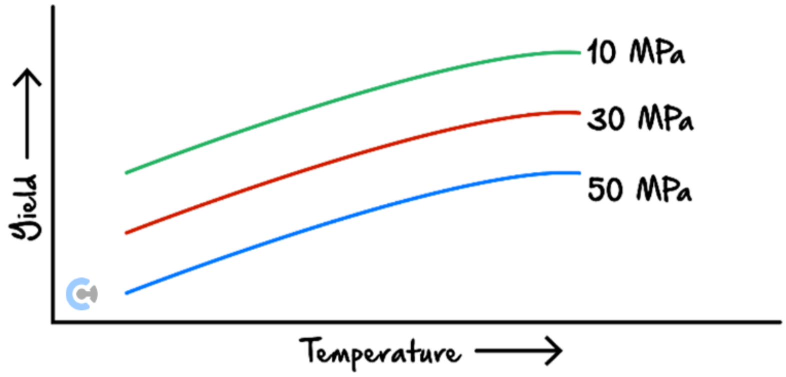
Question 33 (1 mark) **[2.9.5]**

Compounds X, Y and Z are in equilibrium. The diagram shows the effects of temperature and pressure on the equilibrium yield of compound Z.



Which equation would be consistent with this data?

A. $X + 3Y \rightleftharpoons 2Z \quad \Delta H > 0$

B. $X + 3Y \rightleftharpoons 2Z \quad \Delta H < 0$

C. $2X \rightleftharpoons 2Y + Z \quad \Delta H < 0$

D. $2X \rightleftharpoons 2Y + Z \quad \Delta H > 0$

Space for Personal Notes

Question 34 (3 marks) **[2.9.1]**

A gas mixture is placed in the following gas syringe:

Sulphur dioxide and oxygen gas are placed into the gas syringe, whereby they are allowed to reach equilibrium according to the following equation:

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

Once the system reaches equilibrium, some helium gas is added to the mixture. Describe the effect this has on the position of equilibrium. Justify your answer.

As the gas syringe has an unfixed volume, adding inert gas will increase the volume of the gas mixture. This decreases overall concentration. According to Le Chatelier's Principle, the system partially opposes the change by increasing overall concentration, favouring the LHS with more particles. As such, the backwards reaction is favoured.

Check off any learning objectives obtained full marks from the "Contour Check" booklet!

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Sub-Section: Additional Questions

Question 35 (3 marks)

Inspired from VCAA Chemistry Exam 1 2005
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/05chem1.pdf#page=20

Dinitrogen tetroxide (N_2O_4) is a colourless gas. It exists in equilibrium with nitrogen dioxide (NO_2), a brown gas. The concentration of NO_2 in a gas mixture can be determined using a spectrophotometer. The equation for the reaction is:

$$N_2O_4(g) \rightleftharpoons 2NO_2(g); K = 5.5 \times 10^{-3}\ M \text{ at } 25°C \ldots\ldots\ldots\ldots(1)$$

brown

Some pure NO_2 is placed in a gas syringe at 25°C and allowed to reach equilibrium.

a. Keeping the volume constant, the temperature is then raised to 35°C. The brown colour then becomes more intense. Is the above reaction (1) exothermic or endothermic? Explain your answer. (2 marks) **[2.8.1]**

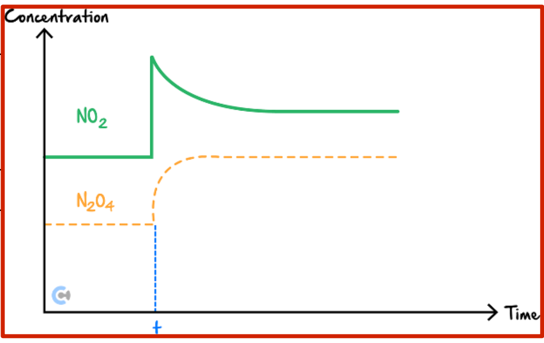
Marks	**0**	**1**	**2**	**3**	**Average**
%	12	13	62	12	**1.8**

Endothermic*
The position of equilibrium has moved to the right (more NO_2 is produced) at the higher temperature. *

b. Keeping the temperature at 35°C the plunger of the syringe is then pushed in so as to halve the volume. Equilibrium is then re-established. Is the brown colour of the mixture more intense or less intense than before the volume was halved? (1 mark) **[2.8.3]**

More intense

When the volume of the syringe is halved, the $[NO_2]$ doubles. As the system responds by the position of equilibrium moving to the side with fewer particles the $[NO_2]$ decreases, but not back to its original concentration, so the brown colour is more intense at the new equilibrium.



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