Chapter 1

Chemical Equilibrium

Answers

Problem Set 1 – Chemical Equilibrium BTG

Progressive Questions

Concept 1

Chemical Equilibrium BTG – Progressive Questions Answers

Understanding reaction rates at a basic level: Q1

1. **[8 marks]**

(a) **Increase** (b) **Decrease** (c) **Decrease** (d) **No Change** (e) **Decrease**

(f) **Decrease** (g) **Increase** (h) **Decrease**

Points to note: For part (d), it is important to just keep in mind that the addition of **solids or liquids have no influence on reaction rate.** For part (h), adding a diluted solution of KI will increase the system volume faster than it increases the concentration, therefore decreasing the reaction rate rather than increasing it.

Marking Criteria	Marks Allocated
• Correct comment made about the change in reaction rate	$1 - 8$
Total	$\mathbf{8}$
Note: No marks for use of terminology that does not include 'Increase', 'Decrease' or 'No Change'	

Recognising endothermic vs exothermic and drawing enthalpy diagrams: Q2 & Q3

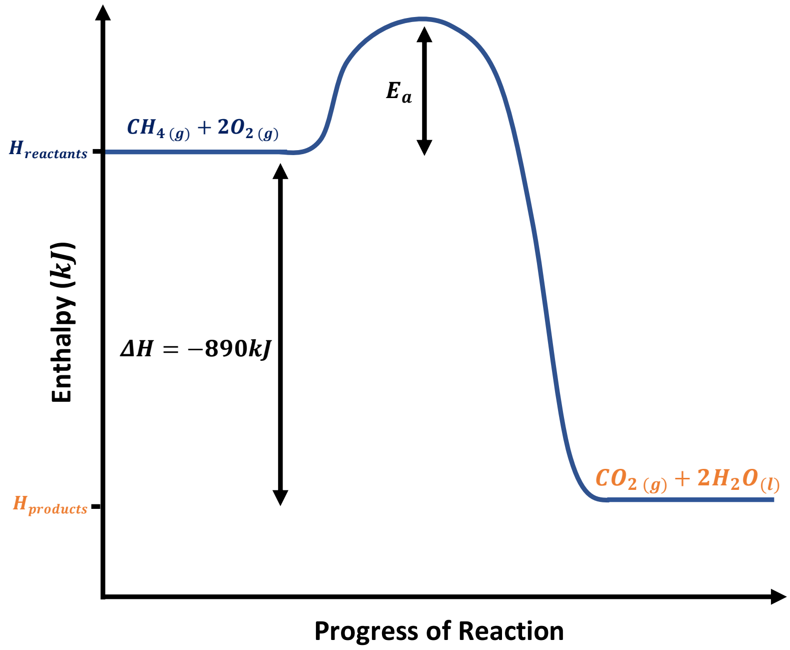
2. **[4 marks]**

(i) **Endothermic** (ii) **Endothermic** (iii) **Exothermic** (iv) **Endothermic**

Points to note: For parts (iii) and (iv), the key point is to remember that exothermic reactions form products with more stable bonds (e.g. water to ice), whereas endothermic reactions form products with less stable bonds (e.g. water to water vapor).

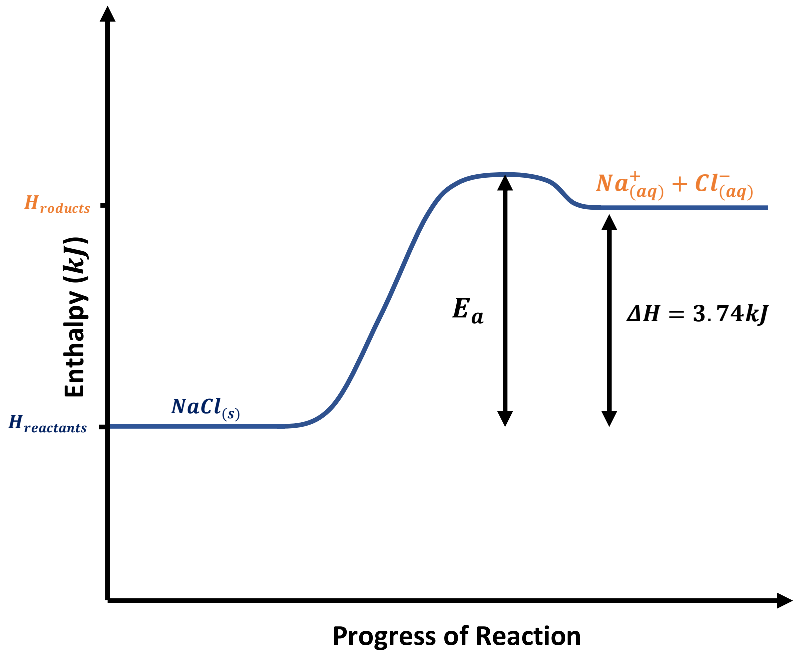
Marking Criteria	Marks Allocated
• Correct determination of whether each reaction is endothermic or exothermic	$1 - 4$
Total	$\mathbf{4}$

1 (a) **[20 marks]**



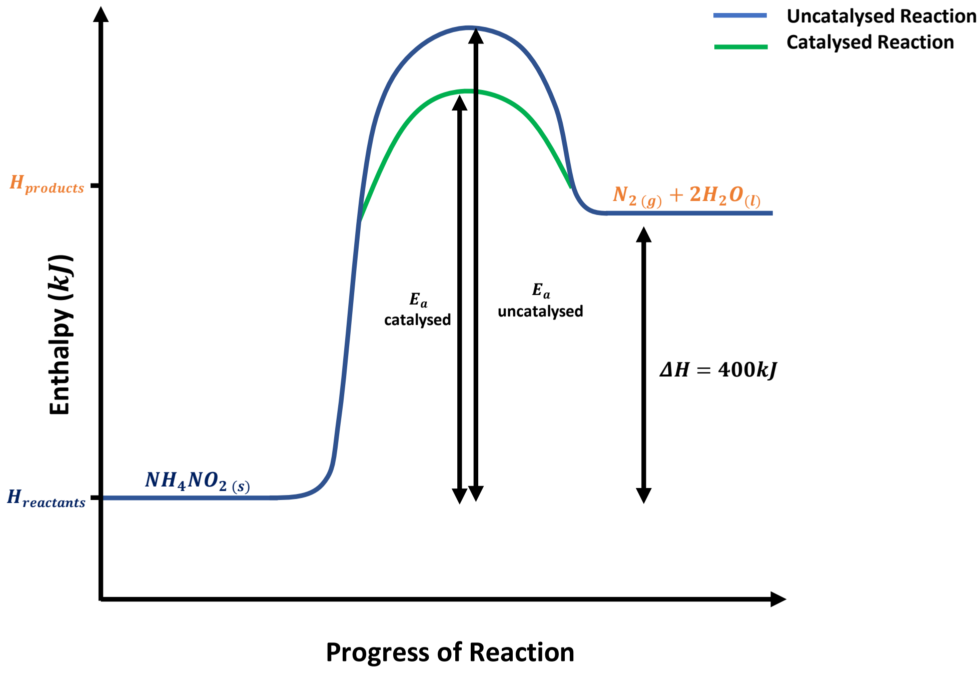
Marking Criteria	Marks Allocated
• Exothermic reaction curve • Correct axis labels • Correct ΔH and E_a labels • Reactants and products correctly labelled	$1 - 4$
Total	**4**

(b)

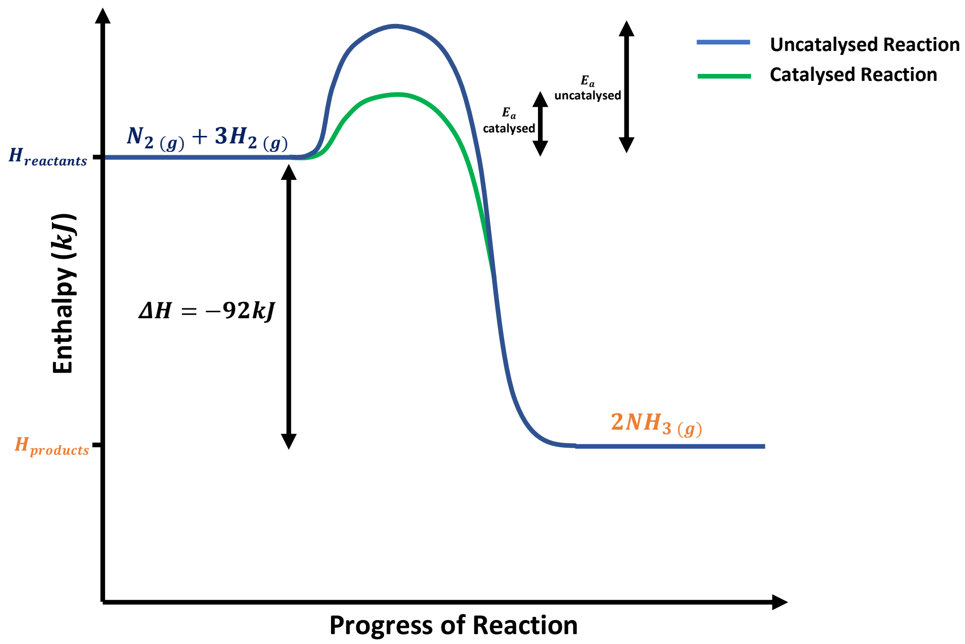


Marking Criteria	Marks Allocated
• Endothermic reaction curve • Correct axis labels • Correct ΔH and E_a labels • Reactants and products correctly labelled	$1 - 4$
Total	**4**

(c)



(d)



Marking Criteria	Marks Allocated
• Exothermic reaction curve • Correct axis labels • Correct ΔH label • Reactants and products correctly labelled • Appropriate catalyst curve • Activation energies appropriately labelled	$1-6$
Total	**6**

Problem Set 1 – Chemical Equilibrium BTG

Repetitive Questions

Concept 1

Chemical Equilibrium BTG – Repetitive Questions Answers

Understanding reaction rates at a basic level: Qs 1.1, 1.11

1.1 **[5 marks]**

(a) **Increase** (b) **Decrease** (c) **No change** (d) **Increase** (e) **Increase**

Marking Criteria	Marks Allocated
• Correct comment made about the change in reaction rate	$1-5$
Total	$\mathbf{5}$
Note: No marks for use of terminology that does not include 'Increase', 'Decrease' or 'No Change'	

1.11 **[6 marks]**

(a) **Decrease** (b) **Increase** (c) **Increase** (d) **Increase** (e) **Decrease**

(f) **Decrease**

Marking Criteria	Marks Allocated
• Correct comment made about the change in reaction rate	$1-8$
Total	$\mathbf{8}$
Note: No marks for use of terminology that does not include 'Increase', 'Decrease' or 'No Change'	

Recognising endothermic vs exothermic and drawing enthalpy diagrams: Qs 1.2, 1.21

1.2 **[4 marks]**

(i) **Exothermic** (ii) **Endothermic** (iii) **Exothermic** (iv) **Endothermic**

Points to note: For these you will need to draw upon your knowledge of recognising endothermic vs exothermic reactions by either the ΔH value or the side of the equation by which the energy is on.

Marking Criteria	Marks Allocated
• Correct determination of whether each reaction is endothermic or exothermic	$1-4$
Total	$\mathbf{4}$

1.21 **[4 marks]**

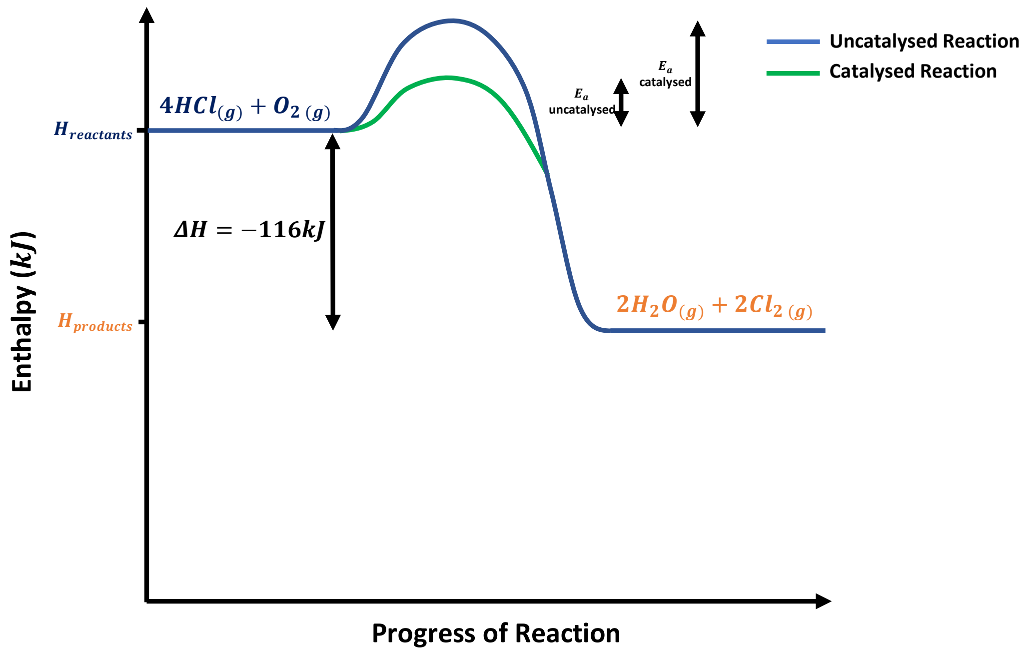
(i) **Exothermic** (ii) **Endothermic** (iii) **Endothermic** (iv) **Exothermic**

Points to note: For this question, the key point is to remember that exothermic reactions form products with more stable bonds (e.g. water to ice), whereas endothermic reactions form products with less stable bonds (e.g. water to water vapor).

Marking Criteria	Marks Allocated
• Correct determination of whether each reaction is endothermic or exothermic	$1-4$
Total	**4**

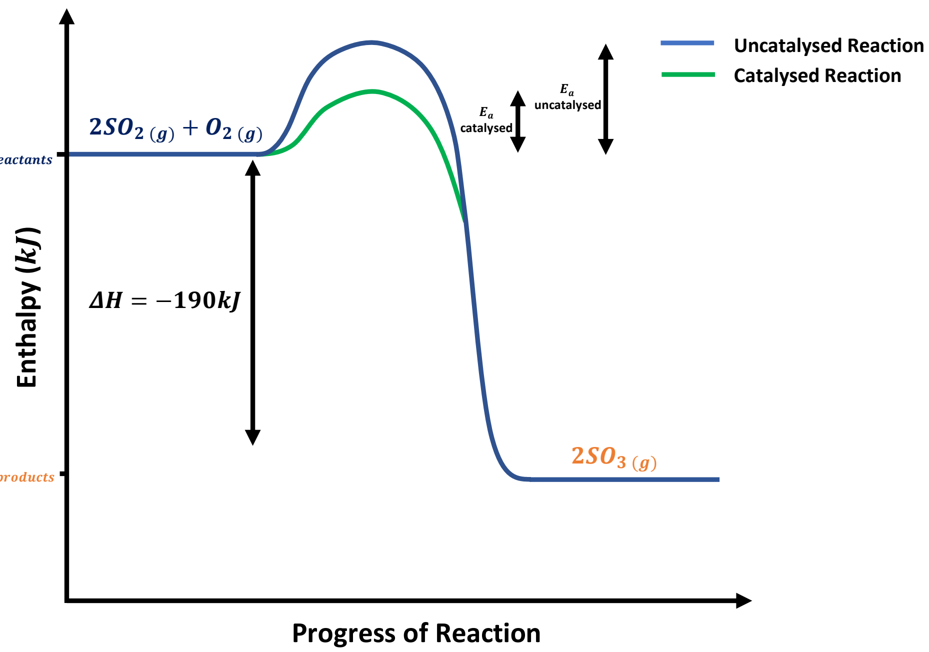
1.3 **[18 marks]**

(a)

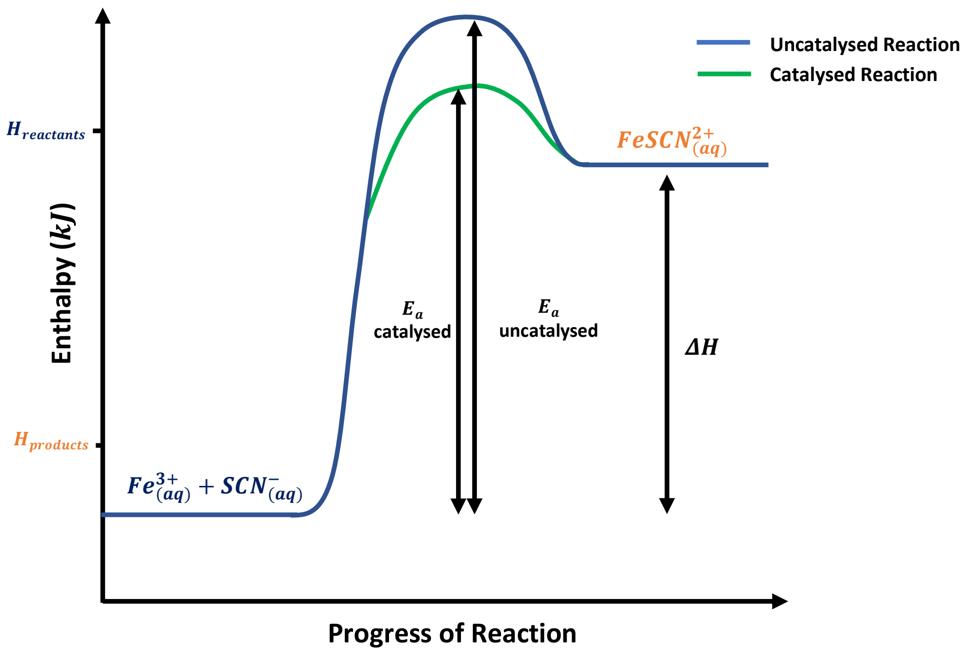


Marking Criteria	Marks Allocated
• Exothermic reaction curve • Correct axis labels • Correct ΔH label • Reactants and products correctly labelled • Appropriate catalyst curve • Activation energies appropriately labelled	$1-6$
Total	**6**

(b)



(c)



Marking Criteria	Marks Allocated
• Endothermic reaction curve • Correct axis labels • Correct ΔH label • Reactants and products correctly labelled • Appropriate catalyst curve • Activation energies appropriately labelled	$1 - 6$
Total	**6**

Problem Set 2 – Qualitative Chemical Equilibrium

Progressive Questions

Concept 1

Equilibrium Constant K_c – Progressive Questions Answers

K_c and reaction extent: Q1 & Q2

1. **[5 marks]**

(a) (i) $K_c = [Cl_2]$ (ii) $K_c = \frac{[Cr_2O_7^{2-}]}{[CrO_4^{2-}]^2[H^+]^2}$ (iii) $K_c = \frac{1}{[O_2]}$

(iv) $K_c = \frac{[Zn^{2+}][NH_3]^2}{[NH_4^+]^2}$ (v) $K_c = \frac{1}{[SO_4^{2-}]^2[H^+]^4}$

Points to note: A key point to remember is that solids and liquids **are not included** in the equilibrium constant. Also remember to raise the concentrations to the power of their co-efficient.

Marking Criteria	Marks Allocated
• Correct equilibrium law calculation	$1-5$
Total	**5**
Note: Deduct one mark if '$K_c =$' is not used	

(b)

Each equilibrium constant, K_c , reflects the extent to which a reaction has occurred.

- Reaction (i) has an extremely small equilibrium constant, which indicates **negligible reaction** occurs so **mostly reactants** are present (with almost no product particles present) **(1)**.
- Reaction (iii) has a large equilibrium constant, which indicates that the reaction occurs to **near completion** so **mostly products** are present (with almost no reactant particles present) **(1)**.
- Reaction (v) it has a moderately sized equilibrium constant, which indicates that the reaction occurs to a **moderate extent**, so **similar amounts** of reactants and products will be present **(1)**.

Marking Criteria	Marks Allocated
• One mark for each correct comment made about the extent of the reaction	$1-3$
Total	**3**

2. **[3 marks]**

(i) $K_c = \frac{[HCl][C_2F_4]}{[CHCF_2]^2}$ (ii) $K_c = \frac{[C_2F_4]}{[CHCF_2]^2}$ (iii) $K_c = [C_2F_4]$

Points to note: The key is to determine when it is a solid or liquid, because then it will no longer be included in the equilibrium constant.

Marking Criteria	Marks Allocated
• Correct equilibrium constant	$1-3$
Total	**3**
Note: deduct one mark if '$K_c =$' is not used	

3. **[8 marks]**

(a) Firstly, we will need to write K_c:

$$K_c = \frac{[H_2][CO_2]}{[H_2O][CO]}$$

$$K_c = \frac{[0.91][0.56]}{[0.1][0.17]}$$

$$= 30 \qquad \textbf{(1)}$$

$$K_c = \frac{[NO_2]^2}{[N_2O_4]}$$

$$K_c = \frac{[0.0015]^2}{[0.81]}$$

$$= 2.8 \times 10^{-6} \qquad \textbf{(1)}$$

With an equilibrium constant of 30 for system A this indicates that the reaction has occurred to a moderate extent with the system containing considerable amounts of reactants and products, but more product than reactant because the constant is larger than 1 **(1)**. For system B, a very small equilibrium constant of 2.8×10^{-6} indicates the reaction has occurred to a negligible extent with the system containing mostly reactants, with almost no product particles present. **(1)**

Marking Criteria	Marks Allocated
• Correct equilibrium constant calculation with appropriate workings	$\mathbf{1-2}$
• Correct comment made about the extent of each reaction	$\mathbf{1-2}$
Total	**4**

(b) When the temperature of both systems is doubled, the average kinetic energy of all reacting particles will increase **(1)**. According to Le Chatelier's Principle, the system will act to partially oppose this temperature increase by favoring the endothermic reaction in order to consume some of the increased system energy **(1)**. As a result, the reverse reaction for system A will be favoured thus reducing the size of its equilibrium constant and therefore the extent to which its reaction occurs **(1)**, and for system B the forward reaction will be favoured thus increasing the size of its equilibrium constant and therefore increasing the extent to which its reaction occurs **(1)**.

Marking Criteria	Marks Allocated
• Stating that an increasing the temperature, increases the average kinetic energy of particles • Application of Le Chatelier's Principle to state that endothermic reaction will be favoured in each system	$1-2$
• One mark for each correct comment made about how the extent of the reaction will change with the changing temperature	$1-2$
Total	**4**
Note: for full marks, student must make mention of whether forward or reverse reaction is favoured for each system	

Concept 2

Le Chatelier's Principle – Progressive Questions Answers

Foundational understanding of LCP: Q1

1. **[8 marks]**

Change to system	Reaction favoured	$[N_2]$	$[H_2]$	$[NH_3]$
1. Some N_2 is added	**Forward**	**Increase**	**Decrease**	**Increase**
2. Some H_2 is removed	**Reverse**	**Increase**	**Decrease**	**Decrease**
3. Some NH_3 is added	**Reverse**	**Increase**	**Increase**	**Increase**
4. Temperature is increased	**Reverse**	**Increase**	**Increase**	**Decrease**
5. Temperature is decreased	**Forward**	**Decrease**	**Decrease**	**Increase**
6. Pressure is increased	**Forward**	**Increase**	**Increase**	**Increase**
7. Volume is increased	**Reverse**	**Decrease**	**Decrease**	**Decrease**
8. Argon gas (inert) is added at constant pressure	**Reverse**	**Decrease**	**Decrease**	**Decrease**

Points to Note: Determining which reaction is favoured should become fairly straightforward however some of the concentration increase/decreases are designed to trip you up:

- For changes 1 & 3, you will need realise that the concentration of N_2 and NH_3 will still be increased because they are only partially consumed, and for change 2 you will need to realise that the concentration of H_2 is still decreased because its concentration is only partially restored
- For changes 7 & 8, you will need to realise that the concentration of all reactants will be decreased because when the volume of the system is increased the system can only partially restore the concentration drops. Irrespective of the reaction that is favoured there will always be a net decrease in the concentrations of all reactants.

Marking Criteria	Marks Allocated
• 1 mark for each correct row	$1-8$
Total	**8**
Note: no half marks are awarded for making only one error	

Observing molar ratios for volume changes and enthalpy for temperature changes: Q2

2. **[8 marks]**

(a) **(i) Right** **(ii) Left** **(iii) No Shift** **(iv) Left** **(v) No Shift**

Points to Note: To determine which way the equilibrium will shift you will simply need to compare the number of moles on each side of the equation and see which side has the largest change, remembering not to include solids or liquids in the 'number of moles'. The side with more moles of gas will be the side the equilibrium position shifts towards. For (iii) and (v) there is no shift because the number of moles on each side is even.

Marking Criteria	Marks Allocated
• 1 mark for each correctly stated change	$1 - 5$
Total	**5**
Note: no marks are awarded for using terminology that is not 'Left', 'Right' or 'No Shift'	

(b) **(i) Right** **(iii) Left** **(v) Right**

Points to Note: For a temperature decrease you will need to find the exothermic reaction of each system, and the products of that exothermic reaction will be the side to which the equilibrium position shifts

Marking Criteria	Marks Allocated
• 1 mark for each correctly stated change	$1 - 3$
Total	**3**
Note: no marks are awarded for using terminology that is not 'Left', 'Right' or 'No Shift'	

Using LCP to predict colour changes: Q3, Q4

3. **[8 marks]**

(a) Light Brown

Marking Criteria	Marks Allocated
• Stating initial colour is 'light brown'	1
Total	**1**

(b)

(i) Darker brown (ii) Lighter brown (iii) Darker brown (iv) No effect

Marking Criteria	Marks Allocated
• 1 mark for each correctly stated colour	$1 - 4$
Total	**4**
Note: no marks are awarded for using terminology that is not 'Lighter brown', 'Darker brown' and 'No effect'	

(c) When the temperature of the system is decreased, the average kinetic energy of all reacting particles will decrease **(1)**. According to Le Chatelier's Principle, the system will act to partially oppose this temperature decrease by favouring the exothermic reaction in order to replace some of the lost energy **(1)**. Thus, the reverse reaction is favoured, resulting in the system will becoming a lighter brown colour as some of the nitrogen dioxide is consumed **(1)**.

Marking Criteria	Marks Allocated

• A temperature decrease, decreases the average kinetic energy of the system particles • According to Le Chatelier's Principle, the system will shift to favour the exothermic reaction, which will reproduce some of the consumed heat • A favoured reverse reaction will consume some NO_2 making the system a lighter brown colour	$1-3$
Total	**3**

4. **[9 marks]**

(i) When some additional chromate ions are added to the system, the concentration of chromate ions will increase, and the system will turn a darker yellow colour **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration increase by favouring the reaction that consumes some of the added chromate ions **(1)**. Thus, the system will favour the forward reaction and the system will restore to a more orangey-yellow colour, however will be more yellow than before the chromate ions were initially added **(1)**.

Marking Criteria	Marks Allocated
• Stating that the additional concentration increases the concentration of the reactants for the forward reaction, accounting for the initial 'darker yellow' colour change • Applying LCP to state the system will act to consume some of the added chromate ions • Correct conclusion that the system will favour the forward reaction and the system will return to 'orangey-yellow', however more yellow than initially	$1-3$
Total	**3**
Note: To attain full marks, there must be mention that the yellow colour change is only partially opposed	

(ii) When the volume of the system is increased by adding water, the concentration of all reacting particles will decrease causing the solution to become a lighter orangey-yellow **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this total concentration decrease by favouring the reaction that produces more moles of aqueous product **(1)**. Thus, the system will favour the reverse reaction and the system will become less orange and more yellow, however will still remain a much lighter colour than initially because the initial concentration drop is only partially opposed **(1)**.

Marking Criteria	Marks Allocated
• Stating that the volume increase causes a concentration decrease, resulting in a lighter orangey-yellow colour • Applying LCP to state the system will act to favour the reaction that produces more moles of aqueous product • Correct conclusion that the system will favour the reverse reaction and the system is a more yellow but lighter colour than initially	$1-3$
Total	**3**

Note: To attain full marks, there must be mention that the colour is lighter because the volume increase is only partially opposed

(iii) When some $NaOH$ is added, this will react with the hydrogen ions thus removing some hydrogen ions from the system. According to Le Chatelier's principle, the system will act to partially oppose this concentration decrease by favouring the reverse reaction (1), so some of the lost hydrogen ions are reproduced (1). This will cause the system to become less orange and more yellow in colour.

Points to note: A common way by which the concentration of ions in aqueous systems is decreased in exams is through adding a salt that will react to neutralise/precipitate with an ion, thus removing it from the system. In this case the hydroxide ions will react with the hydrogen ions, thus decreasing the concentration of hydrogen ions in the system.

Marking Criteria	Marks Allocated
• Determining that NaOH will react with hydrogen ions: $OH^-_{(aq)} + H_3O^+_{(aq)} \rightleftharpoons 2H_2O_{(l)}$ thus decreasing the hydrogen ion concentration in the system • Applying LCP to state the act to reproduce some of the lost hydrogen ions • Correct conclusion that the reverse reaction will be favoured, and the system will become darker yellow	$1-3$
Total	**3**
Note: The equation $OH^-_{(aq)} + H_3O^+_{(aq)} \rightleftharpoons 2H_2O_{(l)}$ does not need to be necessarily mentioned to attain full marks	

Partial pressure and tricky gaseous system questions: Q5, Q6

5. **[6 marks]**

(a) When some water vapour is added to the system, the concentration of the reactants for the reverse reaction will increase **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration increase by favouring the reaction that will consume some of the added water vapour **(1)**. Thus, the reverse reaction will be favoured **(1)**.

Points to note: Water vapour is in a gaseous state, not a liquid state, and therefore will have an influence on the reaction rates of the system

Marking Criteria	Marks Allocated
• Stating that the addition of water vapour will increase the concentration of reactants for the reverse reaction • Applying LCP to state system will act to consume some of the added water vapour • Correct conclusion that the system will favour the reverse reaction	$1-3$
Total	**3**
Note: No marks will be awarded if student does not mention Janet being correct	

(b) Janet is **incorrect.** When the partial pressure of the ammonia gas is increased, the concentration of the reactants for the forward reaction will increase **(1).** According to Le Chatelier's principle, the system will act to partially oppose this concentration increase by favouring the reaction that will consume some of the added ammonia gas **(1)**. Thus, the forward reaction will be favoured **(1)**.

Points to note: This response is very similar to part (a), because partial pressure is directly proportional to the addition/removal of reactant because both affect concentration in the same way.

Marking Criteria	Marks Allocated
• Stating that the ammonia partial pressure increase will increase the concentration of reactants for the forward reaction • Applying LCP to state system will act to consume some of the added ammonia gas • Correct conclusion that the system will favour the forward reaction	$1-3$
Total	**3**
Note: No marks will be awarded if student does not mention Janet being incorrect	

6. **[8 marks]**

(a) She is wrong, correct answer: According to Le Chatelier's Principle, when the pressure of the system is increased, the system will act to partially oppose this change by favouring the reaction that produces less moles of gaseous product **(1)**. Thus the forward reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Applying LCP to state system will act to favour the reaction that produces less moles of gaseous product • Correct conclusion that the system will favour the forward reaction	$1-2$
Total	**2**

(b) She is wrong, correct answer: When the temperature of the system is decreased, the average kinetic energy of all reacting particles will decrease **(1)**. According to Le Chatelier's Principle, the system will act to partially oppose this temperature decrease by favouring the exothermic reaction in order to replace some of the lost energy **(1)**. Thus, the reverse reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Stating that the temperature decrease will decrease the average KE of reacting particles • Applying LCP to state system will act to replace some of the lost energy by favouring the exothermic reaction • Correct conclusion that the system will favour the reverse reaction	$1-3$
Total	**3**

(c) She is wrong, correct answer: When an inert gas is added at a constant pressure, the volume of the system will increase and as a result the concentration of all reacting particles will decrease **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this total concentration decrease by favouring the reaction that produces more moles of gaseous product **(1)**. Thus the reverse reaction will be favoured **(1)**.

Points to note: Since the inert gas is added at a constant pressure, volume must give out in order to not let the pressure rise. If the inert gas was added at a constant volume, then no change would occur to the system.

Marking Criteria	Marks Allocated
• Stating that adding the inert gas at a constant pressure will increase the volume of the system • Applying LCP to state system will act to favour the reaction that produces more moles of gaseous product • Correct conclusion that the system will favour the reverse reaction	$1-3$
Total	**3**

Tricky aqueous system questions: Q7

7. **[4 marks]**

When excess sodium carbonate is added is added to the system it will react with the cobalt ions (Co^{2+}) to produce a cobalt carbonate precipitate **(1)**, as a result decreasing the concentration of cobalt ions in the system **(1)**. According to Le Chatelier's Principle the system will act to partially oppose this concentration decrease by favouring the reaction that will reproduce some of the lost cobalt ions **(1)**. Thus, the reverse reaction will be favoured **(1)**.

Points to note: this is the second kind of trick, precipitation reactions. You will need to be able to recognize that salts will often precipitate with an ion in the system, thus decreasing its concentration.

Marking Criteria	Marks Allocated
• Determining that the carbonate ions will react with the cobalt ions to produce cobalt carbonate: $Co^{2+}_{(aq)} + CO^{2-}_{3\,(aq)} \rightarrow CoCO_{3\,(s)}$ • Stating that the cobalt ion concentration will decrease • Applying LCP to state system will act to reproduce some of the lost cobalt ions • Correct conclusion that the system will favour the reverse reaction	$1-4$
Total	**4**
Note: The equation $Co^{2+}_{(aq)} + CO^{2-}_{3\,(aq)} \rightarrow CoCO_{3\,(s)}$ does not need to be stated to attain full marks	

Yield questions: Q8

8. **[4 marks]**

(i) Increase (ii) Decrease (iii) Increase (iv) Increase

Points to note: Yield is not the same as concentration, it is the amount of a substance you can get from a reaction. Thus for changes (iii) and (iv), whilst the concentration of carbon disulfide is decreased from an increasing volume, the yield is still increased because we are still technically getting more carbon disulfide from a favoured forward reaction.

Marking Criteria	Marks Allocated

• One mark for each correct comment made about the change to the yield of the reaction	$1-4$
Total	**4**
Note: no marks are awarded for terminology that does not include ‘Increase’, ‘Decrease’ or ‘No change’	

Explanation correction questions: Q9

9. **[6 marks]**

Jamie, Alex and Dylan are all technically incorrect however some parts of their statements are correct **(1)**. When the volume of the system is increased by adding water to the system, the concentration of all the reacting particles will decrease causing the solution to turn a lighter blue colour **(1)**. According to Le Chatelier’s principle, the system will act to partially oppose this total concentration decrease by favouring the reaction that produces more moles of aqueous product **(1)**. Thus the system will favour the reverse reaction and the system will become a light pink colour, however will still remain a much lighter colour than initially because the initial concentration drop is only partially opposed **(1)**. Therefore, Jamie’s statement is entirely incorrect because the system will not remain unaffected; Alex is partially correct in saying that the system will turn pink in colour, however it is not because the concentration of water is increased since water keeps a constant concentration; and Dylan is partially correct in saying the system will turn a light blue from dilution, however did not account for the system then turning light pink **(2)**.

Marking Criteria	Marks Allocated
• Determining that the water will dilute the system, causing it to **initially** turn a lighter blue • Applying LCP to state system will act to favour the reaction that produces more moles of aqueous product • Correct conclusion that the system will favour the reverse reaction • Correct conclusion that the system will turn a light pink colour	$1-4$
• Correct comments about the validity of each of the three statements given by Alex, Jamie and Dylan	$1-2$
Total	**6**
Note: 1 mark for correctly commenting on the validity of two statements, 2 marks awarded for correctly commenting on the validity of all three statements	

‘All in one questions’ – difficult exam style questions: Q10

10. **[12 marks]**

(a)

(i) **Increase:** When some additional oxygen gas is added, according to Le Chatelier’s Principle the system will act to partially oppose this change by favouring the reaction that consumes some of the added oxygen gas, which will be the forward reaction **(1)**. Thus the concentration of oxygen gas will decrease, however there will still be a net increase because the change is only partially opposed **(1)**.

(ii) **Decrease:** When the volume of the system is increased, according to Le Chatelier's Principle the system will act to partially oppose this change by favouring the reaction that produces more moles of gaseous product, which will be the reverse reaction **(1)**. Thus the concentration of oxygen gas will increase, however the initial concentration drop is only partially opposed, so there is still a net decrease **(1)**.

(iii) **No Change:** When a catalyst is added to the system there will be no change in the equilibrium position, so according to Le Chatelier's principle the system will not act to partially oppose the change **(1)**. Thus, neither the forward nor reverse reaction will be favoured, so there will be no change in the concentration of oxygen gas **(1)**.

Points to note: Since each of these responses is only worth two marks, you will need to try and condense your LCP responses to save some time and not have to write an excessive amount just for two marks.

Marking Criteria	Marks Allocated
• 1 mark for each correct application of Le Chatelier's Principle to each change	$1-3$
• Correct comment about the changes that will occur to the concentration of oxygen gas	$1-3$
Total	**6**
Note: No marks are awarded for initially stating 'Increase', 'Decrease' or 'No Change' without supporting the claim through LCP	

(b)

(i) **Increase:** When the volume of the system is halved, according to Le Chatelier's Principle the system will act to partially oppose this change by favouring the reaction that produces less moles of gaseous product, which will be the forward reaction **(1)**. Thus the concentration of ethanol will increase, on-top of the initial concentration increase from the volume decrease **(1)**.

(ii) **Decrease:** When the temperature of the system is doubled, according to Le Chatelier's Principle the system will act to partially oppose this change by favouring the endothermic reaction, which will be the reverse reaction **(1)**. Thus the concentration of ethanol will decrease **(1)**.

(iii) **No Change:** When the argon gas is added to the system at a constant volume, according to Le Chatelier's principle, the system will not act to partially oppose this change because no change to the equilibrium position has occurred **(1)**. Thus there will be no change in the concentration of ethanol **(1)**.

Marking Criteria	Marks Allocated
• 1 mark for each correct application of Le Chatelier's Principle to each change	$1-3$
• Correct comment about the changes that will occur to the concentration of oxygen gas	$1-3$
Total	**6**
Note: No marks are awarded for initially stating 'Increase', 'Decrease' or 'No Change' without supporting the claim through LCP	

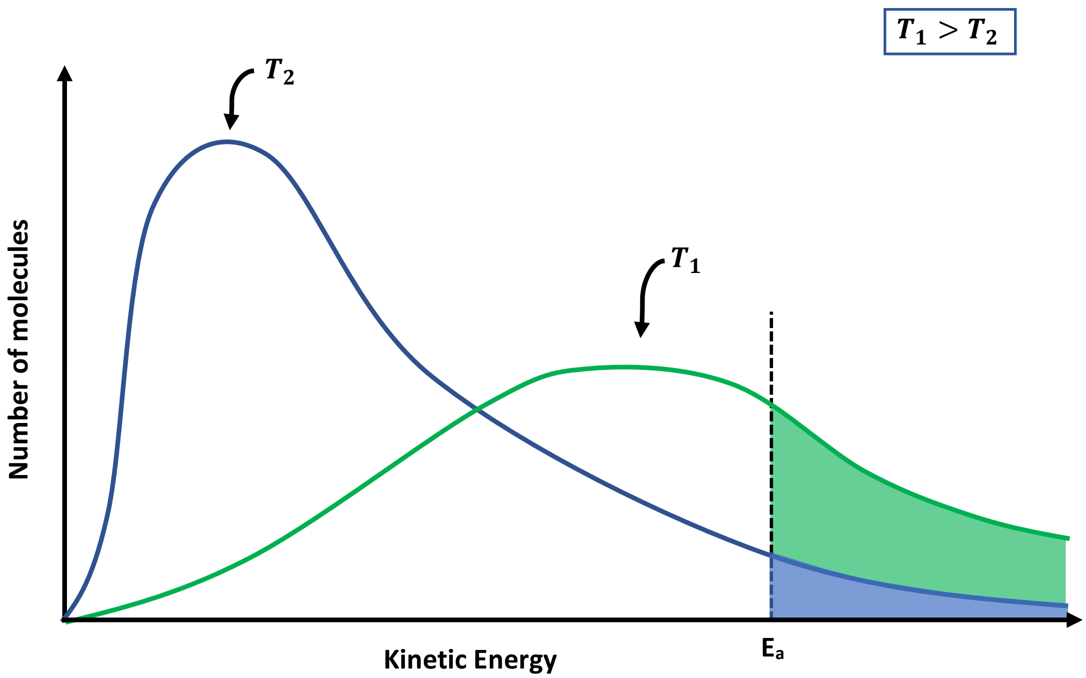
(c) Tom has won the challenge

Concept 3

Collision Theory – Progressive Questions Answers

Non-Reversible Reaction Questions: Q1

1. **[7 marks]**



(2)

This 'dramatic effect' can be best explained through the use of the Maxwell Boltzmann Curve above. When the temperature of the system is decreased from T_1 to T_2, the average kinetic energy of the particles will decrease **(1)**. This kinetic energy decrease means particles will be moving at a lower velocity and therefore collide less frequently with each other **(1)**. A lower average kinetic energy also means that a lower proportion of particles will have sufficient energy to overcome the activation energy **(1)**, as shown in by the leftwards shift of the Maxwell Boltzmann curve **(1)**. The combination of both a decrease in the frequency of collisions and a decrease in the proportion of successful collisions will have a staggeringly negative effect on the rate of successful collisions and therefore reaction rate **(1)**.

Marking Criteria	Marks Allocated
• Clearly drawn Maxwell Boltzmann Curve with appropriate labels	$1-2$
• Temperature decrease, decreases average kinetic energy of particles • Therefore, particles moving at a slower velocity, so collision frequency decreases • Also, the average kinetic energy decrease will decrease the proportion of successful collisions with sufficient energy to overcome the activation energy • Mention of Maxwell Boltzmann Curve to support this decrease in the proportion of successful collisions • Combination of both factors have dramatic effect on reaction rate decrease	$1-5$
Total	**7**
Note: Must make reference to the Maxwell Boltzmann Curve	

Tricky aqueous system questions: Q2

2. **[10 marks]**

(a) There are four macroscopic properties that can be used to predict a shift in the position of chemical equilibrium: temperature, pressure, concentration and colour. Since copper carbonate is a green solid **(1)** and copper ions are blue **(1)** the changes in the colour of the system can be used to determine if system alterations are imposed.

Marking Criteria	Marks Allocated
• Correct determination that copper carbonate is a green solid • Correct determination that copper ions are blue	$1-2$
Total	**2**
Note: Must make reference to the fact that these two colour properties can be tracked to determine system alterations, in order to attain full marks	

(b)

(i) When some additional magnesium carbonate is added to the system, the concentration of carbonate ions will increase since $MgCO_3$ will dissolve in solution. This means that the reverse reactant particles will be in a closer proximity to each other and will therefore incur a higher frequency of collisions, so the rate of the reverse reaction will increase **(1)**. As no reactant particles have been added for the forward reaction, the rate of the forward reaction will initially remain unchanged **(1)**, thus creating a net reverse reaction **(1)**. With a net reverse reaction, over time some copper ions and carbonate ions will be consumed, and some copper carbonate will be produced, causing the reverse reaction rate to gradually decrease and the forward reaction rate to gradually increase until equilibrium is re-established **(1)**

Points to note: this system is tricky to explain because copper carbonate is a solid and therefore its reaction rate does not change throughout, so you need to account for this

Marking Criteria	Marks Allocated
• Carbonate ion concentration increase will increase the reverse reactant collision frequency, so reverse reaction will increase • As no forward reactant particles have been added, the forward reaction rate will initially remain unchanged • Thus there will be a net reverse reaction • Reverse reaction rate will decrease over-time and the forward reaction rate will increase until their rates become equal and equilibrium is established	$1-4$
Total	**4**
Note: Cannot say that the forward reaction rate will increase, must say it is stagnate because it only contains solid reactants	

(ii) When some additional copper carbonate is added to the system, the concentration of copper carbonate will remain unchanged because it is a solid **(1)**. This means that the reaction rate of the forward reaction will remain unchanged since the frequency of the collisions has remain unchanged **(1)**. There is no change in the reverse reaction rate either since the concentration of reacting particles have not changed. Thus, there is no net reaction in either direction **(1)**.

Marking Criteria	Marks Allocated
• Stating that the copper carbonate concentration will remain unchanged because copper carbonate is a solid • Forward reaction rate will therefore remain unchanged • Concluding there is neither a net forward nor reverse reaction since there is also no change in reverse reaction rate	$1-3$
Total	**3**

Tricky gaseous system questions: Q3

3. **[6 marks]**

(a) Metal being added to acid releases hydrogen gas $H_{2\,(g)}$ **(1)**. Before the hydrogen gas is injected, the forward reaction rate is equal to the reverse reaction rate since the system is in equilibrium **(1)**. When the hydrogen gas is injected, the concentration of the hydrogen gas will increase. This means that the forward reactant particles will be in a closer proximity to each other and will therefore incur a higher frequency of collisions, so the rate of the forward reaction increases **(1)**. Over time, the rate of the forward reaction will decrease due to the reactants being consumed at a faster rate than they are produced, until equilibrium is re-established **(1)**.

Points to note: When Collision Theory questions are worth less than 5 marks you will need to condense your normal response by just including the essential information. This is a skill you will acquire through lots of practice.

Marking Criteria	Marks Allocated
• Determining that $H_{2\,(g)}$ was the gas added to the system • Stating that initial the forward and reverse reaction rates are equal • The injection of hydrogen gas increases the forward reactant collision frequency and therefore forward reaction rate • Forward reaction rate will decrease until equal to reverse reaction rate/equilibrium is re-established	$1-4$
Total	**4**
Note: no marks awarded for information that does not fit the criteria above	

(b) Same rate

Marking Criteria	Marks Allocated
• Stating reaction rate is stays the same	1
Total	**1**

(c) Higher

Marking Criteria	Marks Allocated
• Stating reaction rate is higher	1
Total	**1**

Colour changes explained using collision theory: Q4

4. **[5 marks]**

When the temperature of the system is increased, the average kinetic energy of all the particles will increase **(1)**. This means the particles of both the forward and reverse reactions will move at a higher velocity, incurring a higher frequency of collisions to the same extent in both the forward and reverse reactions **(1)**. A higher average particle kinetic energy also means a larger proportion of particles will have sufficient energy to overcome the activation energy for both forward and reverse reactions **(1)**. However, for the endothermic reverse reaction, there will be a greater increase in the proportion of successful collisions, thus creating a net reverse reaction **(1)**. With a net reverse reaction, some $FeSCN^{2+}$ ions will be consumed and more SCN^- ions will be produced, resulting in the solution become a paler brown colour **(1)**.

Points to note: You could probably get away with simplifying this explanation slightly, however this is the 'ideal' kind of answer

Marking Criteria	Marks Allocated
• A temperature increase, increases the average kinetic energy of particles • Particles moving faster so collision frequency will increases for both forward and reverse reactions to the same extent • Both reactions will have a higher proportion of particles with sufficient energy to overcome the activation energy, therefore both rates increase • However, endothermic reverse reaction will have a greater increase in the proportion of successful collisions, creating a net reverse reaction • Concluding a net reverse reaction will produce more SCN^- ions making the solution a pale brown colour	$1-5$
Total	**5**
Note: can be lenient with wording but must meet this marking criteria	

Yield questions: Q5 & Q6

5. **[5 marks]**

The rates of both reactions can be decreased whilst the yield increases by increasing the volume of the system **(1)**. When the volume of the system is increased, the rates of the forward and reverse reactions will decrease as a result of the concentration of all reactant particles in the system decreasing and therefore the frequency of collisions decreasing **(1)**. However, as there is one gaseous mole of reactant on the left-side and two gaseous moles of reactant on the right-side, the rate of the reverse reaction will decrease more than the rate of the forward reaction **(1)**, thus creating a net forward reaction **(1)**. With a net forward reaction, more cobalt and chlorine gas will be produced until equilibrium is re-established, thus the yield will have increased since the amount of cobalt and chlorine gas being produced has increased **(1)**.

Points to note: It is a good strategy to sometimes state your answer straight-away and then prove it, if you can identify the answer without having to write out your thinking first. It helps examiners see the point you are trying to justify with your explanations that follow.

Marking Criteria	Marks Allocated
• A volume increase will decrease the reaction rates whilst increasing the yield	$1-5$

• A volume increase makes particles become spaced further apart, so both reaction rates will decrease • Forward reaction will decrease less than reverse reaction due to a 1:2 gaseous molar ratio • Thus, there will be a net forward reaction • Yield is a measure of the amount of substance generated not the concentration, therefore the yield will increase from a volume increase since more cobalt and chlorine gas is produced	
Total	**6**
Note: can be lenient with wording but must meet this marking criteria	

6. **[5 marks]**

When a catalyst is added to the system, the catalyst will provide an alternate reaction pathway with a lower activation energy **(1)**. As a result, there will be an increase the proportion of collisions with sufficient energy to overcome the activation energy to the same extent for both the forward and reverse reactions because the activation for both reactions has decreased equally **(1)**. Thus, the rates of both the forward and reverse reactions will increase equally, and no net forward or reverse reaction will be created **(1)**. With no net forward or reverse reaction, the amount of nitric oxide and chlorine gas produced will remain unchanged **(1)**. Thus, Lachlan is correct for saying the reaction rates will increase however is incorrect for saying the yield will increase for nitric oxide **(1)**.

Marking Criteria	Marks Allocated
• A catalyst provides an alternate reaction pathway with a lower activation energy • This will increase the proportion of collisions with sufficient energy to overcome the activation energy equally both reactions • The forward and reverse reactions will therefore increase equally • No net forward or reverse reaction will be created, so the yield will remain unchanged • Generalised comment about Lachlan's statement being only partially correct	$1-5$
Total	**5**
Note: can be lenient with wording but must meet this marking criteria	

Volume questions: Q7

7. **[5 marks]**

When the system is diluted and the volume of the system is increased, the rates of the forward and reverse reactions will decrease as a result of the concentration of all reactant particles in the system decreasing and therefore the frequency of collisions decreasing **(1)**. However, as there is one aqueous mole of reactant on the left-side and two aqueous moles of reactant on the right-side, the rate of the reverse reaction will decrease more than the rate of the forward reaction **(1)**, thus creating a net forward reaction **(1)**. With a net reverse/forward reaction, over-time some of reactant ammonia will be consumed and some NH_4^+ and OH^- will be produced until equilibrium is re-established **(1)**, therefore the yield of NH_4^+ will increase. However, all reactant concentrations will be lower than their initial concentrations because the system cannot completely oppose the initial concentration drop **(1)**.

Marking Criteria	Marking Criteria
• A volume increase will decrease the reaction rates of both reaction rates from a collision frequency decrease • The reverse reaction rate will decrease more than forward reaction due to a 1:2 gaseous molar ratio • Thus, there will be a net forward reaction • More ammonium and hydroxide ions will be produced and some ammonia will be consumed as a result of this net forward reaction • Must mention **yield of NH_4^+ will increase**	$1-5$
Total	**5**
Note: can be lenient with wording but must meet this marking criteria	

Inert gas questions: Q8

8. **[5 marks]**

(a) (iii) Constant Temperature, (i.) Constant Volume

Marking Criteria	Marking Criteria
• Option '(iii) Constant Temperature' chosen • Option '(i) Constant Volume' chosen	$1/2$ for each
Total	**1**
Note: no wording is necessary other than '(iii) Constant Temperature'	

(b) i. No change to the partial pressures would occur

Marking Criteria	Marking Criteria
• Deduced no changes to either partial pressures	1
Total	**1**
Note: no wording necessary other than 'No changes'	

ii. Yes

Marking Criteria	Marking Criteria
• Option 'Yes' chosen	1
Total	**1**
Note: no wording is necessary other than 'Yes'	

iii. No

Marking Criteria	Marking Criteria
• Option 'No' chosen	1
Total	**1**
Note: no wording is necessary other than 'No'	

iv. Neither

Marking Criteria	Marking Criteria
• Option 'Neither' chosen	1
Total	**1**
Note: no wording is necessary other than 'Neither'	

Initial Equilibrium Establishment questions: Q9

9. **[7 marks]**

(a) $2NH_{3\,(g)} \rightarrow N_{2\,(g)} + 3H_{2\,(g)}$

Marking Criteria	Marking Criteria
• Forward reaction shows the decomposition of ammonia into nitrogen gas and hydrogen gas: $2NH_{3\,(g)} \rightarrow N_{2\,(g)} + 3H_{2\,(g)}$	1
Total	**1**
Note: no marks, if double arrows is used in the equation (only meant to show the forward reaction)	

(b) The reaction does not go to completion since there is a reverse reaction also taking place that involves the combination of nitrogen and hydrogen gas into ammonia: $N_{2\,(g)} + 3H_{2\,(g)} \rightarrow 2NH_{3\,(g)}$ **(1)**. The combination of the forward and reverse reaction rate creates an equilibrium system preventing a complete reaction from ever happening: $2NH_{3\,(g)} \rightleftharpoons N_{2\,(g)} + 3H_{2\,(g)}$ **(1)**.

Marking Criteria	Marking Criteria
• Presence of the reverse reaction which reproduces some of the ammonia initially injected • Conclusion that the reverse reaction prevents the forward reaction from ever going to completion/it establishes an equilibrium system	$1-2$
Total	**2**
Note: The equilibrium system equation does not need to be necessarily used to attain full marks	

(c) When the ammonia gas is injected into the system, the concentration of ammonia will increase. This means that the forward reactant particles will be in a closer proximity to each other and will therefore incur a higher frequency of collisions, so the rate of the forward reaction will increase **(1)**. As no reactant particles have been added for the reverse reaction, the rate of the reverse reaction will initially remain unchanged **(1)**, thus there will be a net forward reaction **(1)**. With a net forward reaction, over time ammonia will be consumed (therefore decreasing its concentration) and more nitrogen gas and hydrogen gas will be produced (increasing their concentration), causing the forward reaction to gradually decrease and the reverse reaction to gradually increase until equilibrium is re-established and the rates are equal again **(1)**.

Marking Criteria	Marking Criteria
• *When ammonia is added, the frequency of collisions for the forward reaction will increase, so the forward reaction rate will increase*	$1-5$

• *As no reverse reactant particles have been added, the reverse reaction rate will initially remain unchanged* • *Thus there will be a net forward reaction* • *Forward reaction rate will decrease over-time and the reverse reaction rate will increase until their rates become equal and equilibrium is established*	
Total	**5**

'All in one questions' – difficult exam style questions: Q10

10. **[6 marks]**

Statement	True	False
"Increasing the temperature of a system increases the collision frequency of molecules in the endothermic reaction to a greater extent than in the exothermic reaction, thus favouring endothermic reaction"		✔
Explanation (if you ticked 'False'): The collision frequency increases to the same extent for the endothermic and exothermic reaction **(1)**, it is the proportion of successful collisions that increases to a greater extent for the endothermic reaction		
"A catalyst does not favour the forward or reverse reaction, but will cause both these reactions to reach equilibrium at a faster rate"	✔	
Explanation (if you ticked 'False'):		
"Adding an inert gas to a system increases the frequency of collisions between reacting molecules, thus increasing the partial pressures of all reacting molecules"		✔
Explanation (if you ticked 'False'): Inert gases do not react with any reactant particles and as a result the frequency of collisions remains unchanged. It also has no effect on the partial pressures because the inert gas is a completely different gas to the reactant particles **(1)**.		
"Adding an aqueous species to a reaction will increase its concentration and therefore increase the collision frequency between the molecules, but not the percentage of successful collisions"	✔	
Explanation (if you ticked 'False'):		

Marking Criteria	Marking Criteria
• 1 mark for each correctly ticked box	$1-4$
• 1 mark for each correctly given explanation to false statement	$1-2$
Total	**6**
Note: no marks are awarded for an explanation if the wrong box is ticked	

Problem Set 2 – Qualitative Chemical Equilibrium Repetitive Questions

Concept 1

Equilibrium Constant K_c – Repetitive Questions Answers

Writing the equilibrium constant and extent of reaction: Qs 1.1, 1.11, 1.2

1.1 **[4 marks]**

(a) (i) $K_c = \frac{[NO_2]}{[N_2O_4]}$ (ii) $K_c = \frac{[CO_2]^3[H_2O]^4}{[C_3H_8][O_2]^5}$ (iii) $K_c = [Ag^+][Cl^-]$

(iv) $K_c = \frac{1}{[H_3O^+][OH^-]}$

Points to note: Just always remember to not include solids and liquids, and to raise the concentrations to the power of their co-efficient. These should be straightforward otherwise

Marking Criteria	Marks Allocated
• One mark for each correct equilibrium constant determined	$1-4$
Total	**4**
Note: No mark can be awarded if the equilibrium constant has any errors	

(b) Each equilibrium constant, K_c, reflects the extent to which a reaction has occurred. For both reactions (ii) and (iv) their equilibrium constants are not too small or too large, so both reactions occur to a reasonable extent **(2)**.

Marking Criteria	Marks Allocated
• The equilibrium constants indicate that both reaction rates occur to a reasonable extent, with both reactants and products present	$1-2$
Total	**2**

1.11

(i) $K_c = [Pb^{2+}][Cl^-]$ (ii) $K_c = \frac{[NO_2]^2[Cu(NO_3)]^3}{[HNO_3]^8}$ (iii) $K_c = \frac{[H_2SO_4]}{[SO_3]}$

(iv) $K_c = \frac{[SO_2]^4}{[O_2]^7}$ (v) $K_c = \frac{[O_2]^5[NH_3]^4}{[NO]^4}$

Marking Criteria	Marks Allocated
• One mark for each correct equilibrium constant determined	$1-5$
Total	**5**
Note: No mark can be awarded if the equilibrium constant has any errors	

(b) Each equilibrium constant, K_c, reflects the extent to which a reaction has occurred. For reaction (i) it has a moderately sized equilibrium constant which indicates the reaction has occurred to a fair extent so similar amounts of reactants and products will be present **(1)**. For reaction (iv), it has an extremely small equilibrium constant which indicates negligible reaction occurs so it is mostly present as reactants **(1)**. For reaction (v), it is a large equilibrium constant which indicates the reaction occurs to near completion so mostly products are present **(1)**.

Marking Criteria	Marks Allocated
• A moderate equilibrium constant for reaction (i) indicates similar amounts of products and reactants are present • A very small equilibrium constant for reaction (iv) indicates negligible reaction occurs, so mostly present as reactants • A large equilibrium constant for reaction (v) indicates the reaction occurs to near completion, so mostly products are present	$1-3$
Total	**3**
Note: No mark can be awarded if the equilibrium constant has any errors	

1.2

[3 marks]

(i) $K_c = \frac{[Br_2][Cl_2]}{[BrCl]^2}$ (ii) $K_c = \frac{[Cl_2]}{[BrCl]}$ (iii) $K_c = [Cl_2]$

Points to note: Since these reactants will phase change from gaseous, to aqueous and then to solid our focus will need to be on the melting point because when they are solids they will no longer be included in the equilibrium constant. Another important conversion you will need to make is the 173K to -100°C by subtracting 273K, since $K = °C + 273$.

Marking Criteria	Marks Allocated
• One mark for each correct equilibrium constant determined	$1-3$
Total	**3**
Note: No mark can be awarded if the equilibrium constant has any errors	

Reaction extent and K_c temperature dependency: Qs 1.3, 1.31 , 1.32 & 1.33

1.3

[4 marks]

(a) Temperature is the only factor that can permanently influence the value of the equilibrium constant. Therefore a temperature increase will increase the value of K_c since according to Le Chatelier's Principle the system will act to partially oppose this temperature increase by favouring the endothermic reaction, which is the forward reaction **(1)**. Thus the size of K_c will increase since more products will be produced and more reactant will be consumed **(1)**.

Marking Criteria	Marks Allocated
• Applying Le Chatelier's Principle to state that the system will act to partially oppose a temperature increase by favouring the endothermic reaction • Concluding the size of K_c will increase from the forward reaction being favoured	$1-2$
Total	**2**

Note: To attain full marks, there must be mention that temperature is the only factor that can permanently influence the equilibrium constant size, if not included deduct one mark

(b) Temperature is the only factor that can permanently influence the value of the equilibrium constant. Therefore a temperature decrease will decrease the value of K_c since according to Le Chatelier's Principle the system will act to partially oppose this temperature decrease by favouring the exothermic reaction, which is the reverse reaction **(1)**. Thus the size of K_c will decrease since more reactants will be produced and more products will be consumed **(1)**.

Marking Criteria	Marks Allocated
• Applying Le Chatelier's Principle to state that the system will act to counter a temperature decrease by favouring the exothermic reaction • Concluding the size of K_c will decrease from the reverse reaction being favoured	$1-2$
Total	**2**
Note: To attain full marks, there must be mention that temperature is the only factor that can permanently influence the equilibrium constant size, if not included deduct one mark	

1.31 **[5 marks]**

When we are observing the trends of the K_c value with an increasing temperature, we can see that at 500K the K_c value drops dramatically due to the methanol (CH_3OH) changing from a liquid to a gas **(1)**, but overall the trend can be observed that as the temperature increases the equilibrium constant **(1)**. According to Le Chatelier's Principle, a system will act to partially oppose a temperature increase by favouring the endothermic reaction, in order to consume some of the added energy **(1)**. As the K_c value is increasing, it indicates that the forward reaction is favoured in this situation and therefore we can deduce that the forward reaction is endothermic **(2)**.

Points to note: this question is designed your ability to critically analyze a scenario. Questions like these will be asked in WACE exams to help distinguish high-end students.

Marking Criteria	Marks Allocated
• Stating the drop in K_c at 500K is due to a reactant turning from liquid to gas • Identifying the overall trend that K_c is increasing with an increasing temperature • Applying Le Chatelier's Principle to state that the system will act to counter a temperature decrease by favouring the exothermic reaction	$1-3$
• Recognising the value of K_c is increasing so the forward reaction is favoured • Concluding the forward reaction is therefore endothermic	$1-2$
Total	**5**
Note: No marks awarded for stating forward reaction is endothermic without appropriate reasoning	

1.32 **[7 marks]**

Change	**Impact on K at the instant the change is made**	**Impact on K at re-established equilibrium**
a) Increasing the surface area of the solid glucose	**No change**	**No change**

b) Decreasing the total volume of system	**No change**	**No change**
c) Addition of inert gas at constant pressure	**No change**	**No change**
d) Increase in temperature	**Increase**	**Increase**
e) Removal of a catalyst	**No change**	**No change**
f) Addition of oxygen gas	**No change**	**No change**

Points to note: this is a very difficult and confusing question, but the key here is that K_c is temperature dependent and will only change for temperature. A similar concept called the reaction quotient (Q_c) would change for some changes because it tracks concentrations, but this is not what the question is asking. For part (d), when the temperature is increased the **forward endothermic reaction** will be favoured, resulting in **K_c increasing**.

Marking Criteria	Marks Allocated
• One mark for each correctly stated row	$1-7$
Total	**7**
Note: No half-marks awarded for getting half of the row correct	

1.33 **[3 marks]**

Using molar ratios:

$$[H_2O] = 2 \times [N_2]$$
$$= 2 \times 2$$
$$= 4\ mol\ L^{-1} \qquad \textbf{(1)}$$

$$K_c = [N_2][H_2O]$$
$$= [2][4]$$
$$= 8 \qquad \textbf{(1)}$$

An equilibrium constant of 8 indicates that the reaction has occurred to a moderate extent, so similar amounts of reactants and products present, however more reactant than product since the constant is larger than one **(1)**.

Points to note: this question is simple when you recognise that only ammonium nitrite (NH_4NO_2) crystals were initially present, so the concentration of the water vapour will be directly proportional to the concentration of nitrogen gas, you will just need to double it to match the molar ratio. This question is not stock-standard, but is designed to further develop your analytical skills

Concept 2

Le Chatelier's Principle – Repetitive Questions Answers

Foundational understanding of LCP and concentration changes to simple equations: Qs 2.1, 2.11, 2.12

2.1

[4 marks]

a) Le Chatelier's Principle states that if a system is subject to a change, it will adjust itself to partially oppose the effect of that change **(1)**.

Marking Criteria	Marks Allocated
• Definition Le Chatelier's Principle stated to say something along the lines of 'a system subject to change will act to partially oppose the effect of a change'	1
Total	**1**

(b) Right

Marking Criteria	Marks Allocated
• Equilibrium position shift correctly stated	1
Total	**1**

(c) When the system is diluted and the volume of the system is increased, the concentration of all reacting particles will decrease **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this total concentration decrease by favouring the reaction that produces more moles of aqueous product **(1)**. Thus the **forward reaction** will be **favoured**, shifting the equilibrium position to the **right** **(1)**.

Marking Criteria	Marks Allocated
• Stating that diluting the system will decrease the concentration of all ions • Applying LCP to state the system will act to favour the reaction that produces more moles of aqueous product • Correct conclusion that the system will favour the forward reaction, shifting the equilibrium position to the right	$1-3$
Total	**3**
Note: A final statement about the equilibrium position shift must be made to attain full marks	

2.11

[16 marks]

(a) When some additional hydrogen gas is added to the system, the concentration of hydrogen gas will increase **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration increase by favouring the reaction that will consume some of the added reactant hydrogen gas **(1)**. Thus the reverse reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Stating the addition of hydrogen gas will increase the hydrogen gas concentration • Applying LCP to state the system will act to consume some of the added reactant • Correct conclusion that the system will favour the reverse reaction	$1 - 3$
Total	**3**

(b) When the partial pressure of carbon monoxide is lowered, the concentration of carbon monoxide will decrease **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration decrease by favouring the reaction that will reproduce some of the lost carbon monoxide **(1)**. Thus the forward reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Stating the carbon monoxide decrease in partial pressure will also decrease its partial pressure • Applying LCP to state the system will act to reproduce some of the lost carbon monoxide • Correct conclusion that the system will favour the forward reaction	$1 - 3$
Total	**3**

(c) According to Le Chatelier's Principle, when the pressure of the system is increased, the system will act to partially oppose this change by favouring the reaction that produces less moles of gaseous product **(1)**. Thus the reverse reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Applying LCP to state system will act to favour the reaction that produces more moles of gaseous product • Correct conclusion that the system will favour the forward reaction	$1 - 2$
Total	**2**

(d) When the temperature of the system is decreased, the average kinetic energy of all reacting particles will decrease **(1)**. According to Le Chatelier's Principle, the system will act to partially oppose this temperature decrease by favouring the exothermic reaction in order to replace some of the lost energy **(1)**. Thus, the reverse reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Stating that the temperature decrease will decrease the average KE of reacting particles • Applying LCP to state the system will act to replace some of the lost energy by favouring the exothermic reaction • Correct conclusion that the system will favour the reverse reaction	$1 - 3$
Total	**3**

(e) When a catalyst is added to the system there will be no change in the equilibrium position, so according to Le Chatelier's principle the system will not act to partially oppose the change **(1)**. Thus, neither the forward nor reverse reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Applying LCP to state the system will not act to partially oppose the change since there has been no equilibrium position shift • Correct conclusion that the system will not favour either reaction	$1-2$
Total	**2**

(f) When neon gas is added at a constant pressure, the volume of the system will increase and as a result the concentration of all reacting particles will decrease **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this total concentration decrease by favouring the reaction that produces more moles of gaseous product **(1)**. Thus the forward reaction will be favoured **(1)**.

Points to note: Since the inert gas is added at a constant pressure, volume must give out in order to not let the pressure rise. If the inert gas was added at a constant volume, then no change would occur to the system.

Marking Criteria	Marks Allocated
• Stating that adding the neon gas at a constant pressure will increase the volume of the system • Applying LCP to state the system will act to favour the reaction that produces more moles of gaseous product • Correct conclusion that the system will favour the forward reaction	$1-3$
Total	**3**

2.12 **[8 marks]**

Change to system	**Reaction favoured**	$[H_2O]$	$[H_2]$
1. The volume of the system is halved	**Neither**	**Increase**	**Increase**
2. Xenon gas is added at a constant pressure	**Neither**	**Decrease**	**Decrease**
3. Some water vapour is added to the system	**Forward**	**Increase**	**Increase**
4. The temperature of the system is doubled	**Reverse**	**Increase**	**Decrease**
5. The pressure of the system is halved	**Neither**	**Decrease**	**Decrease**
6. The partial pressure of water vapour is increased	**Forward**	**Increase**	**Increase**
7. Some iron oxide Fe_3O_4 is added to the system	**Neither**	**No Change**	**No Change**
8. The temperature of the system is decreased by 100K	**Forward**	**Decrease**	**Increase**

Points to Note: This is definitely a question designed to trip you up and truly test your understanding. To avoid any confusion let us explain the more confusing changes:

- Parts 1 and 2, the volume is increased in both however the number of moles on each side of the reaction is equal so neither reaction will be favoured. But there will still be a net concentration decrease because the volume is increased
- Part 4 and 8, these are simple temperature changes that just require you to observe the enthalpy and determine which reaction is endothermic and which is exothermic.
- Part 5, for a pressure decrease we treat as if the volume of the system is increased, so since there is a 4:4 molar ratio, neither reaction will be favoured however both concentrations will still decrease from the initial drop in concentration
- Part 6, the addition/removal of solids never has an effect on the equilibrium position or concentration of other reactants

Marking Criteria	Marks Allocated
• One mark for each correct row	$1-8$
Total	**8**
Note: No half-marks awarded for getting the majority of a row correct	

Observing molar ratios for volume changes and enthalpy for temperature changes: Qs 2.2, 2.21, 2.22

2.2 **[4 marks]**

(i) No shift (ii) No shift (iii) Right (iv) Right

Marking Criteria	Marks Allocated
• One mark for each equilibrium shift correctly stated	$1-4$
Total	**4**
Note: No marks awarded for using terminology that does not include 'Left', 'Right' or 'No Shift'	

2.21 **[7 marks]**

(a)

(i) Left (ii) No shift (iii) Left (iv) Left

Marking Criteria	Marks Allocated
• One mark for each equilibrium shift correctly stated	$1-4$
Total	**4**
Note: No marks awarded for using terminology that does not include 'Left', 'Right' or 'No Shift'	

(b)

(i) Right (ii) Left (iii) Right (iv) Right

Marking Criteria	Marks Allocated
• One mark for each equilibrium shift correctly stated	$1-3$
Total	**3**
Note: No marks awarded for using terminology that does not include 'Left', 'Right' or 'No Shift'	

2.22 **[2 marks – must correctly choose all options]**

Reactions (I) and (V) will both definitely have equilibrium positions that shift to the right

Points to note: this question is fairly complex, it will first require you to determine which forward reactions are endothermic and then which forward reactions also produce less moles product than moles of reactant. Reactions (I) and (V) are the only endothermic reactions that produce less moles than they use, so are therefore the only changes that definitely shift to the right.

Marking Criteria	Marks Allocated
• Must correctly identify both reaction (I) and (V)	2
Total	**2**
Note: No marks awarded for only getting one of the reactions	

Using LCP to predict colour changes: Qs: 2.3, 2.4, 2.41

2.3 **[4 marks]**

(i) Darker greenish-yellow **(ii) Lighter greenish-yellow** **(iii) Lighter greenish-yellow** **(iv) Darker greenish-yellow**

Points to note: For reaction (i) you need to remember that pressure increase = volume decrease, so the system will become a darker greenish-yellow from the instantaneous increase of all concentrations when the volume is decreased

Marking Criteria	Marks Allocated
• One mark for each colour change that is correctly stated	$1-4$
Total	**4**
Note: No marks awarded for using terminology that does not include 'lighter greenish-yellow', 'darker greenish-yellow' or 'no colour change'	

2.4 **[4 marks]**

(i) Lighter purple/darker pink (ii) Lighter purple (iii) Darker purple (iv) Darker purple & darker pink

Points to note: the more difficult changes are (ii) and (iv). For (ii), when water is added the system will turn a light purple but then produce more permanganate ion (MnO_4^-) from a favoured reverse reaction, however will still be a lighter purple than initially. For (iv), when some manganese ion (Mn^{2+}) is added the system will turn pinkish/purple but then will favour the reverse reaction to become more purple and less pink.

Marking Criteria	Marks Allocated
• One mark for each colour change correctly described	$1-4$
Total	**4**
Note: Can be fairly lenient as long as it is along the lines of the correct colour change	

2.41 **[12 marks]**

Observation	Predicted Cause	Explanation using Le Chatelier's Principle
A colourless solution is added to the mixture and the pH is immediately raised to 7, before returning to 6.	**A base such as sodium hydroxide ($NaOH$) is added**	**When a base is added to the system it will react with the hydrogen ions, thus decreasing the hydrogen ion concentration. According to Le Chatelier's principle the system will act to partially oppose the hydrogen ion concentration decrease by favouring the reverse reaction, thus partially restoring the pH**
A change to the system causes colour to change to a deep orange before returning to a light orange.	**Addition of dichromate ions ($Cr_2O_7^{2-}$)**	**When dichromate ions are added to the system, the system will turn a deep orange in colour. According to Le Chatelier's Principle the system will act to consume some of these dichromate ions by favouring the reverse reaction, causing the system to return towards a light orange**
An addition to the system is made, however the colour initially remains yellow-orange. The colour soon turns to orange.	**Addition of hydrogen ions (H^+)**	**When hydrogen ions are added to the system, according to Le Chatelier's Principle the system will act to consume some of these added hydrogen ions by favouring the forward reaction, thus causing the system to turn orange.**
An addition to the system is made, causing the system to instantaneously lose all its yellow colour. The colour slowly returns to a lighter orange-yellow.	**Removal of chromate ions (CrO_4^{2-})**	**When chromate ions are removed from the system, the system will lose all its yellow colour. According to Le Chatelier's Principle the system will act to replace some of these chromate ions by favouring the reverse reaction, thus making the final solution a lighter yellow-orange colour**

Points to note: This is a key example of the hardest kinds of colour change questions that you will face

Marking Criteria	Marks Allocated
• One mark for each predicted cause appropriately identified	$1-4$
• One mark for correct application of Le Chatelier's Principle • One mark for linking it to the observed colour change or pH change	$1-8$
Total	**12**

Partial pressure and tricky gaseous system questions: Qs: 2.5, 2.51, 2.6, 2.61, 2.62

2.5 **[7 marks]**

(a) Endothermic

Marking Criteria	Marks Allocated
• One mark for correctly determining reverse reaction is endothermic	1

	Total	1
Note: cannot use any terminology other than 'endothermic' to get the mark	

(b) When thermal energy is added the temperature of the system will increase, so the average kinetic energy of all reacting particles will increase **(1)**. According to Le Chatelier's Principle the system will act to partially oppose this temperature increase by favouring the endothermic reaction in order to consume some of the increased system energy **(1)**. Thus, the reverse reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Stating that the temperature increase will increase the average KE of reacting particles • Applying LCP to state the system will act to replace consume some of the added thermal energy by favouring the endothermic reaction • Correct conclusion that the system will favour the reverse reaction	$1-3$
Total	**3**
Note: Give follow through marks from part (a) if they said the reverse reaction is exothermic, so forward reaction is endothermic	

(c) When all of the sulfur trioxide is removed from the system, the concentration of sulfur trioxide will decrease to zero **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration decrease by favouring the reaction that will reproduce some of the lost sulfur trioxide (1). Thus the forward reaction will be favoured (1).

Marking Criteria	Marks Allocated
• Stating the removal of sulfur trioxide will decrease its concentration • Applying LCP to state the system will act to reproduce some of the lost sulfur trioxide • Correct conclusion that the system will favour the forward reaction	$1-3$
Total	**3**
Note: the candidate does not need to state concentration will go to zero to attain full marks, a 'concentration decrease' is acceptable	

(d) When the partial pressure of oxygen gas is increased, the concentration of oxygen gas will increase **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration increase by favouring the reaction that will consume some of the added oxygen gas **(1)**. Thus the forward reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Stating that the oxygen gas partial pressure increase will increase the concentration of oxygen gas • Applying LCP to state the system will act to consume some of the added oxygen gas • Correct conclusion that the system will favour the forward reaction	$1-3$
Total	**3**

2.51 **[8 marks]**

(a)

(i) When the temperature of the system is increased, the average kinetic energy of all reacting particles will increase **(1)**. According to Le Chatelier's Principle the system will act to partially oppose this temperature increase by favouring the endothermic reaction in order to consume some of the increased system energy **(1)**. Thus, the **f**orward reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Stating that the temperature increase will increase the average KE of reacting particles • Applying LCP to state the system will act to replace consume some of the added energy by favouring the endothermic reaction • Correct conclusion that the system will favour the forward reaction	$1-3$
Total	**3**

(ii) When the solid table salt is added to the system, there will be no change in the equation position, so according to Le Chatelier's principle the system will not act to partially oppose the change **(1)**. Thus, neither the forward nor reverse reaction will be favoured **(1)**.

Points to note: Table salt has the chemical formula $NaCl_{(s)}$, but it is a solid so it has no effect on the equilibrium position

Marking Criteria	Marks Allocated
• Applying LCP to state the system will not act to partially oppose the change since there has been no equilibrium position shift • Correct conclusion that the system will not favour either reaction	$1-2$
Total	**2**

(b) Changes (i) and (iii)

Points to note: fresh air is around one-fifth oxygen, and therefore adding fresh air will increase the concentration of oxygen gas in the system, shifting the equilibrium position to the left

Marking Criteria	Marks Allocated
• Correctly stating both alterations (i) and (iii)	2
Total	**2**
Note: no marks awarded if alteration (ii) is included, or if only one correct alteration is included	

2.6 **[12 marks]**

(a) When the temperature of the system is decreased by 23K, the average kinetic energy of all reacting particles will decrease **(1)**. According to Le Chatelier's Principle, the system will act to partially oppose this temperature decrease by favouring the exothermic reaction in order to replace some of the lost energy **(1)**. Thus, the forward reaction will be favoured and the equilibrium position will shift to the left **(1)**.

Points to note: To determine whether there has been a temperature increase/decrease you will need to either add 273K to the 100°C or subtract 273K from 400K, and what you will deduce is that there has been a temperature decrease

Marking Criteria	Marks Allocated
• Stating that the temperature decrease will decrease the average KE of reacting particles • Applying LCP to state the system will act to replace some of the lost energy by favouring the exothermic reaction • Correct conclusion that the system will favour the forward reaction	$1-3$
Total	**3**

(b) According to Le Chatelier's Principle, when the pressure of the system is decreased, the system will act to partially oppose this change by favouring the reaction that produces more moles of gaseous product **(1)**. Thus the reverse reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Applying LCP to state the system will act to favour the reaction that produces more moles of gaseous product • Correct conclusion that the system will favour the reverse reaction	$1-2$
Total	**2**

(c) When the partials pressures of both carbon monoxide and hydrogen gas are decreased, both their concentrations will decrease **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration decrease by favouring the reaction that will reproduce some of the lost carbon monoxide and hydrogen gas **(1)**. Thus the reverse reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Stating that a decrease in the partial pressure of carbon monoxide and hydrogen gas will cause a decrease for both concentrations • Applying LCP to state the system will act to reproduce some of the lost reactants for both • Correct conclusion that the system will favour the reverse reaction	$1-3$
Total	**3**

(d) When some additional carbon monoxide is added to the system, the concentration of reactant carbon monoxide will increase **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration increase by favouring the reaction that will consume some of the added carbon monoxide **(1)**. Thus the forward reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Stating that adding carbon monoxide will increase the concentration of carbon monoxide	$1-3$

• Applying LCP to state the system will act to consume some of the added carbon monoxide • Correct conclusion that the system will favour the forward reaction	
Total	**3**

2.61 **[7 marks]**

(a) According to Le Chatelier's Principle, when the pressure of the system is halved, the system will act to partially oppose this change by favouring the reaction that produces more moles of gaseous product **(1)**. However, both reactions produce equal amounts of products **(1)**, thus neither reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Applying LCP to state the system will act to favour the reaction that produces more moles of gaseous product • Comment made that both sides contain equal moles of gaseous product • Correct conclusion that the system will favour neither reaction	$1-3$
Total	**3**

(b) When the volume of the system is increased, the concentration of all reacting particles will decrease **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this total concentration decrease by favouring the reaction that produces more moles of gaseous product **(1)**. However, both reactions produce equal amounts of products **(1)**, thus neither reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Stating that increasing the volume will decrease the concentration of all reacting particles • Applying LCP to state the system will act to favour the reaction that produces more moles of aqueous product • Comment made that both sides contain equal moles of gaseous product • Correct conclusion that the system will favour neither reaction	$1-4$
Total	**4**

(c) When the inert gas is added to the system at a constant volume, this will have no effect on the concentrations of any reacting particles **(1)**. According to Le Chatelier's principle, the system will not act to partially oppose this change because no change to the equilibrium position has occurred **(1)**.

Marking Criteria	Marks Allocated
• Stating that adding the inert gas at a constant volume will have no concentration effect • Applying LCP to state the system will not partially oppose the change	$1-2$
Total	**2**

2.62 **[9 marks]**

(a) When a scuba diver travels from the water surface to a depth of 20 metres, the pressure of the diver's body will increase **(1)**. According to Le Chatelier's Principle, the system (i.e. divers body) will act to partially oppose a pressure increase by favouring the reaction that produces less moles of gaseous products **(1)**. Thus the forward reaction will be favoured **(1)**, resulting in more nitrogen gas being dissolved into the divers body **(1)**.

Marking Criteria	Marks Allocated
• Stating that as the water depth decreases, the system pressure will increase • Applying LCP to state the system will act to favour the reaction that produces less moles of gaseous product • Correct conclusion that the system will favour the forward reaction • Comment made this will result in more nitrogen dioxide being dissolve into the system	$1-4$
Total	**4**
Note: the term 'divers body' or 'system' can be used to describe where the pressure is being increased	

(b) When divers return to the surface the pressure of their system will decrease **(1)**. According to Le Chatelier's Principle, the system will act to partially oppose a pressure decrease by favouring the reaction that produces more moles of gaseous product **(1)**. Thus the reverse reaction will be favoured **(1)**, resulting in more nitrogen gas being produced. If the diver's pressure decreases too quickly, more gas will be produced than what can be expelled **(1)** – resulting in the accumulation of gas bubbles in the diver's bloodstream and body tissues, which is why they experience decompression sickness **(1)**.

Points to note: To attain the last two marks of this question, it requires quite a great deal of thought and critical analysis of the information provided in the question.

Marking Criteria	Marks Allocated
• Stating that as the water depth increase, the system pressure will decrease • Applying LCP to state the system will act to favour the reaction that produces more moles of gaseous product • Correct conclusion that the system will favour the reverse reaction • Comment made that more gas will be produced than what can be expelled • A concluding statement about the accumulation of bubbles in tissue and bloodstream that causes decompression sickness	$1-5$
Total	**5**

Tricky aqueous system questions: Qs: 2.7, 2.71 & 2.72

2.7 **[4 marks]**

When water is added the system is diluted and the volume of the system is increased, causing the concentration of all reacting particles to decrease **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this total concentration decrease by favouring the reaction that produces more moles of aqueous product **(1)**. Thus the reverse reaction will be favoured **(1)**, causing some of Fe^{3+} and SCN^{-} ions to be restored **(1)**, however there will still be a net decrease in all the concentrations because the initial concentration drop is only partially opposed **(1)**.

Marking Criteria	Marks Allocated
• Stating that diluting the system will decrease the concentration of all ions • Applying LCP to state the system will act to favour the reaction that produces more moles of aqueous product • Correct conclusion that the system will favour the forward reaction, restoring some Fe^{3+} and SCN^- ions • Comment about how there is still a net concentration decrease for all ions	$1-4$
Total	**4**
Note: A final statement about the equilibrium position shift must be made to attain full marks	

2.71 **[8 marks]**

(a) When chlorine powder is added to the system, it will dissolve in the solution thus increasing the concentration of OCl^- ions in solution for both systems I and II **(1)**. According to Le Chatelier's Principle, the system will act to partially oppose this concentration increase by favouring the reaction that will consume some of the OCl^- ions **(1)**. Thus the forward reaction for system II will be favoured **(1)**.

Marking Criteria	Marks Allocated
• Stating the chlorine powder will dissolve, increasing the OCl^- ion concentration • Applying LCP to state system II will act to consume some of the added OCl^- ions • Correct conclusion that the system will favour the forward reaction	$1-3$
Total	**3**

(b) When the forward reaction is favoured as a result of the concentration increase of OCl^- ions, this will cause some of the hydronium ions to be simultaneously consumed **(1)**. Thus the concentration of H_3O^+ will decrease from adding the chlorine powder **(1)**.

Marking Criteria	Marks Allocated
• Stating the favoured forward reaction will also consume some hydronium ions • Stating the hydronium ion concentration will decrease as a result of adding chlorine powder	$1-2$
Total	**2**

(c) Since pH is a measure of the concentration of hydronium ions, adding chlorine pH will increase the pH of water because the concentration of hydronium ions is decreasing **(1)**.

Points to note: this requires an understanding of pH, which may or may not currently make sense, but will when we tackle acids and bases in the next chapter. Just understand that the more hydronium ions the more acidic it will be, so the lower the pH will be.

Marking Criteria	Marks Allocated
• Generalised statement about how the pH will increase as a result of adding chlorine powder	1
Total	**1**

2.72 **[10 marks]**

	Concentration at the Point of Change		Final Concentrations	
Imposed Change	$[Ba^{2+}{}_{(aq)}]$	$[OH^{-}{}_{(aq)}]$	$[Ba^{2+}{}_{(aq)}]$	$[OH^{-}{}_{(aq)}]$
1. Hydrochloric acid is added to the system	**Same**	**Lower**	**Higher**	**Lower**
2. Distilled water is added to double the solution volume	**Lower**	**Lower**	**Lower**	**Lower**
3. The barium hydroxide crystals are cut into smaller pieces	**Same**	**Same**	**Same**	**Same**
4. Two drops of sodium hydroxide are added	**Same**	**Higher**	**Lower**	**Higher**
5. Some barium sulfate ($BaSO_4$) is added to the solution	**Same**	**Same**	**Same**	**Same**

Points to note: this question requires you to look at the different trick changes that can be made to aqueous systems. To answer these question types proficiently, it will require a strong understanding of how concentrations vary for each change

- **1.** For the addition of hydrochloric acid, the hydrogen ions will neutralise with the hydroxide ions ($OH^-_{(aq)} + H_3O^+_{(aq)} \rightleftharpoons 2H_2O_{(l)}$), thus decreasing the hydroxide ion concentration. From there you can figure out the concentration changes because it is the same as the removal of a reactant change
- **2.** For the dilution of the system, irrespective of the reaction favoured there will be a net decrease in all the concentrations because the initial concentration drop can only be partially opposed
- **3.** Increasing the surface area has no effect on the equilibrium position because it is a solid, therefore all the concentrations remain the same
- **4.** Adding sodium hydroxide will increase the hydroxide ion concentration, the rest should be fairly self-explanatory
- **5.** This is a **trick question**, because if you look on your formula sheet you will see barium sulfate is insoluble and will therefore not dissolve in solution. Whenever you are looking at unfamiliar salts in chemistry always check to see if they are insoluble as examiners can try to trick you with that sometimes

Marking Criteria	Marks Allocated
• One mark for stating both of the correct 'concentrations at the point of change'	$1-5$
• One mark for stating both of the correct 'final concentrations	$1-5$
Total	**10**
Note: no half-marks are awarded for getting half of a concentration change correct	

Yield questions: Qs: 2.8, 2.81

2.8 **[8 marks]**

(a)

(i) Decrease (ii) No change (iii) Increase (iv) No change

Points to note: When you are thinking of yield, just think of it as the amount of a substance that is produced relative to the amount of reactant needed. For part (iv) whilst more product is produced, it is at the expense of needing more reactant so the yield remains unchanged

Marking Criteria	Marks Allocated

• One mark for each correct yield change correctly determined	$\mathbf{1-4}$
Total	**4**
Note: No mark awarded for use of terminology that does not include 'increase', 'decrease' or 'no change'	

(b) When you continually remove ammonia from the system, the concentration of ammonia will always remain at zero **(1)**. According to Le Chatelier's Principle, the system will act to partially oppose this concentration drop by favouring the reaction that produces some of the ammonia **(1)**. Thus the forward reaction will be favoured **(1)**, which increases the yield of ammonia produced **(1)**.

Marking Criteria	Marks Allocated
• Stating that as the ammonia is removed, the concentration of ammonia will be zero • Applying LCP to state the system will act to favour the reaction that produces more ammonia • Correct conclusion that the system will favour the forward reaction • Comment made this will result increase the yield of ammonia	$1-4$
Total	**4**
Note: the term 'divers body' or 'system' can be used to describe where the pressure is being increased	

2.81 **[25 marks]**

System Factors	For an Optimal Rate of Reaction [1 mark each]
Surface area of $SrCO_{3(s)}$	**High surface area**
Amount of solid $SrCO_{3(s)}$	**Does not affect reaction rate**
Temperature	**High temperature**
Pressure	**High pressure**
Adding or removing carbon dioxide gas	**Removing carbon dioxide gas**
Presence of a catalyst	**Catalyst present**

(b)

System Factors	For an Optimal Equilibrium Yield [3 marks each]

Surface area of $SrCO_{3(s)}$	**When the surface area of $SrCO_3$ is increased there will be no change in the equilibrium position (1), so according to Le Chatelier's principle the system will not act to partially oppose the change (1). Thus, neither the forward nor reverse reaction will be favoured, so a large surface area is not for an optimal yield (1).**
Amount of solid $SrCO_{3(s)}$	**When some additional $SrCO_3$ is added there will be no change in the equilibrium position (1), so according to Le Chatelier's principle the system will not act to partially oppose the change (1). Thus, neither the forward nor reverse reaction will be favoured, so the amount of $SrCO_3$ is not important, given that there is enough initially to react (1).**
Temperature	**When the temperature of the system is increased, the average kinetic energy of all reacting particles will increase (1). According to Le Chatelier's Principle the system will act to partially oppose this temperature increase by favouring the endothermic reaction in order to consume some of the increased system energy (1). Thus, the forward reaction will be favoured, increasing the yield of product. So the higher the temperature the stronger the yield (1).**
Pressure	**According to Le Chatelier's Principle, the system will act to partially oppose a pressure decrease by favouring the reaction that produces more moles of gaseous product (1). Thus the forward reaction will be favoured (1), so lowering the pressure will bring about a higher yield of products (1).**
Adding or removing carbon dioxide gas	**When you continually remove carbon dioxide from the system, the concentration of carbon dioxide will always remain at zero (1). According to Le Chatelier's Principle, the system will act to partially oppose this concentration decrease by favouring the reaction that produces some of carbon dioxide (1). Thus the forward reaction will be favoured, which increases the yield of product produced (1).**
Presence of a catalyst	**When a catalyst is added to the system there will be no change in the equilibrium position (1), so according to Le Chatelier's principle the system will not act to partially oppose the change (1). Thus, neither the forward nor reverse reaction will be favoured, so it does not matter whether a catalyst is or isn't present for optimal yield (1)**

Points to note: this question is designed to prepare you for yield questions that ask you about optimizing specific conditions for the highest yield

Marking Criteria	Marks Allocated
• One mark for a generalised statement about the effect the change has on the equilibrium • One mark for applying Le Chatelier's principle to determine which reaction is favoured • One mark for linking back to how the favoured reaction optimises yield	$(1-3) \times 6$
Total	**18**

(c) High temperature and removing carbon dioxide gas

Marking Criteria	Marks Allocated
• One mark for stating both high temperature and removal of carbon dioxide gas	1
Total	**1**

Explanation correction questions: Qs 2.9, 2.91, 2.92

2.9 **[12 marks]**

(a) When some $NaOH$ is added to the system, its hydroxide ions will neutralise the hydronium ions, so the concentration of hydronium ions will decrease **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration decrease by favouring the reaction that will reproduce some of the lost hydronium ions **(1)**. Thus the forward reaction will be favoured not the reverse reaction, so this statement is incorrect **(1).**

Marking Criteria	Marks Allocated
• Stating that adding a base will decrease the hydronium ion concentration: $OH^-_{(aq)} + H_3O^+_{(aq)} \rightarrow 2H_2O_{(l)}$ • Applying LCP to state the system will act to replace some of the hydronium ions • Correct conclusion that the system will favour the forward reaction not the reverse reaction	$1-3$
Total	**3**
• Note: the equation $OH^-_{(aq)} + H_3O^+_{(aq)} \rightarrow 2H_2O_{(l)}$ is not necessary to attain full marks	

(b) When the inert gas is added at a constant pressure, the volume of the system will increase and as a result the concentration of all reacting particles will decrease **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this total concentration decrease by favouring the reaction that produces more moles of gaseous product **(1)**. Thus this statement is incorrect because the system will favour the reaction that produces more moles of gas not less **(1)**.

Marking Criteria	Marks Allocated
• Stating that adding the inert gas at a constant pressure will increase the volume of the system • Applying LCP to state the system will act to favour the reaction that produces more moles of gaseous product • Correct conclusion that the statement is incorrect because the system does not favour the side with less moles	$1-3$
Total	**3**

(c) When the inert gas is added to the system at a constant volume, this will have no effect on the concentrations of any reacting particles **(1)**. According to Le Chatelier's principle, the system will not act to partially oppose this change because no change to the equilibrium position has occurred **(1)**. Thus this statement is incorrect because the side with few gas molecules will not be favoured **(1)**.

Marking Criteria	Marks Allocated

• Stating that adding the inert gas at a constant volume will have no concentration effect • Applying LCP to state the system will not partially oppose the change • Concluding the statement is incorrect because the system does not favour the side with less moles	$1-3$
Total	**3**

(d) When the temperature of the system is decreased, the average kinetic energy of all reacting particles will decrease **(1)**. According to Le Chatelier's Principle, the system will act to partially oppose this temperature decrease by favouring the exothermic reaction in order to replace some of the lost energy **(1)**. Thus, the reverse reaction will be favoured making the system more yellow, not orange so this statement is incorrect because its colour change will not be towards orange it will be towards yellow **(1)**.

Marking Criteria	Marks Allocated
• Stating that the temperature decrease will decrease the average KE of reacting particles • Applying LCP to state the system will act to replace some of the lost energy by favouring the exothermic reaction • Correct conclusion that the system will favour the reverse reaction making the system more yellow not orange	$1-3$
Total	**3**

2.91 **[3 marks]**

Neil should correct Jane as follows, "whilst it can be the case that the concentration of $NO_{(g)}$ can be twice the concentration of Cl_2, this is assuming that no changes have occurred other than initial injection of $NOCl$ gas **(1)**. If any other changes were made to the system such as the addition of some chlorine gas then this statement would no longer be true **(1)**. Therefore Jane's statement is only partially correct **(1)**.

Marking Criteria	Marks Allocated
• Explaining that this 2:1 ratio will only occur when no changes have occurred other than the initial injection of $NOCl$ gas • Providing an example of when Jane's statement is not correct • Concluding that Jane's statement is only partially correct	$1-3$
Total	**3**

2.92 **[8 marks]**

(a) **IF OBSERVAION (i) was chosen:** When some $AgNO_{3(aq)}$ is added to the system, the silver ions will precipitate with the chloride ions, so the concentration of chloride ions will decrease **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration decrease by favouring the reaction that will reproduce some of the lost chloride ions **(1)**. Thus the reverse reaction will be favoured **(1)**, producing more $Co(H_2O)_6^{2+}$ ions and becoming more pink. Therefore we can deduce that Peter is correct because the $Co(H_2O)_6^{2+}$ ions are indeed pink not blue **(1)**.

Marking Criteria	Marks Allocated
• Stating that adding the $AgNO_3$ will decrease the chloride ion concentration • Applying LCP to state the system will act to replace some of the chloride ions • Correct conclusion that the system will favour the reverse reaction and linking it to producing more $Co(H_2O)_6^{2+}$ ions • Concluding that Peter is correct and Luke is incorrect	$1-4$
Total	**4**
Note: no marks awarded for simply stating that Peter is correct without providing supporting evidence	

(a) **IF OBSERVATION (ii) was chosen:** When the temperature of the system is increased, the average kinetic energy of all reacting particles will increase **(1)**. According to Le Chatelier's Principle the system will act to partially oppose this temperature increase by favouring the endothermic reaction in order to consume some of the increased system energy **(1)**. Thus, the forward reaction will be favoured, producing more $CoCl_4^{2-}$ ions and becoming more blue **(1)**. Therefore we can deduce that Luke is wrong because the $CoCl_4^{2-}$ ions are blue in colour not the $Co(H_2O)_6^{2+}$ ions **(1)**.

Marking Criteria	Marks Allocated
• Stating that the temperature increase will increase the average KE of reacting particles • Applying LCP to state the system will act to replace consume some of the added energy by favouring the endothermic reaction • Correct conclusion that the system will favour the forward reaction and linking it to producing more $CoCl_4^{2-}$ ions • Concluding that Luke is wrong and Peter is correct	$1-4$
Total	**4**
Note: no marks awarded for simply stating that Peter is correct without providing supporting evidence	

(b) **IF OBSERVATION (i) was chosen:** When some $AgNO_{3(aq)}$ is added to the system, the silver ions will precipitate with the chloride ions, so the concentration of chloride ions will decrease **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration decrease by favouring the reaction that will reproduce some of the lost chloride ions **(1)**. Thus the reverse reaction will be favoured **(1)**, producing more $Co(H_2O)_6^{2+}$ ions and becoming more pink. Therefore we can deduce that the colour of $CoCl_4^{2-}$ ions is blue because the $Co(H_2O)_6^{2+}$ ions are pink.

Marking Criteria	Marks Allocated
• Stating that adding the $AgNO_3$ will decrease the chloride ion concentration • Applying LCP to state the system will act to replace some of the chloride ions • Correct conclusion that the system will favour the reverse reaction and linking it to producing more $Co(H_2O)_6^{2+}$ ions • Concluding that the $CoCl_4^{2-}$ ions is blue by deducing that the $Co(H_2O)_6^{2+}$ ions are pink	$1-4$
Total	**4**
Note: no marks awarded for simply stating that the $CoCl_4^{2-}$ ions are blue without providing supporting evidence	

(b) **IF OBSERVATION (ii) was chosen:** When the temperature of the system is increased, the average kinetic energy of all reacting particles will increase **(1)**. According to Le Chatelier's Principle the system will act to partially oppose this temperature increase by favouring the endothermic reaction in order to consume some of the increased system energy **(1)**. Thus, the forward reaction will be favoured, producing more $CoCl_4^{2-}$ ions and becoming more blue **(1)**. Therefore we can deduce that the $CoCl_4^{2-}$ ions are blue in colour **(1)**.

Marking Criteria	Marks Allocated
• Stating that the temperature increase will increase the average KE of reacting particles • Applying LCP to state the system will act to replace consume some of the added energy by favouring the endothermic reaction • Correct conclusion that the system will favour the forward reaction and linking it to producing more $CoCl_4^{2-}$ ions • Concluding that the $CoCl_4^{2-}$ ions must be blue	$1-4$
Total	**4**
Note: no marks awarded for simply stating that the $CoCl_4^{2-}$ ions are blue without providing supporting evidence	

'All in one questions' – difficult exam style questions: Q10

2.101 **[5 marks]**

Changes (b), (d), (h), (j) and (k)

Points to note: this is a difficult question, that requires a great deal of critical thinking. To ease any confusion, reasoning for the difficult options is below:

- Parts (b) and (d), they are both a volume increase so they will therefore shift their equilibrium position to the left, because the gaseous molar ratio is 1:0
- Parts (e) and (k), both of these involve an understanding that both of these acids are weak acids with equilibrium systems of $HF_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + F^-_{(aq)}$ and $H_3BO_{3\,(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + H_2BO^-_{3\,(aq)}$, so in part (e) when a basic solution is added it will decrease the concentration of both acids, therefore shifting the equilibrium position of our system to the right, and then for part (k) this will increase the concentrations of both acids, therefore shifting the equilibrium position to the left. These two parts are very tricky, but it is really good to re-visit this question after you have completed acids and bases to re-test your understanding of acids & bases and chemical equilibrium
- Part (f) is another trick, since pressure is held constant, when $BF_{3\,(g)}$ is added to the system the volume will be increased in a proportional manner, so the concentration of $BF_{3\,(g)}$ will remain constant. Thus no change in equilibrium position will occur because there has been no concentration changes
- Part (h), the only species that can be removed to decrease the pressure is $BF_{3\,(g)}$ since it is the only gas in the system. As a result the equilibrium position will shift to the left to recover some of the lost $BF_{3\,(g)}$

Marking Criteria	Marks Allocated
• One mark for each correctly stated change that shifts the equilibrium position to the left	$1-5$
Total	**5**

Concept 3

Collision Theory – Repetitive Questions Answers

Non-Reversible Reaction Questions: Qs: 3.1, 3.11

3.1 **[7 marks]**

(a) Concentration remains unchanged because the concentration of liquids cannot be altered **(1)**

Marking Criteria	Marks Allocated
• Stating the concentration of water molecules will remain unchanged	1
Total	**1**

(b) Collision frequency of water remains unchanged because its concentration is unchanged **(1)**

Marking Criteria	Marks Allocated
• Stating the collision frequency of water will remain unchanged	1
Total	**1**

(c) When water is added to the system and the volume of the system is increased, the concentration of $C_{11}H_{22}O_{11}$ will decrease **(1)**. This concentration decrease causes reactant particles to become spaced further apart and therefore collide less frequently **(1)**, thus lowering the collision frequency.

Marking Criteria	Marks Allocated
• When water is added it reduces the reactant particle concentration • Reactant particles become spaced further apart and therefore collision frequency decreases	$1-2$
Total	**2**

(d) The proportion of successful collisions remains unchanged **(1)**

Marking Criteria	Marks Allocated
• Stating the proportion of successful collisions will remain unchanged	1
Total	**1**

(e) Since the collision frequency between $C_{11}H_{22}O_{11}$ has decreased, the rate of successful collisions will decrease **(1)** and as a result the reaction rate will decrease **(1)**.

Marking Criteria	Marks Allocated
• A decrease in collision frequency, decreases the rate of successful collisions • As a result the reaction rate decreases	$1-2$
Total	**2**

3.11 **[7 marks]**

(a) The term 'state of subdivision' only deals with solids and can be defined as the state in which a solid is divided into smaller pieces **(1)**. It applies to any reactions that involves a solid reactant **(1)**.

Point to note: 'State of subdivision' is not a syllabus based term, but it is useful to know for your knowledge of surface area.

Marking Criteria	Marks Allocated
• By definition, the state of subdivision is a state in which a solid is divided into smaller pieces • It applies to any reactions that have at least one solid reactant	$1-2$
Total	**2**

(b)

(i) Collisions can only take place at the surface of a reacting solid **(1)**. As a result, when the solid reactants are ground into a find powder it increases the number of particles that are available to react at one particular time, thus increasing the collision frequency **(1)**. Therefore, the rate of successful collisions increases, which means the reaction rate increases **(1)**.

Marking Criteria	Marks Allocated
• Collisions can only take place at the surface of a reacting solid • An increased surface area increases the frequency of collisions • An increased collision frequency, increases the rate of successful collisions, which increases the reaction rate	$1-3$
Total	**3**

(ii) Removing $MgFe_2O_{4(s)}$ as it is produced has no effect on the rate of the reaction, since solids will always hold a constant concentration, so adding/removing solids has no effect on their concentration, and therefore collision frequency & reaction rate **(1)**.

Marking Criteria	Marks Allocated
• Adding/removing solid reactant has no effect on reaction rate because the concentration of a solid is always constant	1
Total	**1**

(c) No, changes made to a solids surface area only affects the reaction rate, it has no impact on the amount of product that is produced **(1)**.

Marking Criteria	Marks Allocated
• Surface area has no effect on the amount of product that will be produced, it only affects the reaction rate	1
Total	**1**

Tricky aqueous system questions: Qs: 3.2

3.2 **[13 marks]**

(i) When the temperature of the system is increased, the average kinetic energy of all the particles will increase **(1)**. This means the particles of both the forward and reverse reactions will move at a higher velocity, incurring a higher frequency of collisions to the same extent in both the forward and reverse reactions **(1)**. A higher average particle kinetic energy also means a larger proportion of particles will have sufficient energy to overcome the activation energy for both forward and reverse reactions **(1)**. However, for the endothermic reverse reaction, there will be a greater increase in the proportion of successful collisions, thus creating a net reverse reaction **(1)**. With a net reverse reaction, over-time some water and oxygen gas will be consumed and hydrogen peroxide will be produced until equilibrium is re-established, therefore leaving hydrogen peroxide at a higher concentration **(1)**.

Marking Criteria	Marks Allocated
• A temperature increase will increase the average kinetic energy of all reacting particles • Particles will be moving faster so collision frequency will increase equally for both forward and reverse reactions • Both reactions will have a higher proportion of particles with sufficient energy to overcome the activation energy • However, endothermic reverse reaction will have a greater increase in the proportion of successful collisions, thus creating a net reverse reaction • Concluding a net reverse reaction will produce more hydrogen peroxide and thus increasing its concentration	$1-5$
Total	**5**
Note: can be lenient with wording but must meet this marking criteria	

(ii) When water is added and the volume of the system is increased, the rates of the forward and reverse reactions will decrease as a result of the concentration of all reactant particles in the system decreasing and therefore the frequency of collisions decreasing **(1)**. However, as there are two aqueous moles of reactant on the left-side and zero aqueous moles of reactant on the right-side, the rate of the forward reaction will decrease more than the rate of the reverse reaction **(1)**, thus creating a net reverse reaction **(1)**. With a net reverse reaction, over-time some water and oxygen gas will be consumed and some hydrogen peroxide will be produced until equilibrium is re-established, however the concentration of hydrogen peroxide will still be lower than initially because the system cannot fully recover from the initial concentration drop **(1)**.

Marking Criteria	Marking Criteria
• A volume increase will decrease the reaction rates of both reaction rates from a collision frequency decrease on both sides • The reverse reaction rate will decrease less than forward reaction due to a 1:0 aqueous molar ratio • Thus there will be a net reverse reaction • Hydrogen peroxide will be produced from net reverse reaction, however the will still be a net decrease for hydrogen peroxide concentration because system cannot fully recover from the initial concentration drop	$1-4$
Total	**4**

(c) When some oxygen gas is removed from the system, the concentration of the oxygen gas will decrease. This means that the reverse reactant particles will be spaced further apart and will therefore collide less frequently, so the rate of the reverse reaction will decrease **(1)**. As no reactant particles have been removed from the forward reaction, the rate of the forward reaction will initially remain unchanged, thus there will be a net forward reaction **(1)**. With a net forward reaction, over time some hydrogen peroxide will be consumed and more water and oxygen gas will be produced, therefore leaving hydrogen peroxide at a lower concentration **(1)**.

Marking Criteria	Marking Criteria
• The removal of oxygen gas will decrease the rate of the reverse reaction from a decrease in the frequency of collisions • The rate of the forward reaction will remain initially unchanged from no particles being added/removed, thus creating a net forward reaction • Some hydrogen peroxide will be consumed and some oxygen gas and water will be produced, thus decreasing the hydrogen peroxide concentration	$1-4$
Total	**4**
Note: can be lenient with wording but must meet this marking criteria	

Tricky gaseous system questions: Qs: 3.3, 3.31 3.32

3.3 **[11 marks]**

(a) Open system

Marking Criteria	Marks Allocated
• Stating flask 1 is an open system	1
Total	**1**

(b) Closed system

Marking Criteria	Marks Allocated
• Stating flask 2 is a closed system	1
Total	**1**

(c) Flask 1

Marking Criteria	Marks Allocated
• Stating flask 1 had the greatest water loss	1
Total	**1**

(d) In flask 1, as the wind passes by the open system the water vapour will all be swept away, thus making the rate of condensation at zero **(1)**. Since the rate of evaporation still remains fairly moderate **(1)**, this will result in a net forward reaction where over the course of two days we will see a significant amount of water loss in the flask **(1)**.

Marking Criteria	Marks Allocated
• Flask 1 is an open system, so the wind will sweep away all water vapour leaving the rate of condensation/reverse reaction rate at zero • The rate of evaporation remains unchanged, creating a net forward reaction • This net forward reaction will cause the water levels to decrease	$1-3$
Total	**3**
Note: allow for follow through marks from part (c) for any reasoning provided that is correct	

(e) Since flask 2 is a closed system, as wind passes by, the water vapour will not be swept away **(1)**. As a result the rate of condensation will remain equal to the rate of evaporation **(1)** so there will not be any significant change in the level of water in the flask.

Marking Criteria	Marks Allocated
• Flask 2 is a closed system, so the wind will have no effect on the water vapour • The rate of condensation will equal the rate of evaporation, leaving the system in equilibrium • Thus there won't be any significant water level changes	$1-3$
Total	**3**
Note: allow for follow through marks from part (c) for any reasoning provided that is correct	

(f) After waiting two days the vapour pressure in flask 1 will be equal to the atmospheric pressure **(1)** and the vapour pressure in flask 2 will have stayed the same **(1)**.

Marking Criteria	Marks Allocated
• Flask 1 will have a vapor pressure equal to the atmospheric pressure • Flask 2 will have a vapour pressure that stayed the same	$1-2$
Total	**2**

3.31 **[6 marks]**

(a) When some additional chlorine gas is added to the system, the concentration of chlorine gas will increase. This means that forward reactant particles will be in a closer proximity to each other and will therefore incur a higher frequency of collisions, so the rate of the forward reaction will increase **(1)**. As no reactant particles have been added for the reverse reaction, the rate of the reverse reaction will initially remain unchanged **(1)**, thus there will be a net forward reaction **(1)**.

Marking Criteria	Marking Criteria
• The addition of chlorine gas will increase the rate of the forward reaction from an increase in the frequency of collisions • The rate of the reverse reaction will remain initially unchanged from no particles being added/removed • Correct conclusion that there will be a net forward reaction	$1-3$
Total	**3**
Note: can be lenient with wording but must meet this marking criteria	

(b) When the volume of the system is increased, the rates of the forward and reverse reactions will decrease as a result of the concentration of all reactant particles in the system decreasing and therefore the frequency of collisions decreasing **(1)**. However, as there is one gaseous mole of reactant on the left-side and two gaseous moles of reactant on the right-side, the rate of the reverse reaction will decrease more than the rate of the forward reaction **(1)**, creating a net forward reaction **(1)**.

Marking Criteria	Marking Criteria
• A volume increase will decrease the reaction rates of both reaction rates from a collision frequency decrease • The forward reaction rate will decrease less than reverse reaction due to a 1:2 gaseous molar ratio • Correct conclusion that there will be a net forward reaction	$1-3$
Total	**3**
Note: can be lenient with wording but must meet this marking criteria	

3.32 **[11 marks]**

(a) When the carbon powder is turned into larger chunks of solid, the surface area of carbon will decrease **(1)**. This will reduce the number of particles that are available to react at one particular time, thus decreasing the frequency of collisions between forward reactant particles **(1)**. As a result there will be a net reverse reaction and over-time carbon monoxide will be consumed, thus decreasing the rate of the reverse reaction and therefore the rate of carbon monoxide consumption **(1)**

Points to note: whilst adding/removing solid has no effect on the equilibrium position or reaction rate, altering the surface area of a solid does influence the reaction rates and therefore the rate of consumption of carbon monoxide

Marking Criteria	Marking Criteria
• Combining carbon powder into large chunks will decrease the surface area of carbon • This will decrease the frequency of collisions between forward reactant particles creating a net reverse reaction • With a net reverse reaction, over-time carbon monoxide will be consumed, decreasing the reverse reaction rate and therefore the rate of carbon monoxide consumption	$1-3$
Total	**3**
Note: can be lenient with the marking, if the answer is within a reasonable three-mark structure and the same conclusion is drawn	

(b) When some additional oxygen gas is injected into the system, the concentration of oxygen gas will increase. This means that the forward reactant particles will be in a closer proximity to each other and will therefore incur a higher frequency of collisions, so the rate of the forward reaction will increase **(1)**. As no reactant particles have been added for the reverse reaction, the rate of the reverse reaction will initially remain unchanged, thus there will be a net forward reaction **(1)**. With a net forward reaction, over time carbon and oxygen gas will be consumed and more carbon monoxide will be produced, causing the rate of the reverse reaction to increase and therefore increasing the rate at which carbon monoxide is consumed **(1)**.

Marking Criteria	Marking Criteria
• Adding oxygen gas will increase the forward reaction rate from an increase in the frequency of collisions • The rate of the reverse reaction will remain initially unchanged from no particles being added/removed, thus creating a net forward reaction • Some carbon monoxide will be produced from this net forward reaction, therefore increasing the reverse reaction rate/rate at which carbon monoxide is consumed	$1-3$
Total	**3**
Note: can be lenient with wording but must meet this marking criteria	

(c) When the volume of the system is decreased, the rates of the forward and reverse reactions will increase as a result of the concentration of all reactant particles in the system increasing and therefore the frequency of collisions increasing **(1)**. However, as there are 3 moles of reactant on the left-side and 2 moles of reactant on the right-side, the rate of the forward reaction will increase more than the rate of the reverse reaction **(1)**, creating a net reverse reaction **(1)**. Thus, as time progresses, some carbon monoxide will be consumed and more carbon and oxygen gas will be produced, causing the rate of reverse reaction to further decrease and therefore decrease the rate at which carbon monoxide is consumed **(1)**. However there will have still been a net increase in the reverse reaction rate, so the rate of carbon monoxide consumption will have increased **(1)**.

Marking Criteria	Marking Criteria
• A volume decrease will increase the reaction rates of both reaction rates from a collision frequency increase on both sides • However, the forward reaction rate will increase more than reverse reaction due to a 3:2 gaseous molar ratio • Correct conclusion that there is a net forward reaction • More carbon monoxide will be produced from this net reverse reaction, therefore decreasing the reverse reaction rate/rate at which carbon monoxide is consumed • However, there will still be a net increase in the carbon monoxide consumption, because the initial reverse reaction increase is only partially opposed.	$1-5$
Total	**5**
Note: can be lenient with wording but must meet this marking criteria	

Colour changes explained using collision theory: Qs: 3.4, 3.41, 3.42, 3.43, 3.44

3.4 **[4 marks]**

When some chlorine gas is removed from the system, the concentration of chlorine gas will decrease causing the system to turn a lighter greenish-yellow initially **(1)**. This means that the forward reactant particles will be spaced further apart and will therefore collide less frequently, so the rate of the forward reaction will decrease **(1)**. As no reactant particles have been removed from the reverse reaction, the rate of the reverse reaction will initially remain unchanged, thus there will be a net reverse reaction **(1)**. With a net reverse reaction, over time some of the chlorine gas will be reproduced making it slightly more greenish-yellow, however the system will still be a lighter greenish-yellow than initially because the concentration drop of the chlorine gas can only be partially restored **(1)**.

Marking Criteria	Marking Criteria
• Removing chlorine gas will turn the system a lighter greenish-yellow initially • The removal of chlorine gas will also cause the rate of the forward reaction to decrease from a decreased collision frequency • The rate of the reverse reaction will remain initially unchanged from no particles being added/removed, thus creating a net reverse reaction • This will reproduce some chlorine gas, however the system will still remain a lighter greenish-yellow because the concentration drop is only partially restored	$1-4$
Total	**4**
Note: can be lenient with wording but must meet this marking criteria	

3.41 **[14 marks]**

(a)

(i) Increase the concentration of dichromate ions ($Cr_2O_7^{2-}$)

Marking Criteria	Marks Allocated
• Stating the concentration of dichromate ions/$Cr_2O_7^{2-}$ increases	1
Total	**1**

(ii) Increase the concentration of chromate ions (CrO_4^{2-})

Marking Criteria	Marks Allocated
• Stating the concentration of chromate ions/CrO_4^{2-} increases	1
Total	**1**

(iii) Increase the concentration of hydrogen ions

Marking Criteria	Marks Allocated
• Stating the concentration of hydrogen ions increases	1
Total	**1**

(iv) Increase the concentration of hydrogen ions

Marking Criteria	Marks Allocated
• Stating the concentration of hydrogen ions increases	1
Total	**1**

(v) Decrease the concentration of hydrogen ions

Marking Criteria	Marks Allocated
• Stating the concentration of hydrogen ions decreases	1
Total	**1**

(vi) No change to any ion concentration

Points to note: If you look on the formula sheet, you will notice iron (III) hydroxide is insoluble, so it will not have any affect on any of the ion concentrations. Trick questions will often take advantage of the insolubility tables to confuse students.

Marking Criteria	Marks Allocated
• Stating there are no changes to the concentrations of any ions	1
Total	**1**

(b)

(i) When some potassium dichromate solution is added, the concentration of dichromate ions will increase **(1)**. This means that the forward reactant particles will be in a closer proximity to each other and will therefore incur a higher frequency of collisions, so the rate of the forward reaction will increase **(1)**. As no reactant particles have been added for the reverse reaction, the rate of the reverse reaction will initially remain unchanged, thus there will be a net forward reaction **(1)**. With a net forward reaction, over time some of the dichromate ions will be consumed, however the concentration of dichromate ions will still be greater than initially because the initial concentration increase of dichromate ions can only be partially consumed **(1)**.

Marking Criteria	Marking Criteria
• Adding potassium dichromate will increase the dichromate ion concentration • This will cause the rate of the forward reaction to increase from an increased collision frequency • The rate of the reverse reaction will remain initially unchanged from no particles being added/removed, thus creating a net forward reaction • This will consume some of the dichromate ions, however the dichromate ions will still be in a higher concentration because the initial concentration increase can only be partially consumed	$1-4$
Total	**4**
Note: can be lenient with wording but must meet this marking criteria	

(ii) When some potassium hydroxide solution is added, the hydroxide ions will react with the hydrogen ions, thus decreasing the concentration of hydrogen ions **(1)**. This means that the reverse reactant particles will be spaced further apart and will therefore collide less frequently, so the rate of the reverse reaction will decrease **(1)**. As no reactant particles have been removed from the forward reaction, the rate of the forward reaction will initially remain unchanged, thus there will be a net forward reaction **(1)**. With a net forward reaction, over time some of the hydrogen ions will be reproduced, however the concentration of hydrogen ions will still be less than before the change because the initial concentration decrease of hydrogen ions can only be partially reproduced **(1)**.

Marking Criteria	Marking Criteria

• Adding sodium hydroxide will consume some of the hydrogen ions, thus decreasing the hydrogen ion concentration • This will cause the rate of the reverse reaction to decrease from a decreased collision frequency • The rate of the forward reaction will remain initially unchanged from no particles being added/removed, thus creating a net forward reaction • This will reproduce some of the hydrogen ions, however they will still be in a lower concentration because the initial hydrogen ion concentration decrease can only be partially reproduced	$1-4$
Total	**4**
Note: can be lenient with wording but must meet this marking criteria	

3.42 **[5 marks]**

(a) When water is added and the volume of the system is increased, the concentrations of all reacting particles will decrease, turning the solution from a dark purple to a lighter purple **(1)**. This concentration decrease will also cause the rates of the forward and reverse reactions to decrease as a result of a decreased collision frequency **(1)**. However, as there are 14 aqueous moles of reactant on the left-side and 6 aqueous moles of reactant on the right-side, the rate of the reverse reaction will decrease more than the rate of the forward reaction **(1)**, creating a net reverse reaction **(1)**. With a net reverse reaction, as time progresses more permanganate ions (MnO_4^-) will be produced making the solution more purple, however the system will still end up a lighter purple because the initial concentration drop of permanganate ions can only be partially restored **(1)**.

Marking Criteria	Marking Criteria
• Adding water will decrease the concentration of all ions, making the system a lighter purple • This concentration drop will cause the rates of the forward and reverse reactions to both decrease from the decreased collision frequency • However, the reverse reaction will decrease more than the forward reaction due to a 14:6 aqueous molar ratio • Correct conclusion there is a net reverse reaction • A net reverse reaction will make the system more purple, but still a lighter purple than before the change because the initial permanganate ion concentration drop can only be partially restored	$1-5$
Total	**5**
Note: can be lenient with wording but must meet this marking criteria	

3.43 **[10 marks]**

(a) As a result of this temperature increase, there would be a net forward endothermic reaction, so we would see the bromine water be evaporated at a faster rate than the bromine gas condensates **(1)**, resulting in the gaseous area becoming a darker reddish-brown and the reddish-brown water levels decreasing **(1)**.

Points to note: the concentration of liquids do not change, so the colour of the bromine water will never change. Also note that since we are discussing observations, you want to make reference to the gaseous area and liquids by their colours not by 'bromine water' and 'bromine gas', because saying 'the concentration of bromine gas increases' is not an observation. And also note that this change requires you to realise that the forward reaction is endothermic, by knowing that endothermic reactions are bond breaking processes.

Marking Criteria	Marking Criteria
• Temperature increase will cause a net forward reaction, so rate of evaporation is faster than rate of condensation • Gaseous area will become a darker reddish-colour and reddish-brown water levels will decrease	$1-2$
Total	**2**
Note: For first mark, candidate does not necessarily have to mention 'rate of evaporation' and 'rate of condensation' however must at least make reference to forward and reverse reaction rates	

(b) As a result of this volume decrease the gaseous area will become a darker reddish-brown colour **(1)**. There would also be a net reverse reaction, so the bromine gas would condensate faster than the bromine water is evaporated **(1)**, resulting in the gaseous area becoming a lighter reddish-brown colour and the reddish-brown water levels increasing **(1)**, however the gaseous system will still be a darker reddish-brown colour because the initial concentration increase is only partially consumed **(1)**

Marking Criteria	Marking Criteria
• Volume decrease will make gaseous area become darker reddish-brown colour • Volume decrease will also cause a net reverse reaction, so rate of condensation is faster than rate of evaporation • The gaseous area becomes a lighter reddish-brown colour and reddish-brown water levels decrease • However gaseous area is still a darker reddish-brown colour since initial change is only partially opposed	$1-4$
Total	**4**
Note: For second mark, candidate does not necessarily have to mention 'rate of evaporation' and 'rate of condensation' however must at least make reference to forward and reverse reaction rates	

(c) When the bromine water is initially poured out, we will see the reddish-brown water levels decrease. There will also be a gaseous volume increase so the gaseous area will become a lighter reddish-brown colour **(1)**. As a result of this gaseous volume increase, there will be a net forward reaction, so the bromine water would evaporate at a faster rate than the bromine gas condensates **(1)**, further decreasing the reddish-brown water levels and making the gaseous area a more reddish-brown colour **(1)**, however still a lighter reddish-brown colour because the initial concentration drop is only partially restored **(1)**

Marking Criteria	Marking Criteria
• Volume decrease will make gaseous area become darker reddish-brown colour • Volume decrease will also cause a net reverse reaction, so rate of condensation is faster than rate of evaporation • The gaseous area becomes a lighter reddish-brown colour and reddish-brown water levels decrease	$1-4$

• However gaseous area is still a darker reddish-brown colour since initial change is only partially opposed	
Total	**4**
Note: For second mark, candidate does not necessarily have to mention 'rate of evaporation' and 'rate of condensation' however must at least make reference to forward and reverse reaction rates	

3.44 **[4 marks]**

When the volume of the gaseous area is decreased, the rate of the reverse reaction will increase as a result of the concentration of bromine gas increasing and therefore the frequency of collisions increasing **(1)**. However, the rate of the forward reaction will initially remain unchanged because it contains no gaseous particles, thus creating a net reverse reaction **(1)**. As time progresses, more bromine water will be produced and more bromine gas will be consumed **(1)**. However, since the forward reaction only contains liquids, its concentration will forever remain unchanged and as a result the rate of evaporation will forever remain unchanged **(1)**.

Points to note: this question could technically be answered in one sentence, by stating that the forward reaction only contains liquids so therefore its reaction rate will forever remain unchanged, however this is a four mark question and it is designed this way to force you to elongate your responses, as this is a key skill when you are struggling to answer a question in full.

Marking Criteria	Marking Criteria
• The volume decrease will increase the rate of the reverse reaction from increasing collision frequency • Rate of the forward reaction is not gaseous, so will remain unchanged initially, thus creating net reverse reaction • More bromine water will be produced until equilibrium is re-established • However since bromine water is a liquid, its concentration will remain forever unchanged so the rate of evaporation will forever remain unchanged	$1-4$
Total	**4**
Note: Can be very lenient with the marking criteria, and the four marks can be awarded so long as the question is answered correctly and with appropriate depth	

Yield questions: Qs: 3,5, 3.51, 3.52, 3.53, 3.54, 3.6, 3.61, 3.62

3.5 **[8 marks]**

(a) $294kJ$

Points to note: $1.5 \times 196 = 294kJ$. This question is a good test of your stoichiometry knowledge, which will be used in later chapters.

Marking Criteria	Marks Allocated
• Determining that $294kJ$ of energy will be released	1
Total	**1**

(b) Decreasing the temperature

Marking Criteria	Marks Allocated
• Stating that decreasing the temperature will increase the yield	1
Total	**1**

(c) When the temperature of the system is decreased, the average kinetic energy of all the particles will decrease **(1)**. This means the particles of both the forward and reverse reactions will move at a slower velocity and will therefore collide less frequently to the same extent in both the forward and reverse reactions **(1)**. A lower average kinetic energy also means a smaller proportion of particles will have sufficient energy to overcome the activation energy for both the forward and reverse reactions **(1)**. However, for the exothermic forward reaction, there will be a smaller decrease in the proportion of successful collisions, thus creating a net forward reaction **(1)**. With a net forward reaction, over-time some sulfur dioxide and oxygen gas will be consumed and some sulfur trioxide will be produced, causing the forward reaction rate to gradually decrease and the reverse reaction rate to gradually increase until equilibrium is re-established **(1)**. Thus the yield of the reaction will increase since the amount of sulfur trioxide being produced has increased **(1).**

Marking Criteria	Marks Allocated
• A temperature decrease, decreases the average kinetic energy of particles • Particles moving slower so collision frequency will decrease to the same extent for both reactions • Both reactions will have a lower proportion of particles with sufficient energy to overcome the activation energy • Exothermic forward reaction has a smaller decrease in proportion of successful collisions, thus creating a net forward reaction • Over-time the rate of the forward reaction will decrease and the reverse reaction will increase until equilibrium is re-established • This net forward reaction will produce more sulfur trioxide, therefore increasing the yield of the reaction	$1-6$
Total	**6**
Note: can be lenient with wording but must meet this marking criteria	

3.51 **[8 marks]**

(a) When the temperature of the system is decreased, the average kinetic energy of all the particles will decrease **(1)**. This means the particles of forward reactant particles will move at a slower velocity and will therefore collide less frequently **(1)**. A lower average kinetic energy also means a smaller proportion of particles will have sufficient energy to overcome the activation energy, thus further decreasing the rate of successful collisions and therefore decreasing the forward reaction rate **(1)**.

Marking Criteria	Marks Allocated
• A temperature decrease, decreases the average kinetic energy of particles • Particles moving slower so collision frequency so collision frequency decreases and proportion of particles with sufficient energy to overcome activation energy will decrease • This will decrease the rate of successful collisions and therefore reaction rate	$1-3$
Total	**3**
Note: Can be very lenient with answer, as long as candidate meets the marking criteria to a fair extent	

(b) When the temperature of the system is decreased, the average kinetic energy of all the particles will decrease **(1)**, so the rate of the reverse reaction will also decrease from a decreased collision frequency and smaller proportion of particles with sufficient energy to overcome the activation energy **(1)**. However, since the reverse reaction is endothermic, it will experience a greater decrease in the proportion of successful collisions, thus creating a greater decrease in the rate of successful collisions and therefore reaction rate **(1)**.

Points to note: For both of these three mark questions, you will want to try and condense your answer as much as possible to save time, because for a three-mark collision theory question you won't need to go into extreme detail

Marking Criteria	Marks Allocated
• A temperature decrease, decreases the average kinetic energy of particles • Particles moving slower so collision frequency so collision frequency decreases and proportion of particles with sufficient energy to overcome activation energy will decrease, and additionally the reverse reaction will experience a greater decrease in proportion of successful collisions • This will decrease the rate of successful collisions and therefore reaction rate to a greater extent	$1-3$
Total	**3**
Note: can be very lenient with answer, as long as candidate meets the marking criteria to a fair extent	

(c) With a net forward reaction **(1)**, more calcium hydroxide ($Ca(OH)_2$) will be produced as time progresses, thus increasing the yield of the reaction **(1)**.

Marking Criteria	Marks Allocated
• A net forward reaction will produce more calcium hydroxide/ $Ca(OH)_2$ • This will increase the yield of the reaction	$1-2$
Total	**2**

3.52 **[8 marks]**

(a) The rates of the forward and reverse reactions are equal

Marking Criteria	Marks Allocated
• Stating the rates of the forward and reverse reactions are equal	1
Total	**1**

(b) The concentration for both reactions will remain unchanged

Marking Criteria	Marks Allocated
• No initial concentration changes for both reactions	1
Total	**1**

(c) The frequency of collisions will increase equally for both reactions

Marking Criteria	Marks Allocated

• Stating the frequency of collisions will increase equally	1
Total	**1**

(d) The proportion of successful collisions will increase for both reactions **(1)**, however increase more for the reverse reaction **(1)**

Marking Criteria	Marks Allocated
• Proportion of successful collisions will increase for both reactions • However the proportion will increase more for reverse reaction	$1-2$
Total	**2**

(e) The rate of the reverse reaction will be higher than the rate of the forward reaction

Marking Criteria	Marks Allocated
• Correct conclusion the reverse reaction rate is higher than forward reaction rate	1
Total	**1**

(f) When the temperature of the system is **increased**, the **average kinetic energy of all the particles will increase** (1). This means the particles of both the forward and reverse reactions will move at a **higher velocity, incurring a higher frequency of collisions** to the **same extent** in both the **forward and reverse reactions** (1). A higher average particle kinetic energy also means a **larger proportion of particles will have sufficient energy to overcome the activation energy** for both forward and reverse reactions (1). However, for the endothermic **reverse** reaction, there will be a **greater increase in the proportion of successful collisions**, thus creating a net **reverse** reaction (1). With a net **reverse** reaction, over time some ammonia to be consumed and some nitrogen gas and hydrogen gas will be produced, causing the reverse reaction to gradually decrease and the forward reaction to gradually increase until equilibrium is re-established (1).

Marking Criteria	Marks Allocated
• A temperature increase will increase the average kinetic energy of all reacting particles • Particles will be moving faster so collision frequency will increase equally for both forward and reverse reactions • Both reactions will have a higher proportion of particles with sufficient energy to overcome the activation energy • Endothermic reverse reaction has a greater increase in proportion of successful collisions with sufficient energy to overcome the activation energy, thus creating a net reverse reaction • Concluding a net reverse reaction will gradually decrease the reverse reaction rate and gradually increase the forward reaction rate until equilibrium is re-established	$1-5$
Total	**5**
Note: can be lenient with wording but must meet this marking criteria	

(g) The concentrations of nitrogen gas and hydrogen gas will be higher than their initial concentrations **(1)** and the concentration of ammonia will be lower than its initial concentration **(1)**.

Marking Criteria	Marks Allocated
• Concentrations of nitrogen gas and hydrogen gas will be higher than initially • Concentration of ammonia will be lower than initially	$1-2$
Total	**2**

3.53

[2 marks]

At zero kelvin the kinetic energy of all particles will be zero **(1)**, therefore no collisions will occur so the reaction rates of both the forward and reverse reactions will be decreased to zero **(1)**.

Marking Criteria	Marks Allocated
• At zero kelvin, all particles will have a zero kinetic energy • Therefore no collisions will occur, so the reaction rates will both be decreased to zero	$1-2$
Total	**2**

3.54

[6 marks]

To minimize the amount of $NH_4NO_{2\,(s)}$ decomposition that occurs, the system should operate at a low temperature **(1)**. When the temperature of the system is decreased, the average kinetic energy of all the particles will decrease **(1)**. This means the particles of both the forward and reverse reactions will move at a slower velocity and will therefore collide less frequently to the same extent in both the forward and reverse reactions **(1)**. A lower average kinetic energy also means a smaller proportion of particles will have sufficient energy to overcome the activation energy for both the forward and reverse reactions **(1)**. However, for the exothermic reverse reaction, there will be a smaller decrease in the proportion of successful collisions, thus creating a net reverse reaction **(1)**. With a net reverse reaction, some of the $NH_4NO_{2\,(s)}$ will be consumed, decreasing the yield of $NH_4NO_{2\,(s)}$ and therefore reducing the amount of decomposition that occurs **(1)**.

Marking Criteria	Marks Allocated
• A minimised $NH_4NO_{2\,(s)}$ decomposition will occur from a low system temperature • A temperature decrease, decreases the average kinetic energy of particles • Particles moving slower so collision frequency will decrease for both forward and reverse reactions and therefore their rates • Both reactions will have a lower proportion of particles with sufficient energy to overcome the activation energy • Exothermic forward reaction will have a smaller decrease in proportion of successful collisions, thus creating a net reverse reaction • Concluding a net reverse reaction will reduce the amount of decomposition that occurs, since yield of $NH_4NO_{2\,(s)}$ decreases	$1-6$
Total	**6**
Note: For the final mark, could also mention that temperature decreases both reaction rates irrespective of which is favoured, so rate of decomposition will always decrease with decreasing temperature	

3.6 [3 marks]

When a catalyst is added to the system, the catalyst will provide an alternate reaction pathway with a lower activation energy **(1)**. As a result, there will be an increase the proportion of collisions with sufficient energy to overcome the activation energy to the same extent for both the forward and reverse reactions because the activation for both reactions has decreased equally **(1)**. Thus, the rates of both the forward and reverse reactions will increase equally and no net forward or reverse reaction will be created **(1)**.

Marking Criteria	Marks Allocated
• The addition of catalyst will provide an alternate reaction pathway with a lower activation energy • This will increase the proportion of collisions with sufficient energy to overcome the activation energy equally for both the forward and reverse reactions • Thus the reaction rates for the forward and reverse reactions will increase equally	$1-3$
Total	**3**
Note: no marks for merely stating that the reaction rate is increased, since this is already stated in the question	

3.61 [4 marks]

- Increasing the system temperature **(1)**
- Addition of hydrogen gas **(1)**
- Addition of iodine gas **(1)**
- Removing hydrogen iodine gas **(1)**

Points to note: no changes to the volume or pressure of the system will have any effect because the system has a 2:2 molar ratio, so there will never be a net reaction in either direction

Marking Criteria	Marks Allocated
• Increasing the system temperature • Addition of hydrogen gas • Addition of iodine gas • Removing hydrogen iodine gas	$1-4$
Total	**4**

3.62 [2 marks]

Any two of the following

- Decreasing the volume of the system **(1)**
- Adding nitrogen dioxide (NO_2) gas to the system **(1)**
- Increasing the pressure of the system **(1)**

Points to note: a pressure increase is technically the same as a volume decrease, so we would recommend not using both options to attain full-marks, because your success will vary dependent on the person who is marking your paper

Marking Criteria	Marks Allocated

Any two of the following: • Decreasing the volume of the system • Adding nitrogen dioxide (NO_2) gas to the system • Increasing the pressure of the system	$1-2$
Total	**2**

Volume questions: Qs: 3.7, 3.71, 3.72

3.7

[3 marks]

Change	Change in Forward Reaction	Change in Reverse Reaction
A	**No change**	**Increase**
B	**No change**	**Increase**
C	**No change**	**Increase**

Points to note: this question is very tricky and requires good analytical skills to get each part right. If you think about each change you realise they all have the same effect of a volume decrease. Let's discuss each change:

- For change A, when the water is added into the sealed vial, the gaseous volume available will decrease so the reverse reaction rate will increase because particles are in a closer to each other. The rate of the forward reaction will remain unchanged, because the concentration of water is always constant
- For change B, when the volume of the system is halved, this decreases the gaseous volume so the reverse reaction rate will increase. The rate of the reverse reaction will remain unchanged because the concentration of water is always constant
- For change C, when water vapour is injected it will condense to form water ($H_2O_{(g)} \rightleftharpoons H_2O_{(l)}$), thus raising the water levels and decreasing the gaseous volume available. This volume decrease will increase the reverse reaction rate, whilst the forward reaction rate remains constant because the concentration of water is always constant

Marking Criteria	Marks Allocated
• 1 mark for each correct row	$1-3$
Total	**3**
Note: no half-marks awarded for getting half of a row correct	

3.71

[5 marks]

(a) When water is added and the volume of the system is increased, the rates of the forward and reverse reactions will decrease as a result of the concentration of all reactant particles in the system decreasing and therefore the frequency of collisions decreasing **(1)**. However, as there are 2 aqueous moles of reactant on the left-side and 1 aqueous moles of reactant on the right-side, the rate of the forward reaction will decrease more than the rate of the reverse reaction **(1)**, thus creating a net reverse reaction **(1)**. With a net reverse reaction, over time some dichromate ions and water will be consumed and some hydrogen chromate ions will be produced, causing the reverse reaction rate to gradually decrease and the forward reaction rate to gradually increase until equilibrium is re-established **(1)**.

Marking Criteria	Marking Criteria
• A volume increase will decrease the reaction rates of both reaction rates from a collision frequency decrease on both sides	$1-4$

• The forward reaction rate will decrease more than reverse reaction due to a 2:1 aqueous molar ratio • Thus creating a net reverse reaction • Over time the reverse reaction rate will gradually decrease and the forward reaction rate will gradually increase until equilibrium is re-established	
Total	**4**
Note: can be lenient with wording but must meet this marking criteria	

(b) The concentration of dichromate ions will have decreased from the net reverse reaction and from the initial addition of water **(1)**

Marking Criteria	Marking Criteria
• Dichromate ion/$Cr_2O_7^{2-}$ concentration is decreased	1
Total	**1**

3.72 **[5 marks]**

When the volume of the system is decreased, the rates of the forward and reverse reactions will increase as a result of the concentration of all reactant particles in the system increasing and therefore the frequency of collisions increasing **(1)**. However, as there are 2 moles of reactant on the left-side and 3 moles of reactant on the right-side, the rate of the reverse reaction will increase more than the rate of the forward reaction **(1)**, thus creating a net reverse reaction **(1)**. With a net reverse reaction, over time some reverse reactants will be consumed and some forward reactants will be produced, causing the reverse reaction rate to gradually decrease and the forward reaction rate to gradually increase until equilibrium is re-established **(1)**. These concentration changes will have shifted the equilibrium position more to the left **(1)**.

Marking Criteria	Marking Criteria
• A volume decrease will increase the reaction rates of both reaction rates from a collision frequency increase on both sides • The reverse reaction rate will increase more than forward reaction due to a 2:3 molar ratio • Thus creating a net reverse reaction • Over time the reverse reaction rate will gradually decrease and the forward reaction rate will gradually increase until equilibrium is re-established • This will cause concentration changes that shift the equilibrium position to the left	$1-5$
Total	**5**
Note: can be lenient with wording but must meet this marking criteria	

Inert gas questions: Qs: 3.8

3.8 **[10 marks]**

(a) Constant pressure

Point to note: No visible changes would occur if the volume was constant, because there is no effect at a constant volume. It is this process of elimination that is a good strategy to use when you don't know the answer.

Marking Criteria	Marking Criteria
• A constant pressure was maintained	1
Total	**1**

(b) No, inert gases do not react with other particles

Marking Criteria	Marking Criteria
• **No**	1
Total	**1**

(c) Right

Marking Criteria	Marking Criteria
• Equilibrium position will shift to the right	1
Total	**1**

(d) Initially when the neon gas is added, the system will become a light brown colour **(1)** and over time the system will restore back to a darker brown colour, however still a lighter colour than when the neon gas was initially added **(1)**.

Marking Criteria	Marking Criteria
• The volume increase will initially make the system a lighter brown colour • Over time colour will return to a darker brown, however still lighter than before the neon gas was added	$1-2$
Total	**2**

(e) When an inert gas is added at a constant pressure and the volume of the system is increased **(1)**, the rates of the forward and reverse reactions will decrease as a result of the concentration of all reactant particles in the system decreasing and therefore the frequency of collisions decreasing **(1)**. However, as there is one gaseous mole of reactant on the left-side and two gaseous moles of reactant on the right-side, the rate of the reverse reaction will decrease more than the rate of the forward reaction **(1)**, thus creating a net forward reaction **(1)**. With a net forward reaction, over time some dinitrogen tetroxide will be consumed and some nitrogen dioxide will be produced, causing the forward reaction rate to gradually decrease and the reverse reaction rate to gradually increase until equilibrium is re-established **(1)**.

Marking Criteria	Marking Criteria
• Adding an inert gas at a constant pressure will increase the system volume • A volume increase will decrease the reaction rates of both reaction rates from a collision frequency decrease on both sides • The reverse reaction rate will decrease more than forward reaction due to a 1:2 gaseous molar ratio • Thus creating a net forward reaction	$1-5$

• Over time the forward reaction rate will gradually decrease and the reverse reaction rate will gradually increase until equilibrium is re-established	
Total	**5**

Initial Equilibrium Establishment questions: Qs: 3.9

3.9 **[11 marks]**

(a) $2SO_{3(g)} \rightleftharpoons O_{2(g)} + 2SO_{2(g)}$

Marking Criteria	Marking Criteria
• Co-efficients of 2, 1 and 2: $2SO_{3(g)} \rightleftharpoons O_{2(g)} + 2SO_{2(g)}$	1
Total	**1**

(b) When sulfur trioxide is injected into to the system, the concentration of reactant sulfur trioxide will no longer be at zero **(1)**. This means that the frequency of collisions between the forward reactant particles will go from zero to a higher frequency, so the rate of the forward reaction will increase **(1)**. As time progresses, some of the sulfur trioxide will be consumed so the forward reaction rate will gradually decrease until equilibrium is established **(1)**.

Points to note: As you are approaching each reaction individually, you will need to put thought into how you approach a three-mark question like this because the question will have non-systematic marking criteria.

Marking Criteria	Marking Criteria
• Adding sulfur trioxide will increase the sulfur trioxide concentration from zero • This will increase the frequency of collisions between forward reactant particles and therefore the forward reaction rate will increase • Some of this sulfur trioxide will be consumed, gradually decreasing the forward reaction rate until equilibrium is re-established	$1-3$
Total	**3**

(c) When the sulfur trioxide is injected into the system, the concentration of reverse reactant particles will initially stay at zero since no reverse reactant particles are initially added **(1)**. However, as time progresses, some of the sulfur trioxide will be consumed and some oxygen gas and sulfur dioxide will be produced **(1)**, increasing the frequency of collisions between the reverse reactant particles. This increased collision frequency will cause the reverse reaction rate to gradually increase until equilibrium is established **(1)**.

Marking Criteria	Marking Criteria
• The reverse reactant particles will initially stay at a concentration of zero • As sulfur trioxide is consumed, oxygen gas and sulfur dioxide will be produced, increasing the reverse reactant collision frequency • The reverse reaction rate will gradually increase until equilibrium is established	$1-3$
Total	**3**

(d) When a vanadium oxide catalyst is added to the system, the catalyst will provide an alternate reaction pathway with a lower activation energy **(1)**. As a result, there will be an increase the proportion of collisions with sufficient energy to overcome the activation energy for the forward reaction, which will increase the rate at which sulfur trioxide is consume **(1)**. This means that oxygen gas and sulfur dioxide gas will be produced at a faster rate, so the rate of the reverse reaction will be increased at a faster rate **(1)**. Thus the addition of a vanadium oxide catalyst will increase the rate at which equilibrium is established **(1)**.

Marking Criteria	Marking Criteria
• The vanadium oxide catalyst will provide an alternate reaction pathway with a lower activation energy • This will increase the proportion of collisions with sufficient energy to overcome the activation energy for the forward reaction, increasing the rate of the forward reaction • This means oxygen gas and sulfur dioxide gas will be produced at a faster rate, so the reverse reaction rate will increase at a faster rate • Thus the vanadium oxide catalyst increases the rate at which equilibrium is established	$1-4$
Total	**4**

'All in one questions' – difficult exam style questions: Qs: 3.101

3.101 **[7 marks]**

All of the statements made by Jane, Dylan and Alex are all only partially correct **(1)**. When a catalyst is added to a system, the catalyst will provide an alternate reaction pathway with a lower activation energy **(1)**. As a result, there will be an increase the proportion of collisions with sufficient energy to overcome the activation energy to the same extent for both the forward and reverse reactions because the activation for both reactions has decreased equally **(1)**. Thus, the rates of both the forward and reverse reactions will increase equally and no net forward or reverse reaction will be created **(1)**. So in reference to each of their statements, Jane is correct in saying that the equilibrium position will not shift, however is incorrect in saying that the reaction rates do not increase because they do increase from the addition of a catalyst **(1)**. For Dylan, he is correct in saying that it will increase the rates of the forward and reverse reactions, but is incorrect in saying that the endothermic reaction is favoured, because a catalyst will increase both reaction rates equally **(1)**. For Alex, he is correct in saying that the catalyst does not shift the equilibrium position, however is incorrect in saying that the forward reaction is favoured, when a catalyst increases the rates of the forward and reverse reactions equally **(1)**.

Point to note: With questions like these, start by giving the correct answer and then working through each of the statements.

Marking Criteria	Marking Criteria
• Stating that the statements made by Jane, Dylan and Alex are all only partially correct	1
• A catalyst will provide an alternate reaction pathway with a lower activation energy • There will be an increase the proportion of collisions with sufficient energy to overcome the activation energy equally • Thus the rate of both reactions will increase equally and there will be no net forward or reverse reaction	$1-3$
• One mark for each person that is correctly corrected	$1-3$
Total	**7**

Problem Set 3 – Visualising Chemical Equilibrium

Progressive Questions

Concept 1

Concentration and Reaction Rate Graphs – Progressive Questions Answers

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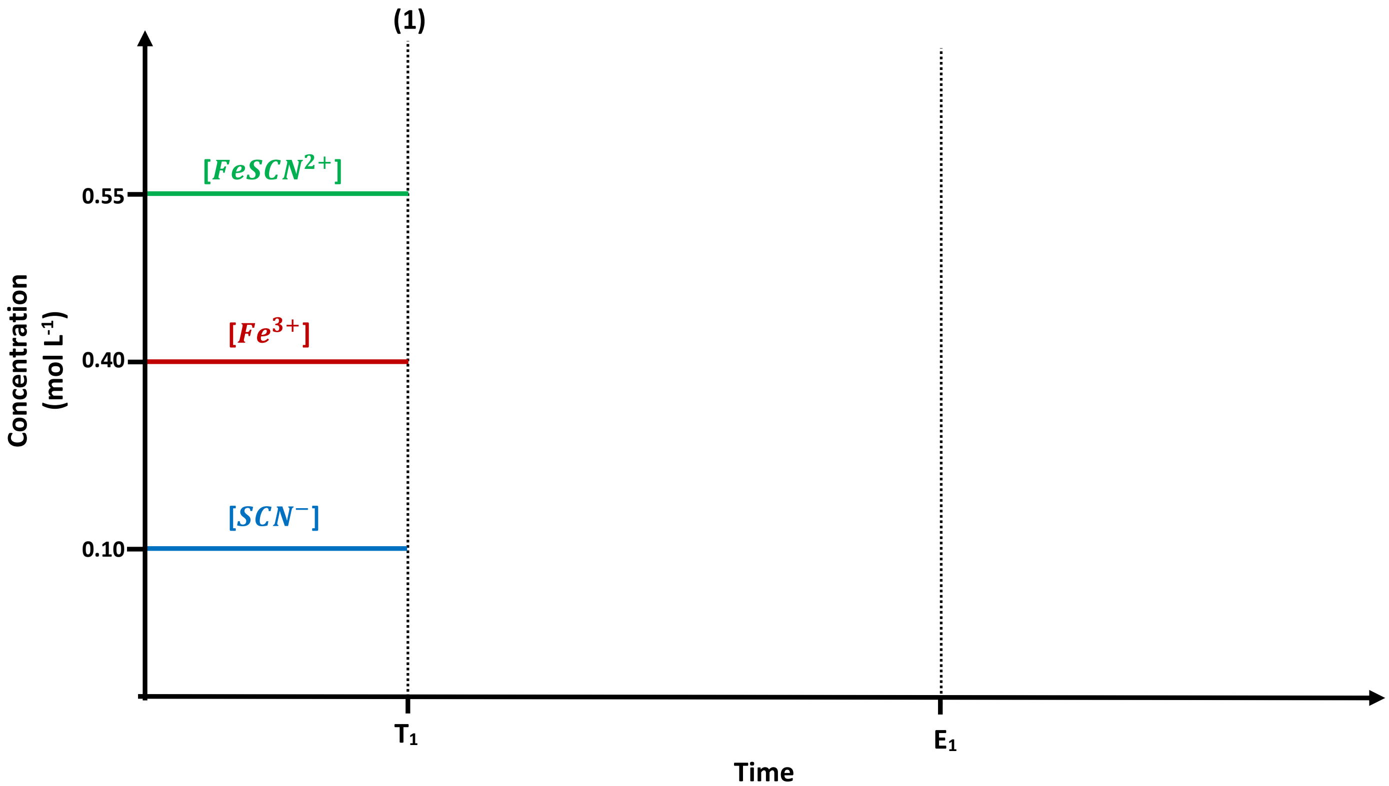
Drawing concentration graphs with given concentrations: Q1

1. **[9 marks]**

(a)



Marking Criteria	Marks Allocated
• Correct positioning and labelling of initial concentration curves such that $[FeSCN^{2+}] > [Fe^{3+}] > [SCN^{-}]$	1
Total	**1**

(b) A few drops of an aqueous solution containing Fe^{3+} ions was added

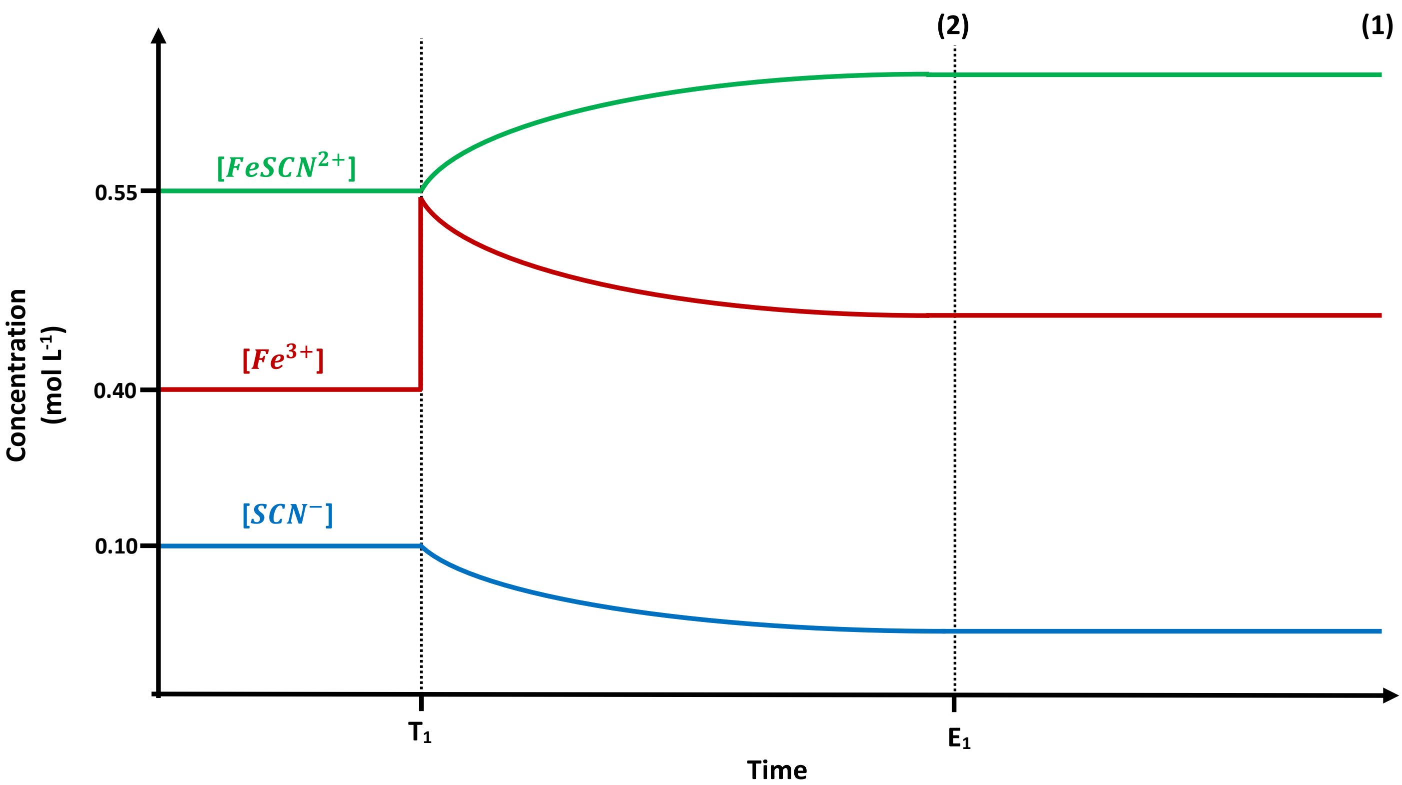
Marking Criteria	Marks Allocated
• A solution of Fe^{3+} ions was added	1

	Total	1

(c) When some additional Fe^{3+} ions are added to the system, the concentration of the Fe^{3+} ions will increase, making the solution a darker brown colour initially **(1)**. According to Le Chatelier's principle, the system will act to partially oppose this concentration increase by favouring the reaction that will consume some of the added Fe^{3+} ions **(1)**. Thus the forward reaction will be favoured, consuming some of the added Fe^{3+} ions and producing more $FeSCN^{2+}$ ions, thus turning the solution back to a red-orange colour **(1)**.

Marking Criteria	Marks Allocated
• Stating that the concentration increase of the Fe^{3+} ions will make the solution a darker brown colour • Applying LCP to state the system will act to consume some of the added Fe^{3+} ions • Correct conclusion that the system will favour the forward reaction and as a result turn back to a more red-orange colour because of the $FeSCN^{2+}$ ion concentration increase	$1-3$
Total	**3**
Note: A 'red-orange' colour or 'red-brownish' colour can be used to state the final colour of the solution	

(d)



Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous spike in $[Fe^{3+}]$ concentration curve	$1-2$

• Correct curvature and orientation of all curves to establish equilibrium at E_1	
Equilibrium lines • Equilibrium lines from T_0 to T_1 and E_1 onwards	1
Total	**4**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and an additional mark for not maintaining a 1:1:1 ratio for the concentration curves	

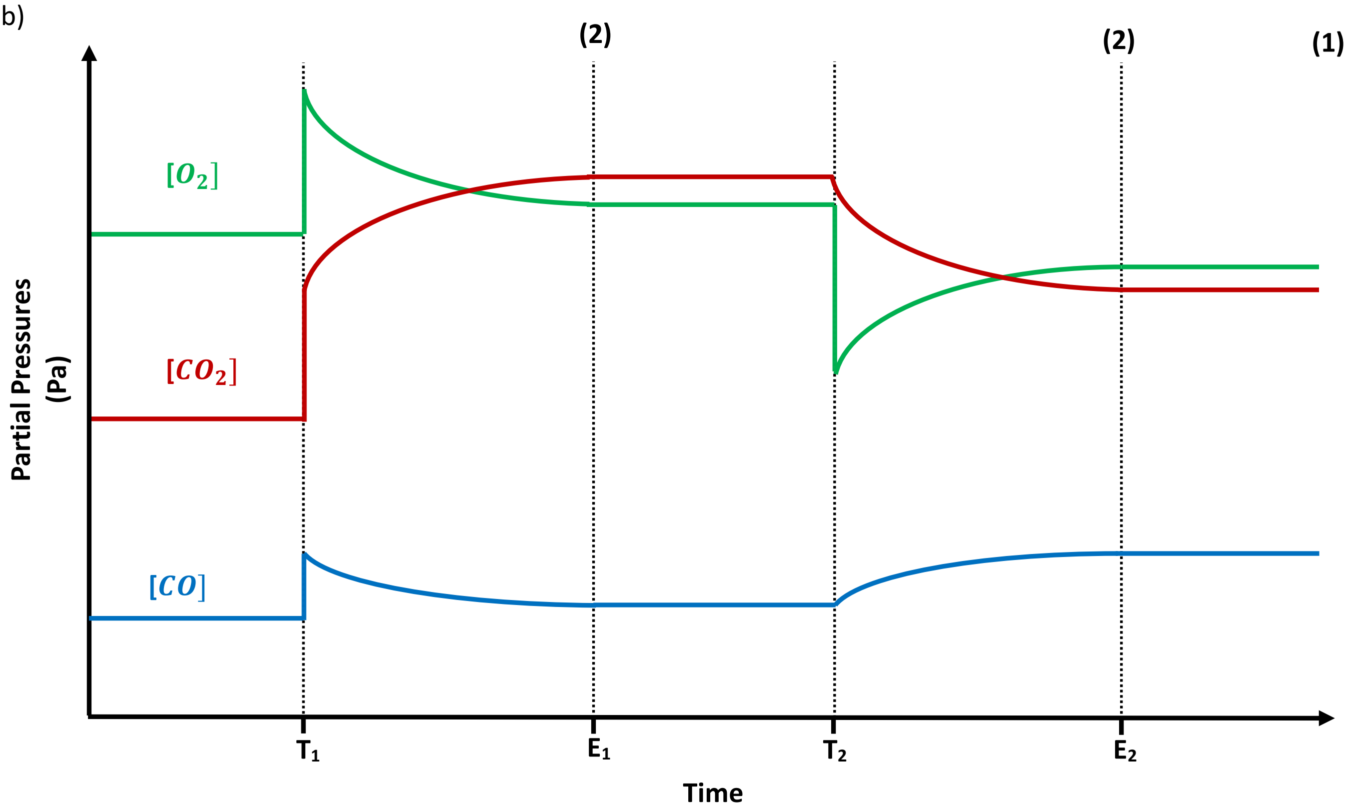
Illustrating gas changes on concentration graphs: Q2

2. **[6 marks]**

(a) $N_{2\,(g)} + O_{2\,(g)} \rightleftharpoons 2NO$

Marking Criteria	Marks Allocated
• $N_{2\,(g)} + O_{2\,(g)} \rightleftharpoons 2NO$	1
Total	**1**

(b)

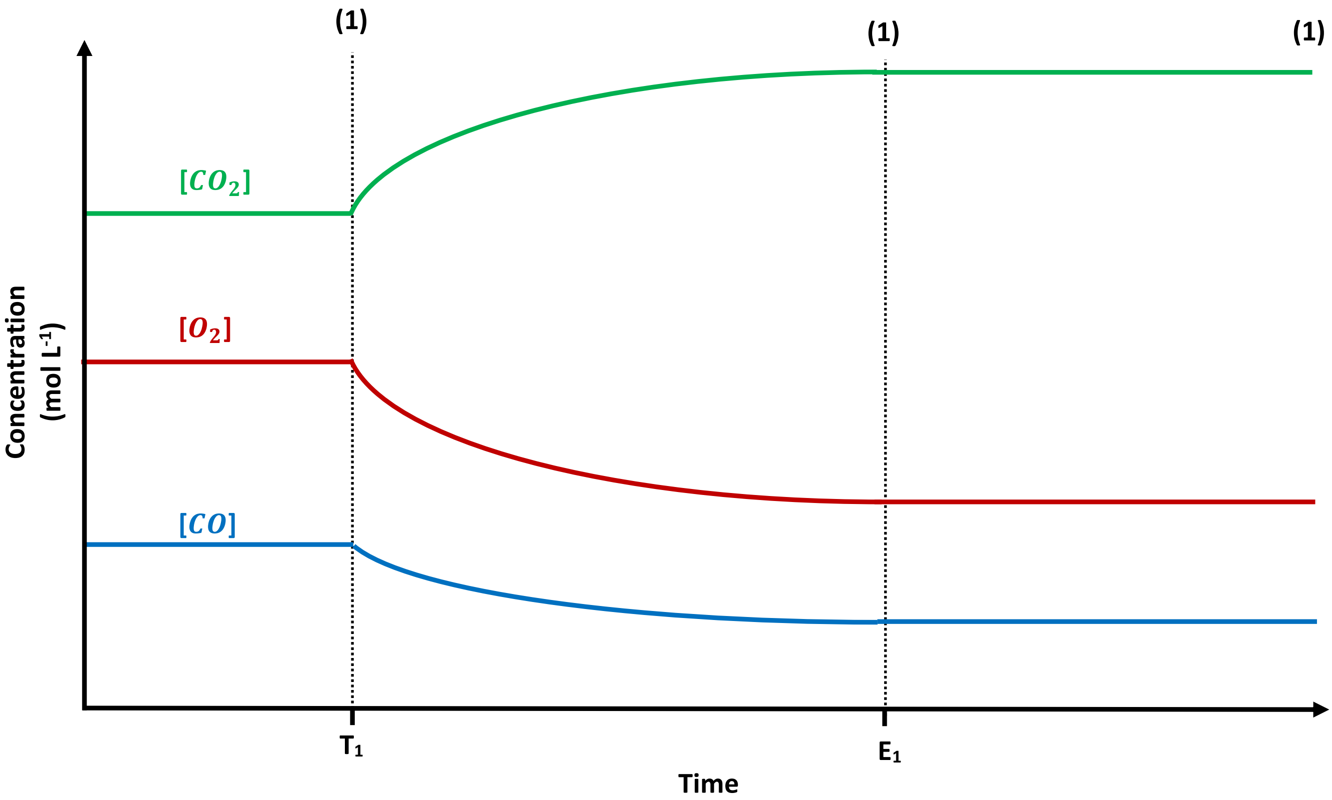


Points to note: At T_2, when the 'fresh-air' is added the nitrogen gas will react with the oxygen gas, so the concentration of oxygen will drop at T_2. It also important to label the y-axis with partial pressure rather than concentration, because the question specifically asks us to

Marking Criteria	Marks Allocated
From T_1 to E_1: • Correct upward spike of all partial pressure curves at T_1 • Correct curvature and orientation of all curves moving towards E_1	$1-2$

From T_2 to E_2: • Correct downward spike of $[O_2]$ partial pressure curve at T_2 • Correct curvature and orientation of all curves from T_2 to E_2	$1-2$
Equilibrium lines • Equilibrium lines from E_1 to T_2 and E_2 onwards	1
Total	**5**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and an additional mark for not maintaining a 1:2:2 ratio for the concentration curves. Also deduct a mark if y-axis label does not state 'partial pressure'	

3. **[3 marks]**



Marking Criteria	Marks Allocated
From T_0 to T_1: • Correct positioning and labelling of initial concentration curves such that $[CO_2] > [O_2] > [CO]$	1
From T_1 to E_1: • Correct curvature and orientation of all curves moving towards E_1	1
From E_1 onwards: • Equilibrium lines from T_0 to T_1 and E_1 onwards	1
Total	**3**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and an additional mark for not maintaining a 1:2:2 ratio for the concentration curves	

Direct analysis of concentration and reaction rate graphs to deduce specific changes: Q4 & Q5

4. **[7 marks]**

(a) From T_0 to T_1, the system is in equilibrium so all macroscopic properties remain constant, including partial pressure.

Marking Criteria	Marks Allocated
• Partial pressure will remain constant because system is initially in equilibrium from T_0 to T_1	1
Total	**1**

(b) The most likely change to occur at T_1 would be a temperature decrease **(1)**. This is because it is the only change that will cause the concentrations of H_2O and N_2 to both decrease without showing any initial spikes or drops in concentration is through decreasing the system temperature **(1)**

Marking Criteria	Marks Allocated
• Establishing a temperature decrease is the change made at T_1 • A temperature decrease will decrease the concentrations curves of both H_2O and N_2 without causing any initial spikes/drops, which matches the shape of the curves given	$1-2$
Total	**2**

(c) The most likely change to occur at T_2 would be a volume decrease **(1)**. That is because it is the only change that can initially spike the concentrations of H_2O and N_2 simultaneously and then cause both of their concentrations to decrease over-time from a favoured reverse reaction **(1)**.

Marking Criteria	Marks Allocated
• Establishing a volume decrease is the change made at T_2 • A temperature decrease will spike the concentrations of both H_2O and N_2 initially and then cause them to decrease over-time, which matches the shape of the curves given	$1-2$
Total	**2**
Note: Marks can be awarded for using 'pressure increase' however the better answer to use is volume decrease, since a pressure increase is a result of a volume decrease, it is not a change itself.	

(d) The most likely change to occur would be either the addition of a catalyst or the addition of an inert gas at a constant volume **(1)**. Both changes will have no effect on spiking/dropping the concentrations or causing there to be a net forward/reverse reaction, which is what is shown by the continued equilibrium lines from T_3 onwards.

Marking Criteria	Marks Allocated
• Establishing the addition of a catalyst **or** the addition of an inert gas at constant volume are the two possible changes made at T_3	$1-2$

• Both changes will not create any spikes/drops or any inert forward/reverse reactions, which matches the continued equilibrium lines shown	
Total	**2**
Note: Must state **both** the addition a catalyst or the addition of an inert gas at a constant volume to get the first mark	

5. **[6 marks]**

(a) From the reaction rate graph shown we can see that the temperature of the system is decreased and there is a favoured forward reaction **(1)**. According to Le Chatelier's Principle, the system will act to partially oppose a temperature increase by favouring the exothermic reaction, in order to reproduce some of the lost energy **(1)**. Thus since the forward reaction is favoured, we can deduce that it is exothermic **(1)**.

Marking Criteria	Marks Allocated
• The reaction rate graphs indicates that the temperature is decreased and that the forward reaction is favoured • According to Le Chatelier's Principle, the system will act to favour the exothermic reaction • Correct conclusion that the forward reaction is exothermic	$1-3$
Total	**3**

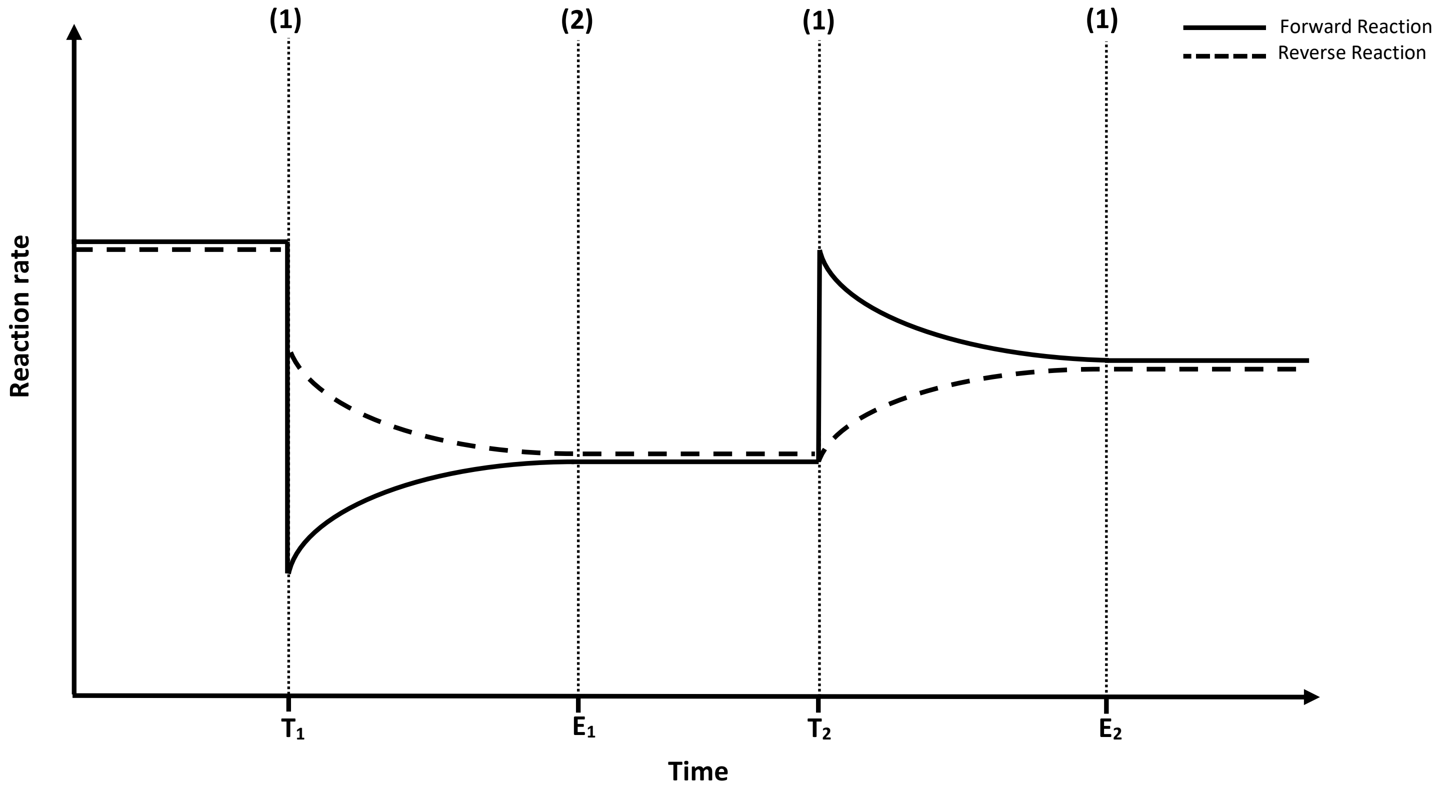
(b) Considering it is not a temperature change, and there is an instantaneous decrease in both reaction rates, it is clear that there must be a volume increase at T_2 **(1)** or the addition of an inert gas at a constant pressure **(1)** because these are the only two changes that can cause pattern shown on the graph **(1)**.

Points to note: a common trick is just stating volume increase without also stating the addition of an inert gas a constant pressure

Marking Criteria	Marks Allocated
• Stating that the instantaneous decrease in both rates can only occur through a temperature decrease or a volume increase. So therefore the two changes that can occur are: • A volume increase; or • The addition of inert gas at a constant pressure	$1-3$
Total	**3**

Illustrating volume and partial pressure changes on reaction rate graphs: Q6

6. **[5 marks]**

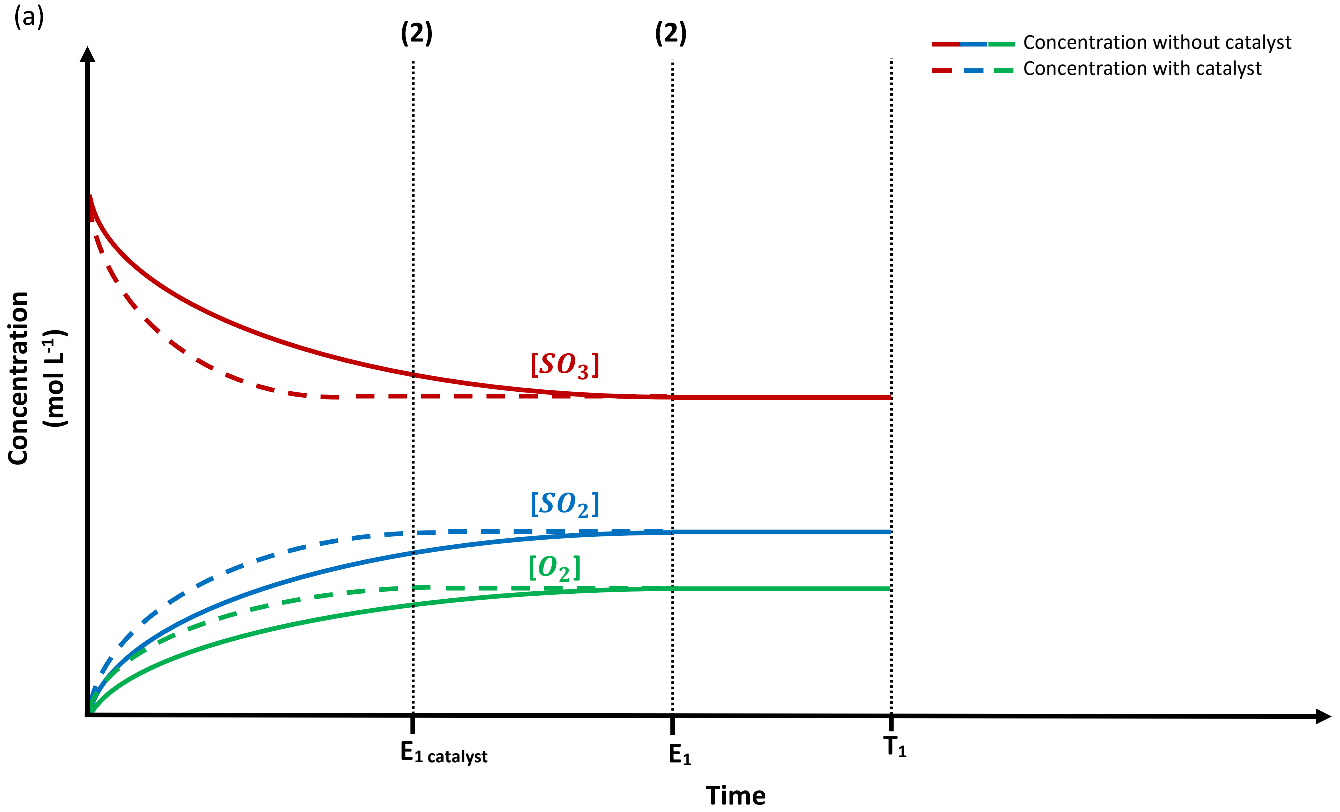


Marking Criteria	**Marks Allocated**
From T_1 to E_1: • Instantaneous drop in both curves, however greater drop in the forward reaction curve at T_1 • Correct curvature and orientation of both curves to re-join at E_1	$1-2$
From T_2 to E_2: • Instantaneous spike in the forward reaction curve at T_2 • Correct curvature and orientation of both curves to re-join at E_2	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
Total	**5**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc.	

Concentration and reaction rate combination questions (WACE exam level): Q7, Q8 & Q9

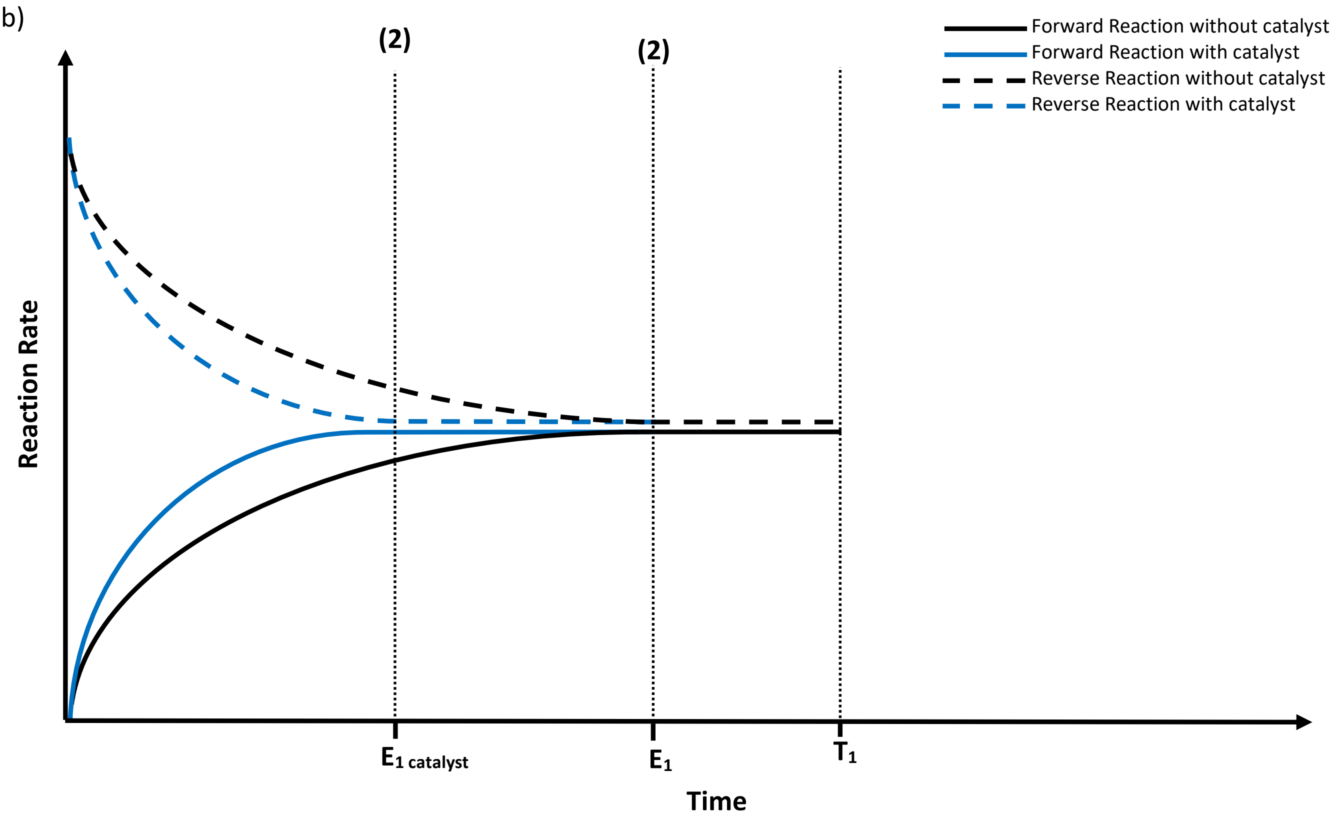
7. **[11 marks]**

(a)



Marking Criteria	Marks Allocated
Catalyst absent concentration curves: • Correct curvature and orientation of all curves, with $[SO_2]$ and $[O_2]$ starting from a zero concentration • All curves reach equilibrium at E_1	$1-2$
Catalyst concentration curves • Correct orientation and shape of all curves, with $[SO_2]$ and $[O_2]$ starting from a zero concentration • All curves reach equilibrium at $E_{1\ catalyst}$	$1-2$
Total	**4**
Note: Deduct one mark for not maintaining 1:2:2 ratio and deduct one mark if no legend is used	

(b)

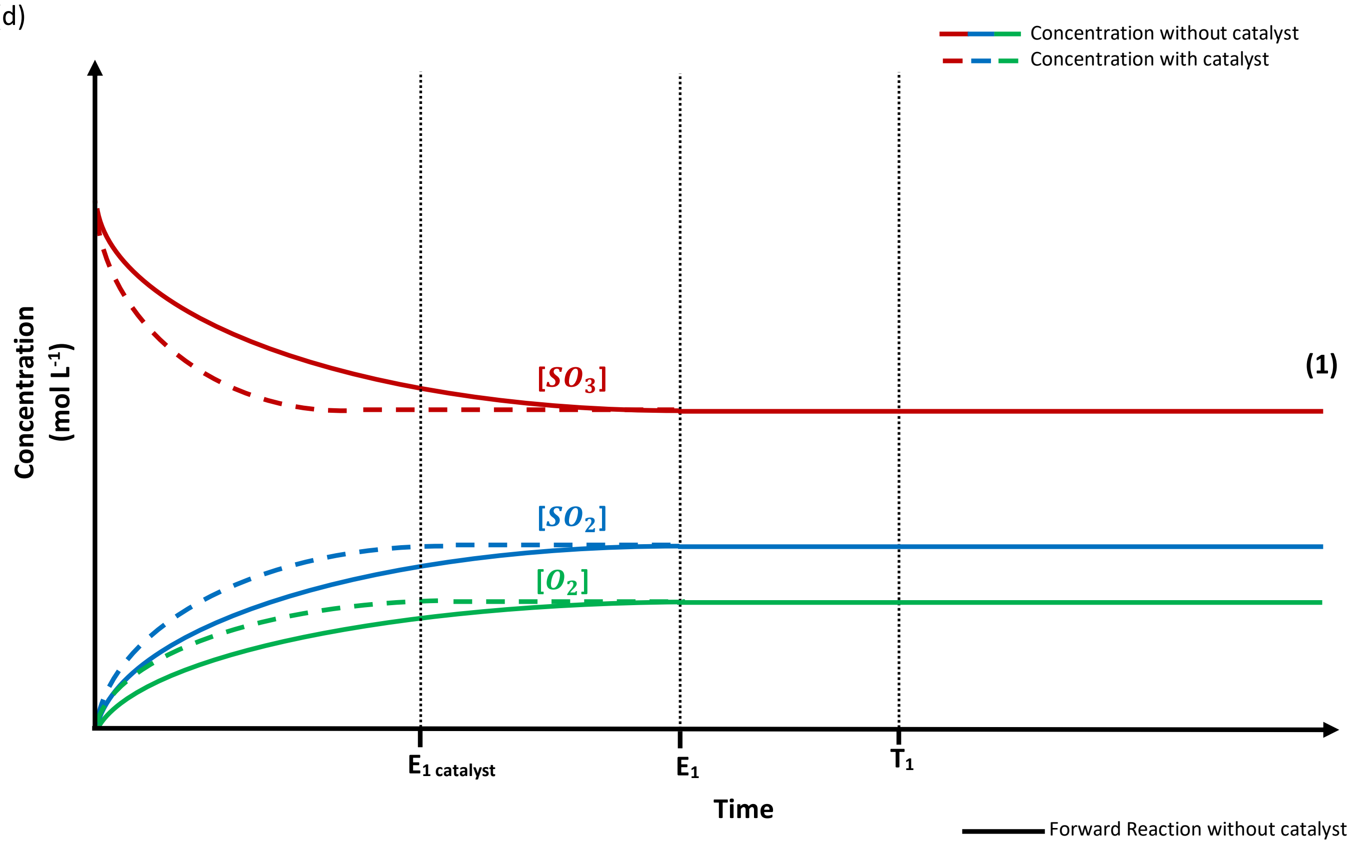


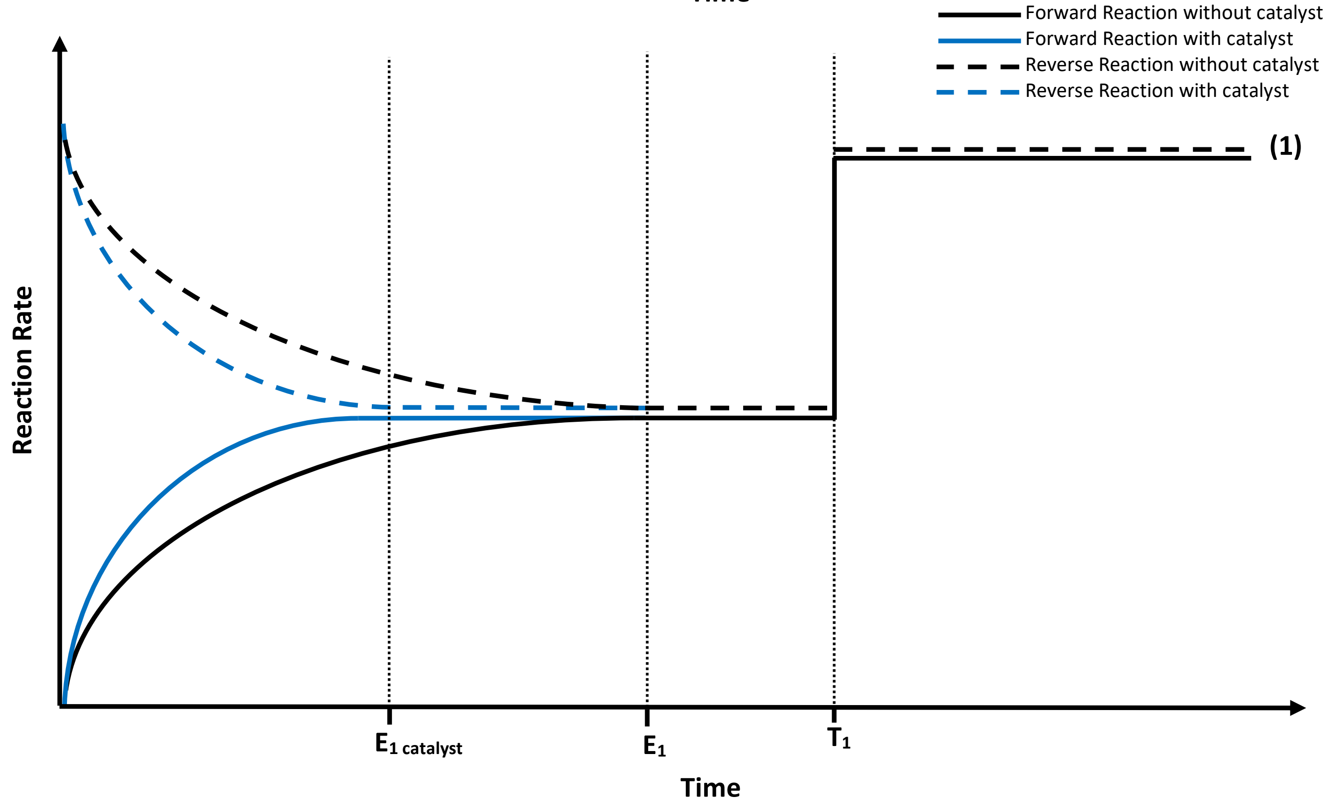
Marking Criteria	Marks Allocated
Catalyst absent concentration curves: • Correct orientation and shape of both curves, with forward reaction rate starting from zero • Both curves re-join to reach equilibrium at E_1	$1-2$
Catalyst concentration curves • Correct orientation and shape of both curves, with catalysed forward reaction rate starting from zero • Both curves re-join to reach equilibrium at $E_{1\ catalyst}$	$1-2$
Total	**4**
Note: Deduct one mark if no legend is used	

(c) Vanadium oxide has the molecular formula of V_2O_5

Marking Criteria	Marks Allocated
• Correct molecular formula of V_2O_5	1
Total	**1**

(d)





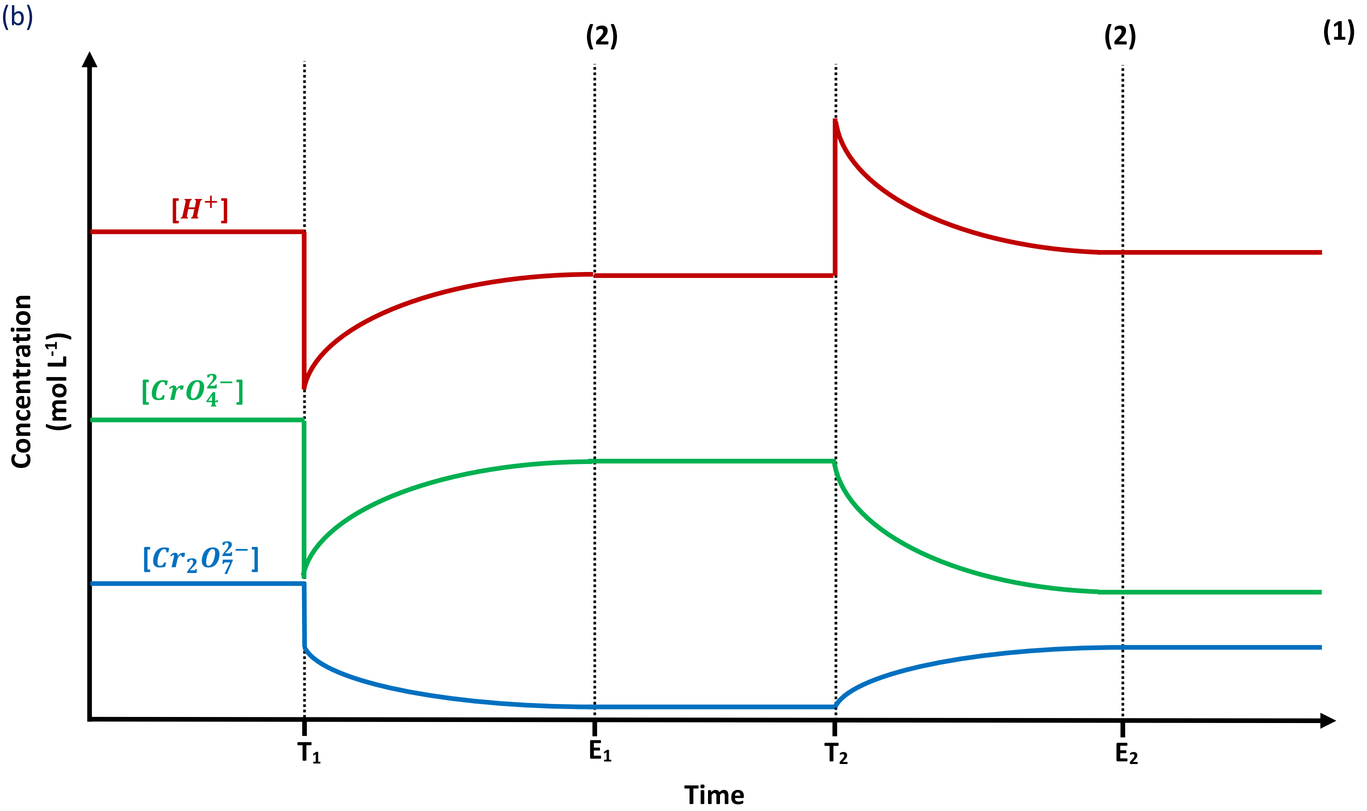
Marking Criteria	Marks Allocated
• Correct continuation of horizontal concentration lines for concentration graph • Correct spike and then horizontal continuation for reaction rate graph	$1-2$
Total	**2**

8. **[16 marks]**

(a) Liquids and solids are not included on a concentration graph because their concentrations always remain constant, therefore leaving no reason to include them **(1)**. Since water is a liquid it will not be included **(1)**.

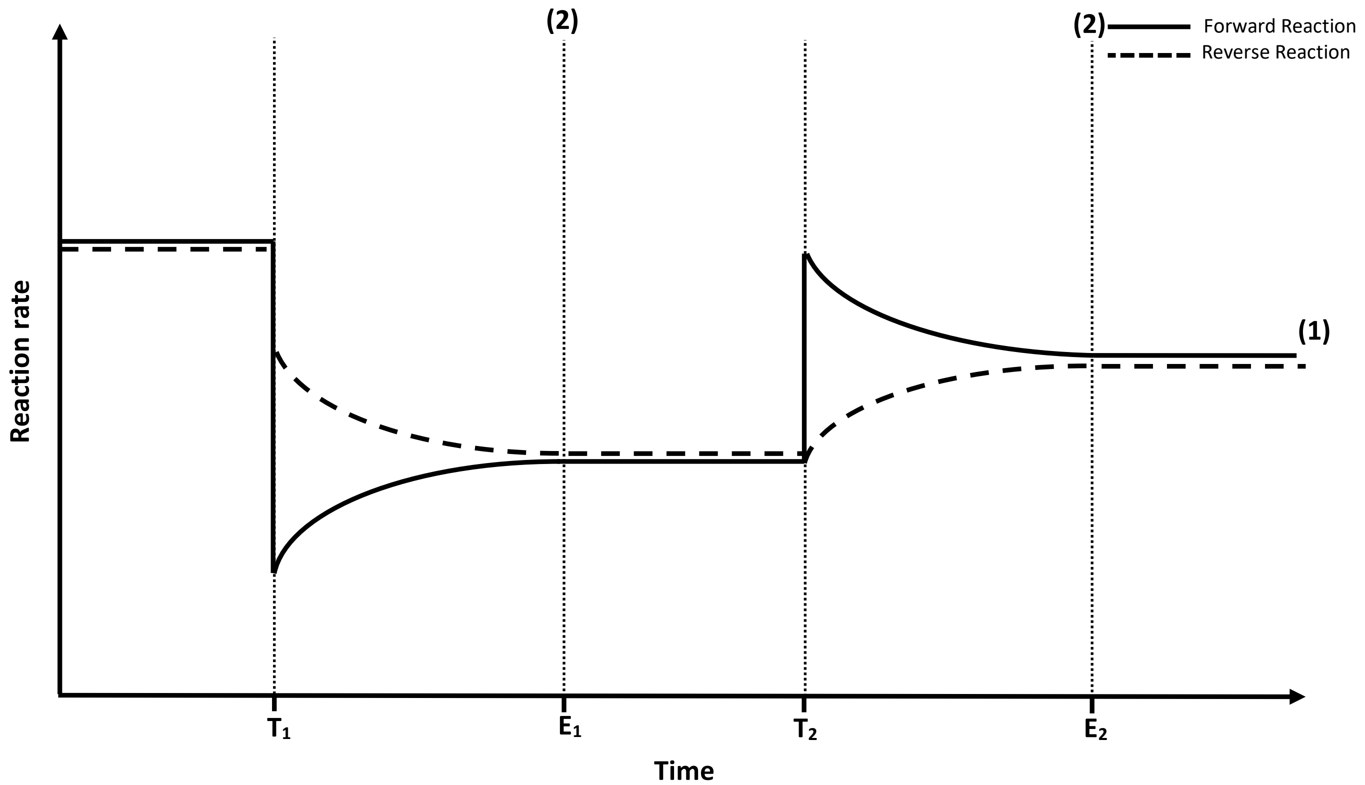
Marking Criteria	Marks Allocated
• Water should not be included on the concentration graph • Solids and liquids will always maintain a constant concentration, so there is no reason to include them	$1-2$
Total	**2**

(b)



Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous drop in all curves, proportional to 2:2:1 ratio • Correct curvature and orientation of all curves to reach equilibrium at E_1	$1-2$
From T_2 to E_2: • Instantaneous spike in the concentration of H^+ • Correct curvature and orientation of all curves to reach equilibrium at E_2	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
Total	**5**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 2:2:1 ratio	

(c)



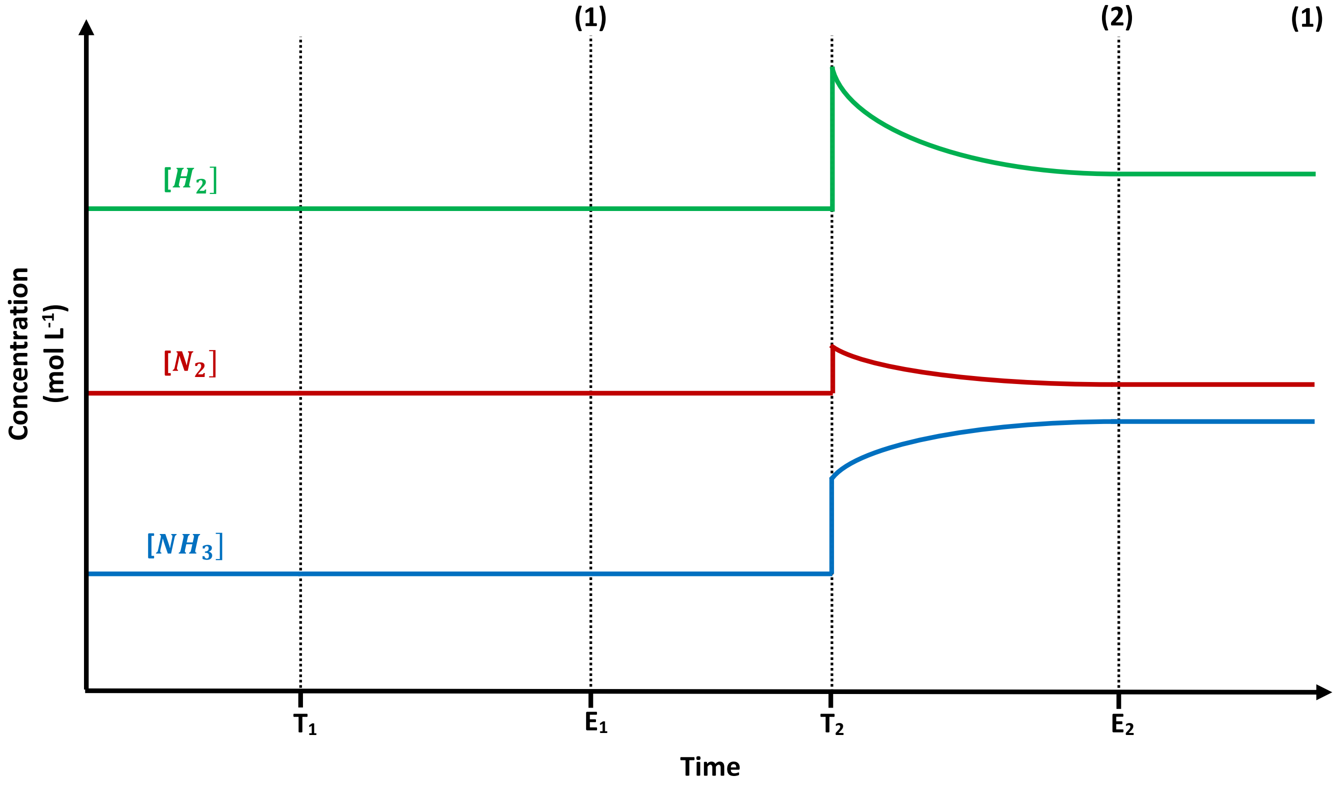
Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous drop in both curves, however greater drop for the forward reaction curve at T_1 • Correct curvature and orientation of both curves to re-join at E_1	$1-2$
From T_2 to E_2: • Instantaneous spike in the forward reaction curve at T_2 • Correct curvature and orientation of both curves to re-join at E_2	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
Total	**5**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc.	

(d) At T_1 when the water is added, the solution will go from a yellow colour to a lighter yellow colour, since there will be a concentration drop of all ions **(1)**. As shown in the rate graph, this will produce a net reverse reaction which over time will increase the chromate ion (CrO_4^{2-}) concentration turning the solution back to a yellow colour that is lighter than it was initially **(1)**. At T_2 when the hydrogen ion concentration is increased, there will be a net forward reaction, decreasing the concentration of chromate ions and increasing the concentration of dichromate ions ($Cr_2O_7^{2-}$) (as shown in the concentration graph) **(1)**. These concentration changes will turn the solution from yellow to a more orangy-yellowish colour **(1)**.

Marking Criteria	Marks Allocated
Changes at T_1: • When water is added, solution will turn to a light yellow from concentration drop • A net reverse reaction will produce more chromate ions, to turn it to a lighter yellow colour than it was initially	$1-2$

Changes at T_2: • Increasing the hydrogen ion concentration will create a net forward reaction, producing more dichromate ions and consuming some chromate ions • This will turn the solution to a more orangy-yellowish colour	$1-2$
Total	**4**
Note: Must reference the concentration and reaction rate graphs at least once each to attain full marks, otherwise deduct $1-2$ marks	

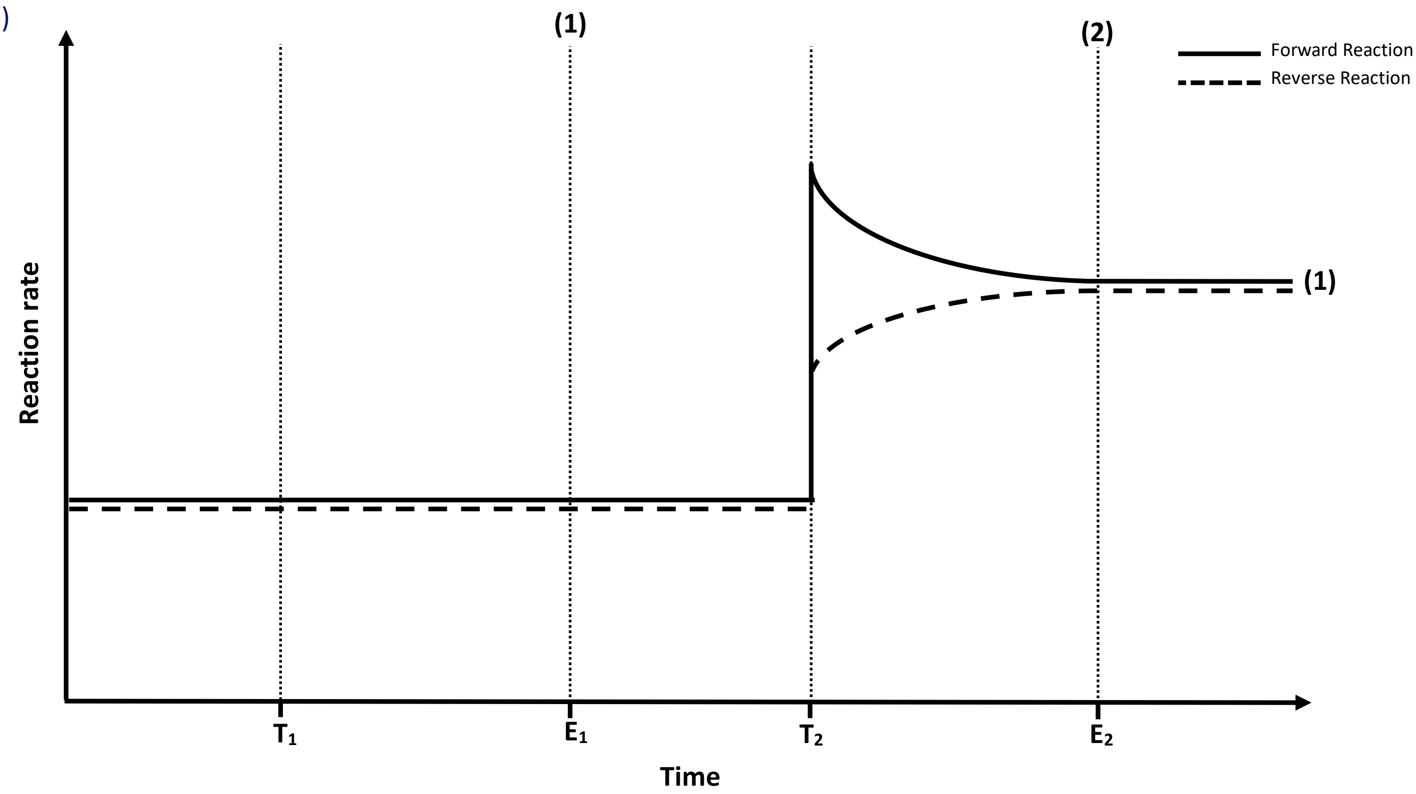
9. **[8 marks]**



Points to note: the removal of an inert gas at a constant pressure, means that the volume will need to decrease in order to keep the pressure from reducing. So when drawing the concentration graph, we will need to treat the change at T_2 as a volume decrease scenario

Marking Criteria	Marks Allocated
From T_1 to E_1: • Equilibrium lines continued for all curves	1
From T_2 to E_2: • Instantaneous spike for all curves, maintaining a 1:3:2 ratio • Correct curvature and orientation of both curves to re-join at E_2	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
Total	**4**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 1:3:2 ratio	

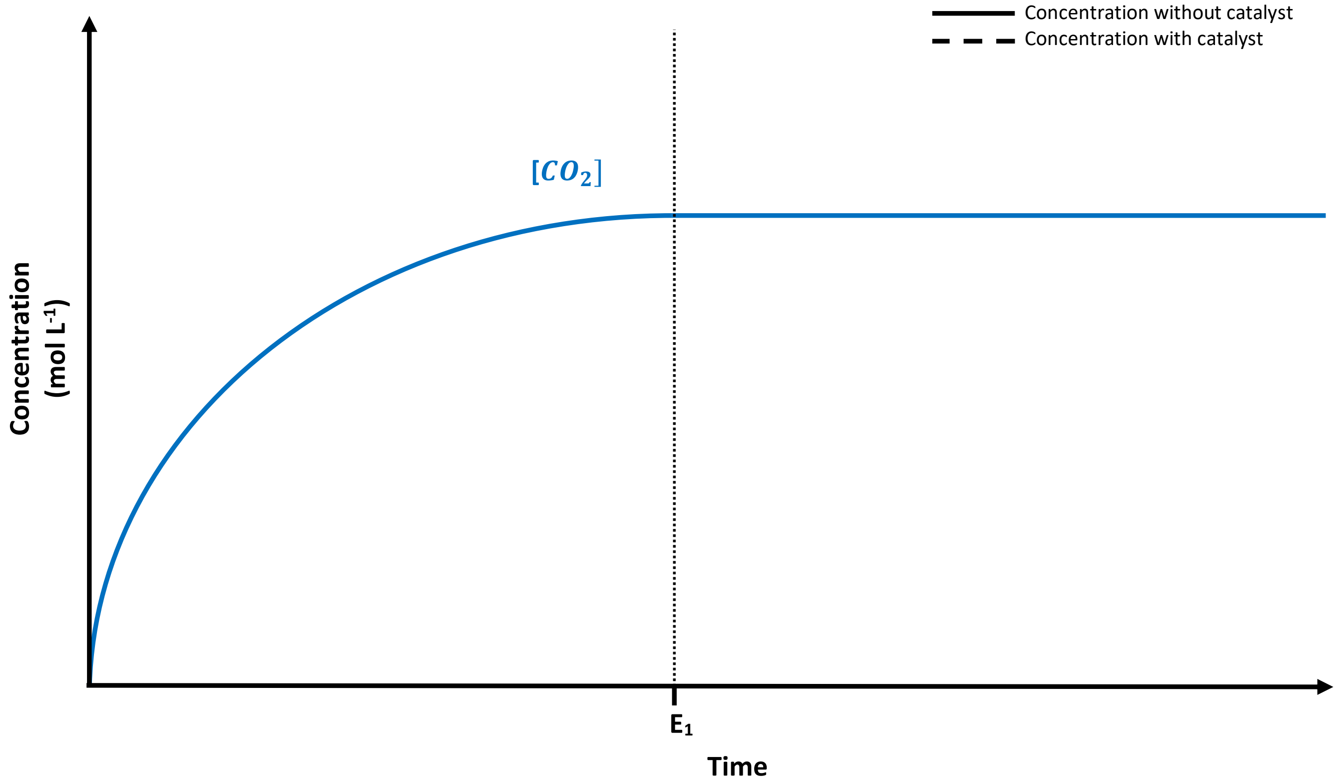
(b)



Marking Criteria	Marks Allocated
From T_1 to E_1: • Reaction rate lines kept constant	1
From T_2 to E_2: • Instantaneous spike in both curves, however greater increase in the forward reaction curve at T_2 • Correct curvature and orientation of both curves to re-join at E_2	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
Total	**4**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc.	

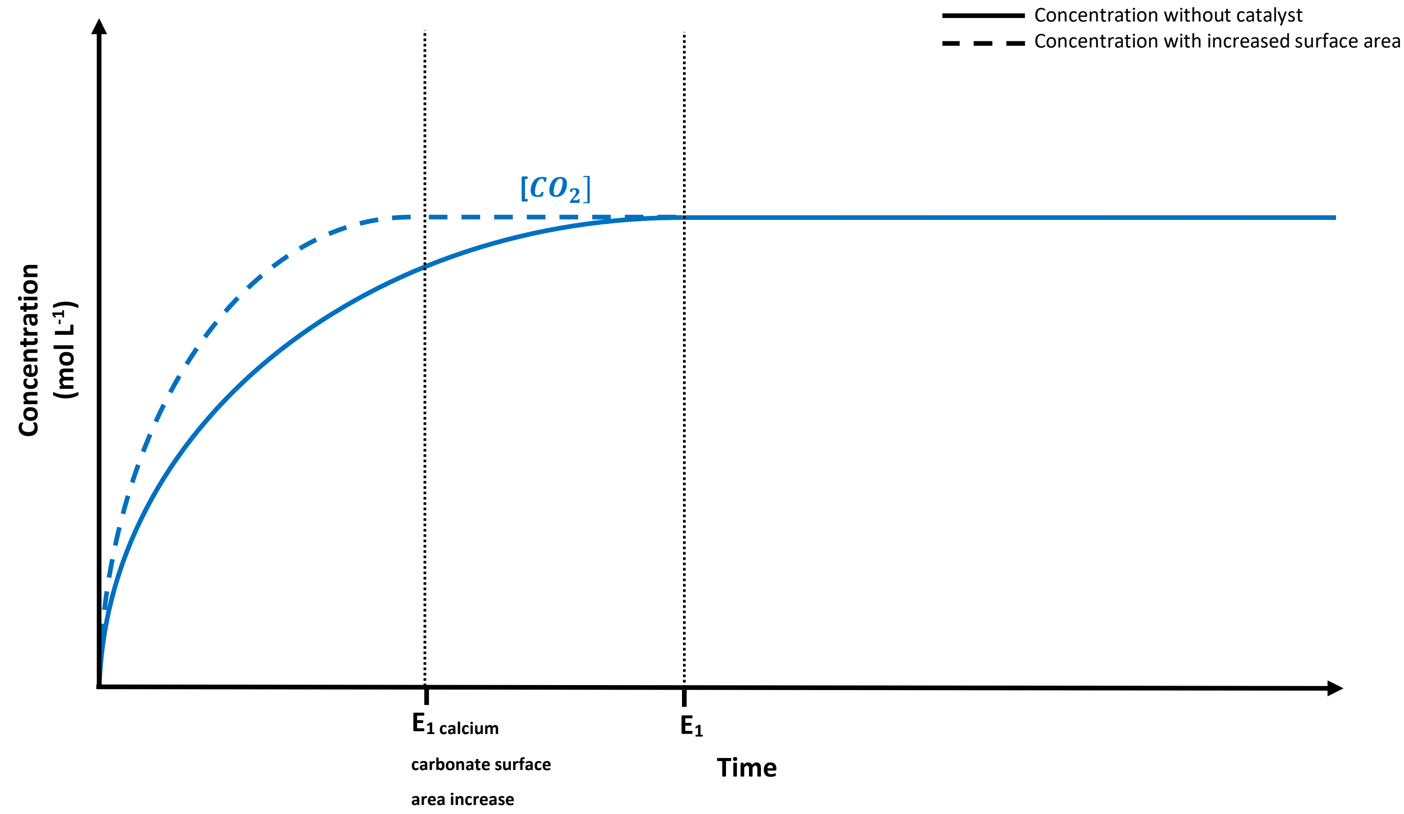
10. **[4 marks]**

(a)



Marking Criteria	**Marks Allocated**
From T_0 to E_1: • Correct curvature and orientation of curve, with $[CO_2]$ starting from a zero concentration • Equilibrium established at E_1	$1 - 2$
Total	**2**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc or for any unnecessary concentration curves that shouldn't be included	

(b)



Points to note: increasing the surface area of a reactant has the identical effect of the addition of the catalyst in that it increases the rate at which equilibrium is established. This increase in reaction rate is what you want to show on the concentration graph, by drawing an earlier establishment of equilibrium of the CO_2 concentration curve.

Marking Criteria	Marks Allocated
From T_0 to E_1: • Correct curvature and orientation of surface area curve • Equilibrium established at $E_{1\ \text{calcium carbonate surface area increase}}$	$1-2$
Total	**2**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc or for not including a 'legend/key'	

Concept 5

Ocean Equilibrium- Progressive Questions Answers

Ocean Equilibrium short answer questions: Q1

1. **[8 marks]**

(a) When the concentration of atmospheric carbon dioxide increases, this will shift the carbon dioxide equilibrium shared with the ocean to the right: $CO_{2(g)} \rightleftharpoons CO_{2(aq)}$, increasing the amount of carbon dioxide dissolved in the water **(1)**. This will increase the amount of carbonic acid in the water because an increase in the dissolved carbon dioxide concentration will the equilibrium position of the production of carbonic acid to shift to the left: $H_2O_{(l)} +$

$CO_{2(aq)} \rightleftharpoons H_2CO_{3(aq)}$ **(1)**. With an increased carbonic acid concentration, more carbonic acid will ionise to produce more hydronium ions: $H_2CO_{3(aq)} + H_2O_{(l)} \rightleftharpoons HCO_3{}^-{}_{(aq)} + H_3O^+{}_{(aq)}$ **(1)**.

Marking Criteria	Marks Allocated
• Increasing the concentration of atmospheric carbon dioxide will increase the concentration of dissolved carbon dioxide: $CO_{2(g)} \rightleftharpoons CO_{2(aq)}$ • A increased concentration of dissolved carbon dioxide will shift the equilibrium position for the production of carbonic acid to the right: $H_2O_{(l)} + CO_{2(aq)} \rightleftharpoons H_2CO_{3(aq)}$ • An increased carbonic acid concentration will shift the equilibrium position for the ionisation of carbonic acid to the right: $H_2CO_{3(aq)} + H_2O_{(l)} \rightleftharpoons HCO_3{}^-{}_{(aq)} + H_3O^+{}_{(aq)}$ increasing the hydronium ion concentration	$1-3$
Total	**3**

(b) With an increased hydronium ion concentration, the system for the second ionisation of carbonic acid: $HCO_3{}^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$ will shift to the left in order to consume some of the hydronium ions **(1)**, however this will also consume some of the carbonate ions, thus decreasing the carbonate ion concentration **(1)**.

Marking Criteria	Marks Allocated
• An increased hydronium ion concentration will shift the equilibrium position of the second ionisation of carbonic acid to the left: $HCO_3{}^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$ • This will consume some of the carbonate ions, thus decreasing the carbonate ion concentration	$1-2$
Total	**2**

(c) With a decrease in the carbonate ion concentration, the system for the production of calcium carbonate: $Ca^{2+}{}_{(aq)} + CO_3{}^{2-}{}_{(aq)} \rightleftharpoons CaCO_{3(s)}$ will shift to the left in order to reproduce some of the lost carbonate ions **(1)**, meaning there will be less calcium carbonate available in our oceans **(1)**. This loss of calcium carbonate will be consumed from reefs and other marine life, making it harder for coral reefs to sustain its calcium carbonate body **(1)**.

Marking Criteria	Marks Allocated
• A decreased carbonate ion concentration will shift equilibrium position of the production of calcium carbonate to the left: $Ca^{2+}{}_{(aq)} + CO_3{}^{2-}{}_{(aq)} \rightleftharpoons CaCO_{3(s)}$ • This will reduce the amount of calcium carbonate available in our oceans • A loss of calcium carbonate makes it harder for coral reefs to gather calcium carbonate particles to form their calcium carbonate bodies	$1-3$
Total	**3**

Problem Set 3 – Visualising Chemical Equilibrium

Progressive Questions

Concept 1

Concentration and Reaction Rate Graphs – Repetitive Questions

Answers

1.1 **[9 marks]**

(a)

Time (t)	**Change to system**	$[Cu^{2+}{}_{(aq)}]$	$[Cu(NH_3)_4{}^{2+}{}_{(aq)}]$	$[NH_{3(aq)}]$
T_1	Some copper (II) ions are added	1.02	1.25	$\mathbf{(0.80)}$
T_2	(The temperature is raised)	$\mathbf{(1.10)}$	1.15	1.20

Points to note: To determine each of the concentrations, you will need to make use of the molar ratios.

- So for T_1 when the concentration of $Cu(NH_3)_4{}^{2+}$ is increased by 0.05, it means that the concentration of ammonia will decrease by four times that amount (i.e. 0.2). Note that you can't use the copper ion concentration because you don't know how much copper ions were added initially to increase its concentration
- For T_2, when the concentration of $Cu(NH_3)_4{}^{2+}$ is decreased by 0.05 and the concentration of ammonia is increased by 0.2, we can deduce that the concentration increase of the copper ions will be 0.1, based on its molar ratios.

Marking Criteria	Marks Allocated
• Correct determination of $[NH_3] = 0.80\ mol\ L^{-1}$ at T_1 • Correct determination of $Cu^{2+}] = 1.10\ mol\ L^{-1}$ at T_2	$1 - 2$
Total	**2**

(b) K_c values will always return to the same value once equilibrium has been re-established if temperature remains constant. So both equilibrium constants should be the same before and after T_1 **(1)**.

$$K_c = \frac{[Cu(NH_3)_4^{2+}]}{[Cu^{2+}][NH_3]^4}$$

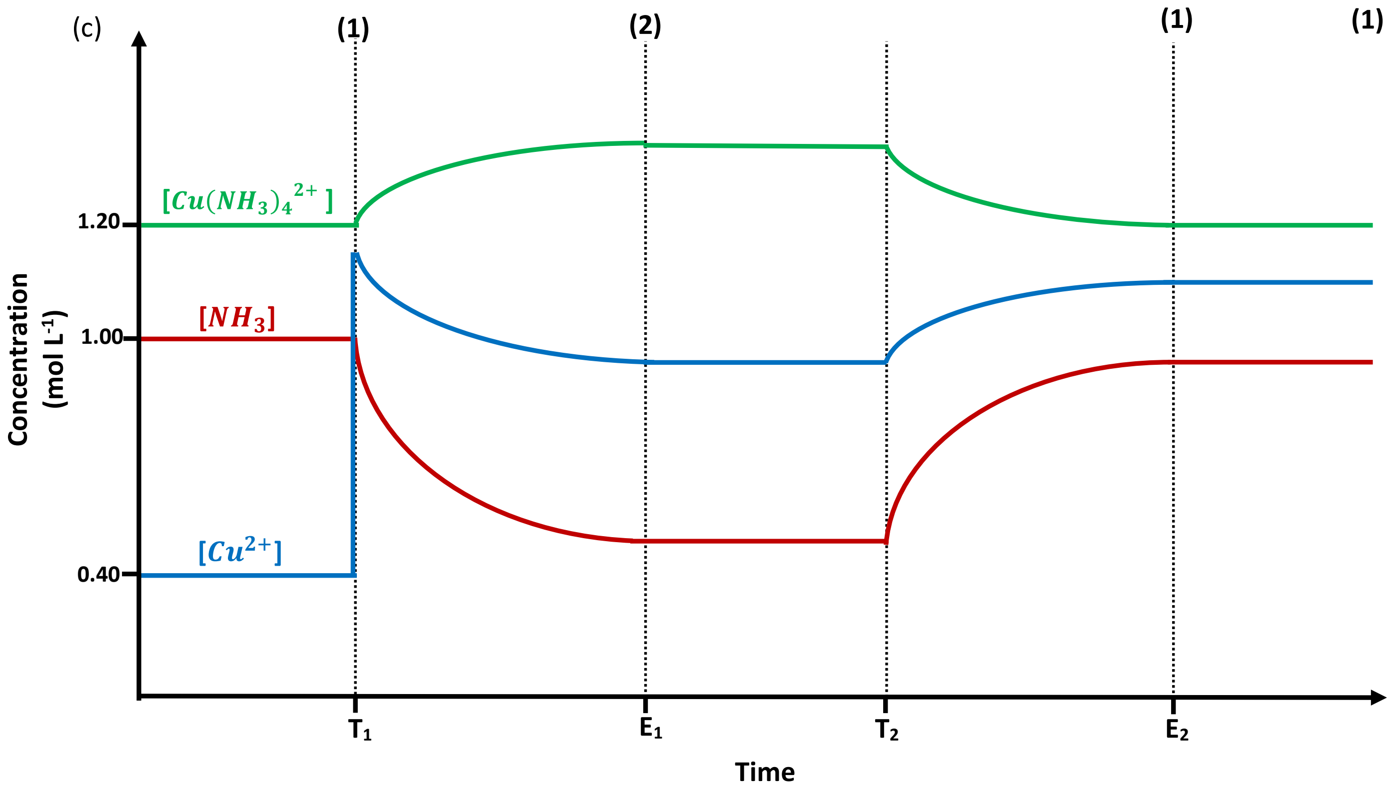
$$K_{c\ initially} = \frac{[1.20]}{[0.4][1]^4} \qquad K_{c\ after\ T_1} = \frac{[1.25]}{[1.02][0.8]^4}$$

$$K_{c\ initially} = 3 \qquad K_{c\ after\ T_1} = 3$$

(1)

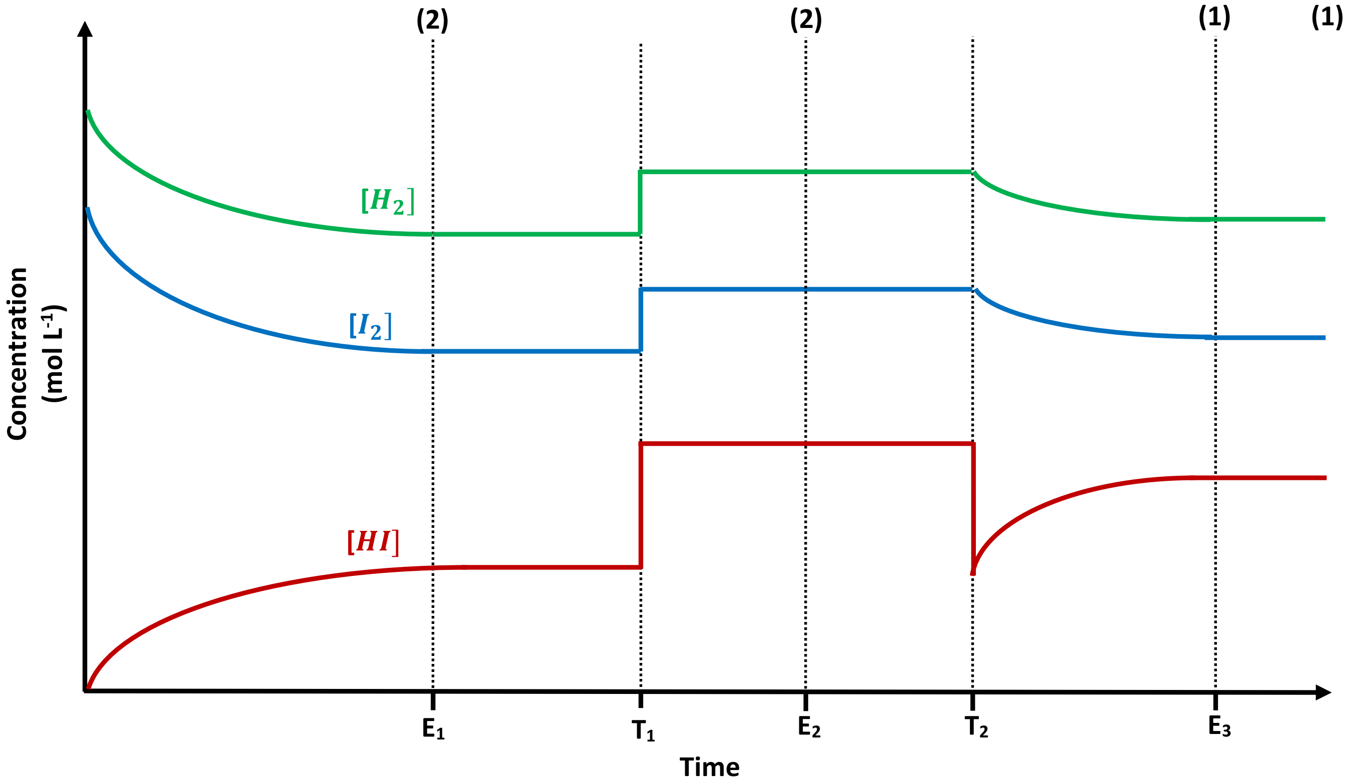
Marking Criteria	Marks Allocated
• Stating that the K_c values should be equal before and after the change at T_1 • Correct determination that both K_c values equal 3	$1 - 2$
Total	**2**
Note: Deduct one mark for any errors made in workings	

(c)



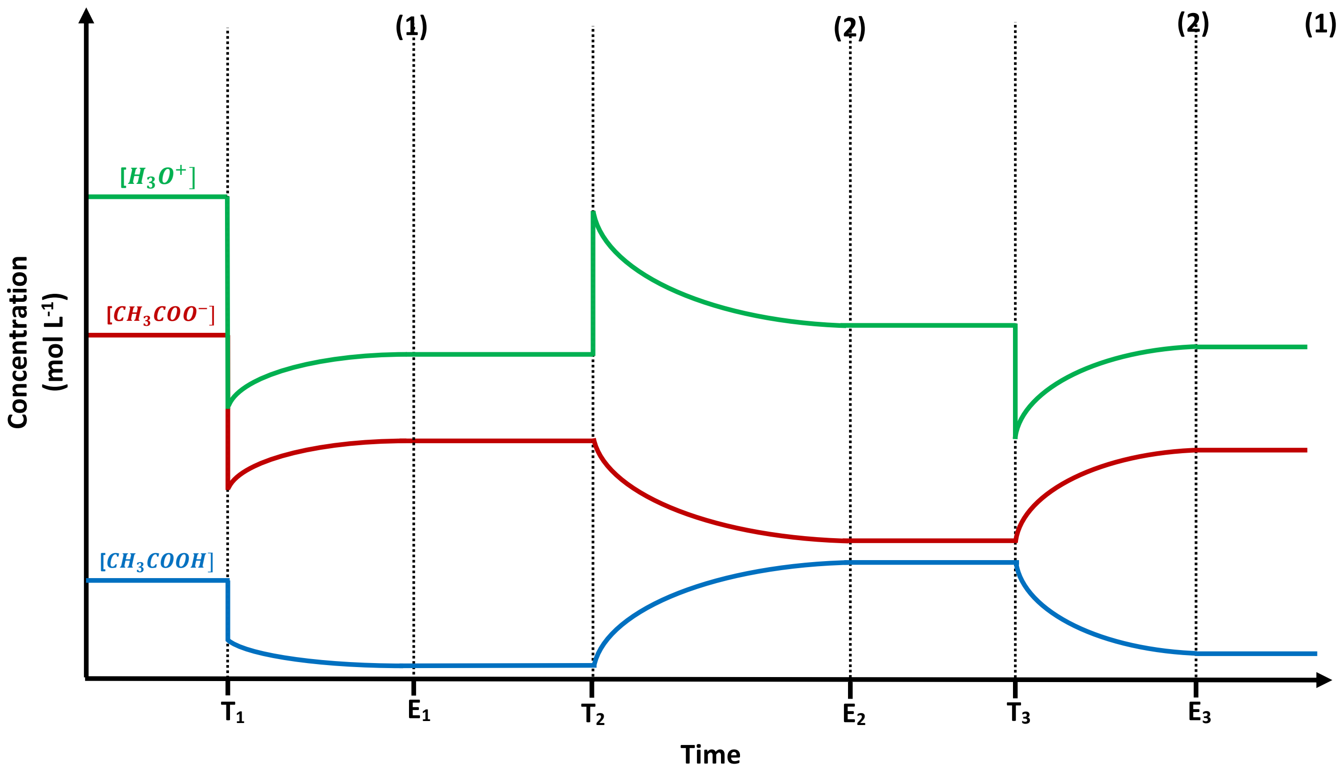
Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous spike for copper ions at T_1 • Correct curvature and orientation for all curves to reach equilibrium at E_1	$1-2$
From T_2 to E_2: • Correct curvature and orientation for all curves to reach equilibrium at E_2	1
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
• Correct concentration labels of $\left[Cu^{2+}{}_{(aq)}\right] = 0.40$, $\left[NH_{3\,(aq)}\right] = 1.00$, $\left[Cu(NH_3)_4{}^{2+}{}_{(aq)}\right] = 1.20$ on the y-axis	1
Total	**5**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 1:4:1 ratio	

1.2 **[6 marks]**



Marking Criteria	Marks Allocated
From T_0 to E_1: • Correct curvature and orientation of all curves, with $[HI]$ starting from a zero concentration • All curves reach equilibrium at E_1	$1-2$
From T_1 to E_2: • Instantaneous spike for all curves, proportional to 1:1:2 ratio • Continuation of equilibrium lines from T_1 to E_2	$1-2$
From T_2 to E_3: • Correct curvature and orientation for all curves to reach equilibrium at E_2	1
Equilibrium lines • Equilibrium lines from E_2 to T_2 and E_3 onwards	1
Total	**6**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 1:1:2 ratio	

1.21 **[6 marks]**

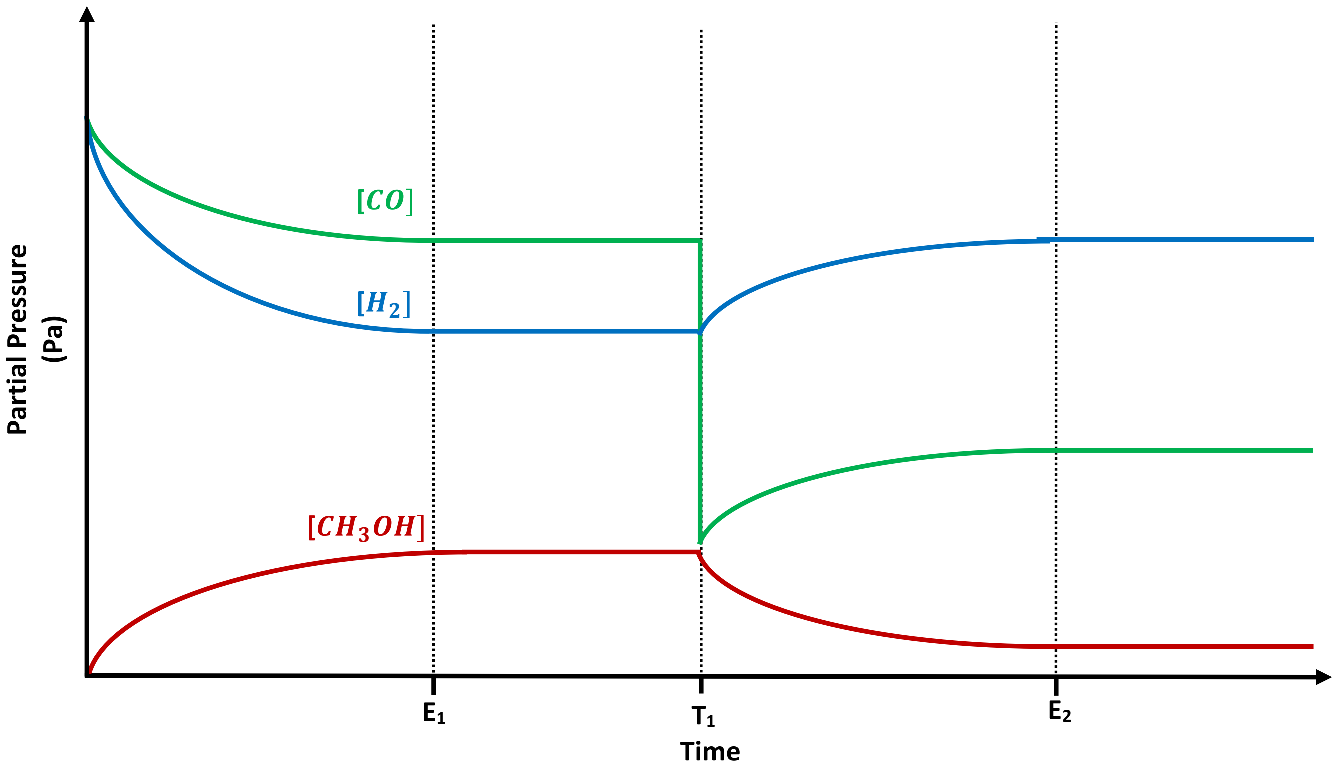


Points to note: For change T_1, when more of the same solution is added, the concentration of the ions will remain unchanged because the solution added has an identical concentration

Marking Criteria	Marks Allocated
From T_1 to E_1: • Continuation of all equilibrium lines from T_1 to E_1	1
From T_2 to E_2: • Instantaneous spike in the $[H^+]$ concentration curve at T_2 • Correct curvature and orientation for all curves to reach equilibrium at E_2	$1-2$
From T_3 to E_3: • Instantaneous drop in all concentration curves at T_3, proportional to 1:1:1 ratio • Correct curvature and orientation for all curves to reach equilibrium at E_3	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_3 onwards	1
Total	**6**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 1:1:1 ratio	

1.22 **[5 marks]**

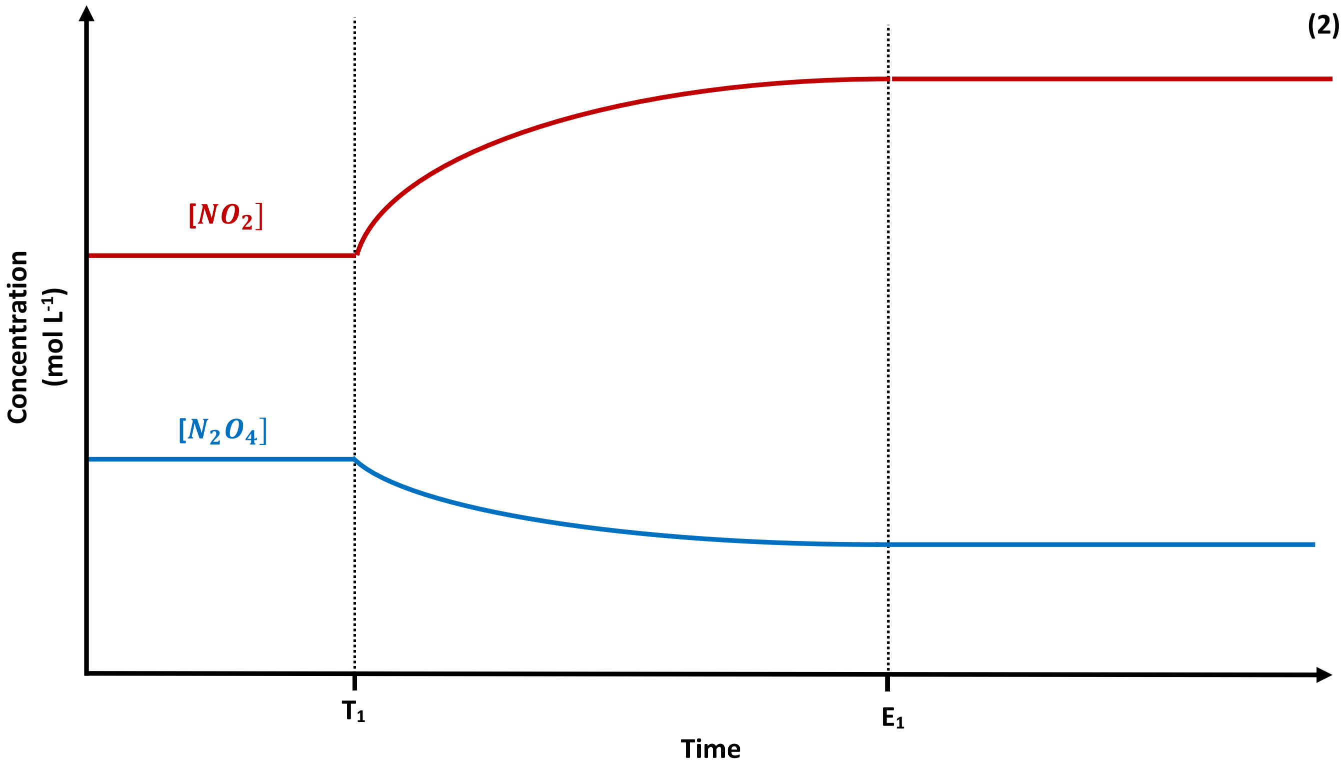
(2) (2) (1)



Marking Criteria	Marks Allocated
From T_0 to E_1: • Correct curvature and orientation of all curves, with $[CH_3OH]$ starting from a zero concentration • All curves reach equilibrium at E_1	$1-2$
From T_1 to E_2: • Instantaneous drop in the $[CO]$ concentration curve at T_1 • Correct curvature and orientation for all curves to reach equilibrium at E_2	$1-2$
Equilibrium lines • Equilibrium lines from E_1 to T_1 and E_2 onwards	1
Total	**5**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 2:1:1 ratio. Also can deduct a mark if the y-axis is labelled with 'Concentration' instead of 'Partial Pressure'	

1.3 **[4 marks]**

(2)



As you can see from the concentration graph above, when the temperature of the system is increased, the concentration of nitrogen dioxide (NO_2) increases and the concentration of nitrogen tetroxide (N_2O_4) decreases **(1)**, indicating that the forward reaction is favoured **(1)**.

Marking Criteria	Marks Allocated
Concentration curve • Correct curvature and orientation of curves from T_1 to E_1 • Equilibrium from T_0 to T_1 and E_1 onwards	$1-2$
Explanation: • Reference to the concentration graph, that NO_2 increases and the N_2O_4 decreases • Correct conclusion that the forward reaction is favoured	$1-2$
Total	**4**

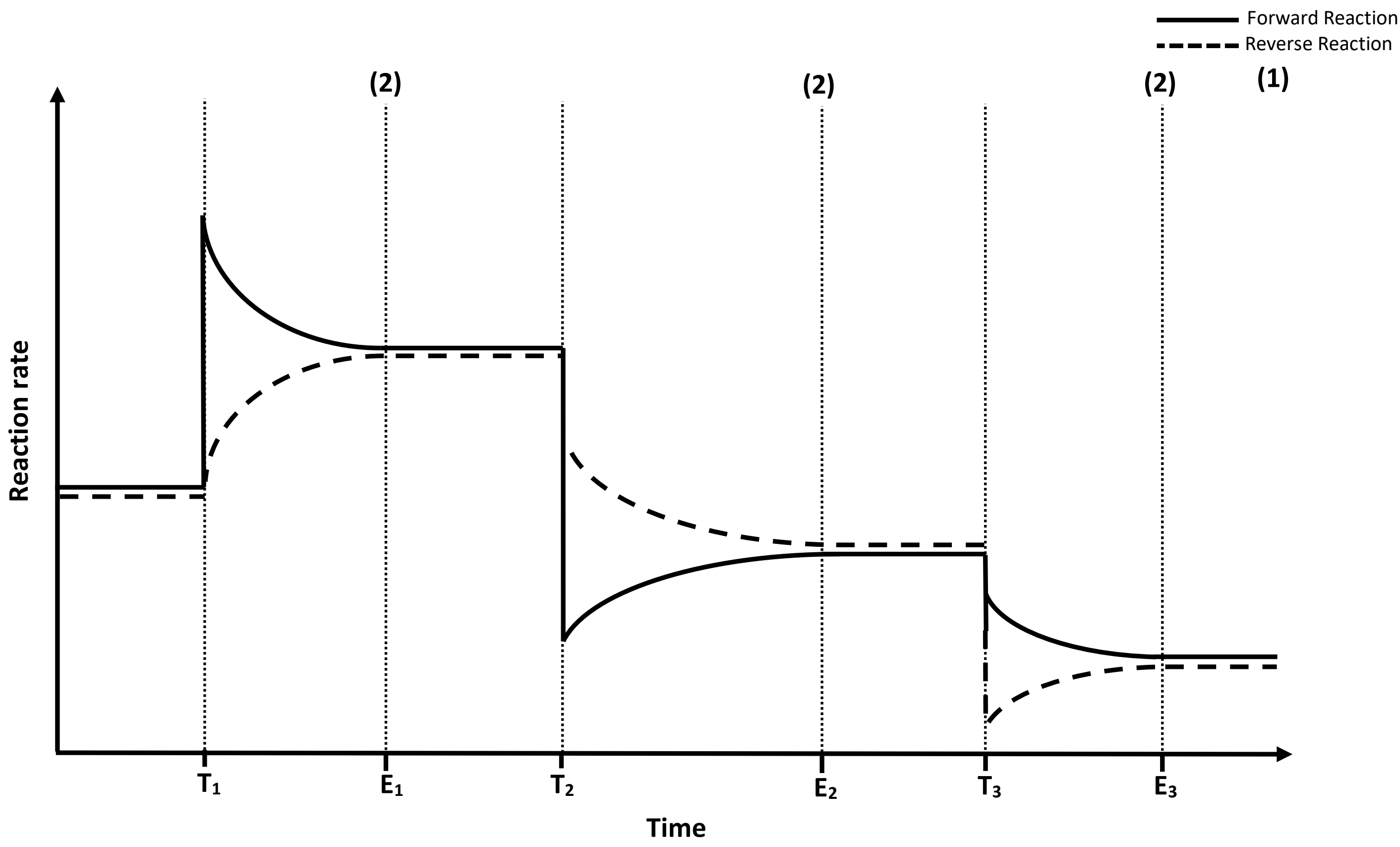
1.5 **[10 marks]**

(a) The changes made at T_1, T_2 and T_3 are:

- At T_1 some additional hydrogen gas is added to the system **(1)**
- At T_2 the volume of the system is doubled **(1)**
- At T_3 the temperature of the system is decreased **(1)**

Points to note: this is a pretty hard 3 marks to attain and requires a very strong understanding of equilibrium changes. Our advice for approaching questions like these would be to use a process of elimination by considering the features of changes to concentration, pressure, temperature and the addition of a catalyst, to whittle your way down to the correct answer.

Marking Criteria	Marks Allocated
• 1 mark for each change stated correctly to T_1, T_2 and T_3	$1-3$
Total	**3**



Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous spike of forward reaction curve at T_1 • Correct curvature and orientation for all curves to re-join at E_1	$1-2$
From T_2 to E_2: • Instantaneous drop in both curves at T_2, however a greater drop in the forward reaction curve • Correct curvature and orientation for all curves to re-join at E_2	$1-2$
From T_3 to E_3: • Instantaneous drop in both curves at T_3, however a greater drop in the reverse reaction curve • Correct curvature and orientation for all curves to re-join at E_3	$1-2$

Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2, E_2 to T_3 and E_3 onwards	1
Total	**7**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc.	

1.51 **[6 marks]**

Time	Imposed change(s)	Brief Explanation
T_1	**The removal of NH_3 (1)**	**The removal of NH_3 will instantaneously decrease the reverse reaction rate, whilst keeping the forward reaction initially constant; which is what is shown on the graph (1).**
T_2	**The addition of a catalyst (1)**	**The addition of a catalyst is the only way by which the rates of both reactions can be increased to the same extent simultaneously with no net forward or reverse reaction created (1)**
T_3	**A decrease in the system volume (1)**	**A decrease in volume will increase both rates instantaneously, however cause a net forward reaction because it produces less moles of product, which is what is shown on the graph (1).**

Points to note: For the change at T_3, this can easily trick students into thinking it is both a volume decrease and a temperature increase. However, in a temperature increase scenario the reverse reaction would increase more than the forward reaction since it is endothermic, thus

Marking Criteria	Marks Allocated
• 1 mark for each imposed change stated correctly	$1-3$
• 1 mark for each appropriate explanation given. Cannot simply re-state the changes shown on the graph	$1-3$
Total	**6**
Note: no marks are awarded for getting the correct imposed change, if a second or third incorrect imposed change has been stated in the same box. No marks are awarded for the explanation if the stated imposed change is incorrect	

1.52 **[15 marks]**

(a) T_3

Marking Criteria	Marks Allocated
• Stating T_3 is the time a catalyst was added to the system	1
Total	**1**

(b) When a catalyst is added to a system it will be represented on a reaction rate graph by a spike of both the forward and reverse reactions **(1)**, with no net forward or reverse reaction created **(1)**, which is what is shown at T_3 on the reaction rate graph

Marking Criteria	Marks Allocated
• The addition of a catalyst will create an equal instantaneous spike both reaction rates, which is shown at T_3	$1-2$

• The addition of a catalyst will also create no net forward or reverse reaction that follows from this instantaneous spike, which is shown at T_3	
Total	**2**

(c)

- At T_1: this represents a decrease in temperature, an increase in the system volume or the addition of an inert gas at constant pressure **(3)**
- At T_2: this represents the addition of an inert gas at constant volume **(1)**
- At T_4: this represents the either the removal of carbon dioxide gas or the removal of hydrogen gas **(2)**

Points to note: this is a very hard question and requires a very strong understanding of equilibrium changes. We recommend that using the process of elimination is the best method for ensuring you include all the correct changes, otherwise you may miss some of them. To explain each of the changes for any assistance:

- At T_1, we see both reaction rates decrease with a net reverse reaction produced, meaning this could either be a temperature decrease and/or volume increase scenario. To check whether either of these are applicable, you think about which reaction would be favoured in each scenario. For a temperature decrease the reverse reaction would be favoured since it is exothermic, and for a volume increase the reverse reaction would be favoured since it produces more moles of gas. Thus the change at T_1 can be both a temperature decrease and volume increase. An additional trick of this part of the question, is that you also need to remember the addition of an inert gas at a constant pressure will also increase the volume of the system, so accounting for this is also important for gaining full marks.
- At T_2, we know that the only change that can keep a reaction rate continue at the same rate, is via the addition of a gas at constant volume. It can't be the addition of catalyst because a catalyst will still increase the reaction rate of both reactions
- At T_4, we see an instantaneous drop in the rate of the forward reaction whilst the reverse reaction rate stays constant which means it is the removal of a forward reactant. Thus it is either the removal of carbon dioxide gas or the removal of hydrogen gas

From this question it should also be clear that there are six changes that need to be identified because there are six marks to be gained. This is a common thing to pick up on, if you are often pondering in exams if your answers are sufficient. If it is six marks you will need to make six distinctive points, it is five marks you will need to make fix distinctive points and so on…

Marking Criteria	Marks Allocated
At T_1: • Temperature decrease • Increase in the system volume • Addition of an inert gas at constant pressure	$1-3$
At T_2: • Addition of an inert gas at constant volume	1
At T_4: • Removal of carbon dioxide gas • Removal of hydrogen gas	$1-2$
Total	**6**
Note: award only one mark for stating that T_4 involves the removal of reactant. Must state the removal of carbon dioxide and the removal of hydrogen gas to get both marks	

(d) T_4

Marking Criteria	Marks Allocated
• Stating T_4 is the time a catalyst was added to the system	1

	Total	1

(e) When a catalyst is added to the system, on a concentration graph this will represented by showing the system to continue to remain in equilibrium, with no changes occurring, which is what is shown at T_4 **(1)**

Marking Criteria	Marks Allocated
• The addition of catalyst will have no effect on the concentration curves and will keep the system continuing in equilibrium, which is shown at T_3	1
Total	**1**

(f)

- At T_1: this represents an increase in the temperature **(1)**
- At T_2: this represents the doubling of the systems volume or the addition of an inert gas at constant pressure to double the system volume **(2)**
- At T_3: this represents the addition of some methane (CH_4) **(1)**

Points to note: again for ensuring you get full marks for this section, it is a good idea to use the process of . To explain each of the changes for any assistance:

- At T_1, it is clear that it is a temperature change because there are no instantaneous spikes in any of the concentration changes. From that point it is just determining which reaction is favoured, and it is clear that the forward reaction is favoured since the carbon dioxide and hydrogen gas concentrations increase. Since we can then deduce that the forward reaction is endothermic, then it indicates that this must be a temperature increase scenario
- At T_2, all of the concentrations drop instantaneously to half their original concentrations and then it is clear that the forward reaction is favoured from the carbon dioxide and hydrogen gas concentration increases. This should be an obvious sign that it is a volume increase scenario, the trick of this question is to again remember that the volume of the system can also be increased by the addition of an inert gas at constant pressure, so accounting for this is crucial for getting both marks. It is also important to identify that the volume of the system is doubled since all the concentrations are halved, this is often a way in which teachers can deduct marks if they are feeling harsh, as we have chosen to do in this question ☺
- At T_3: as there is an instantaneous increase in the concentration of methane whilst all other concentrations initially remain constant and then the forward reaction is favoured, it is clear that this can only be the addition of some additional methane to the system

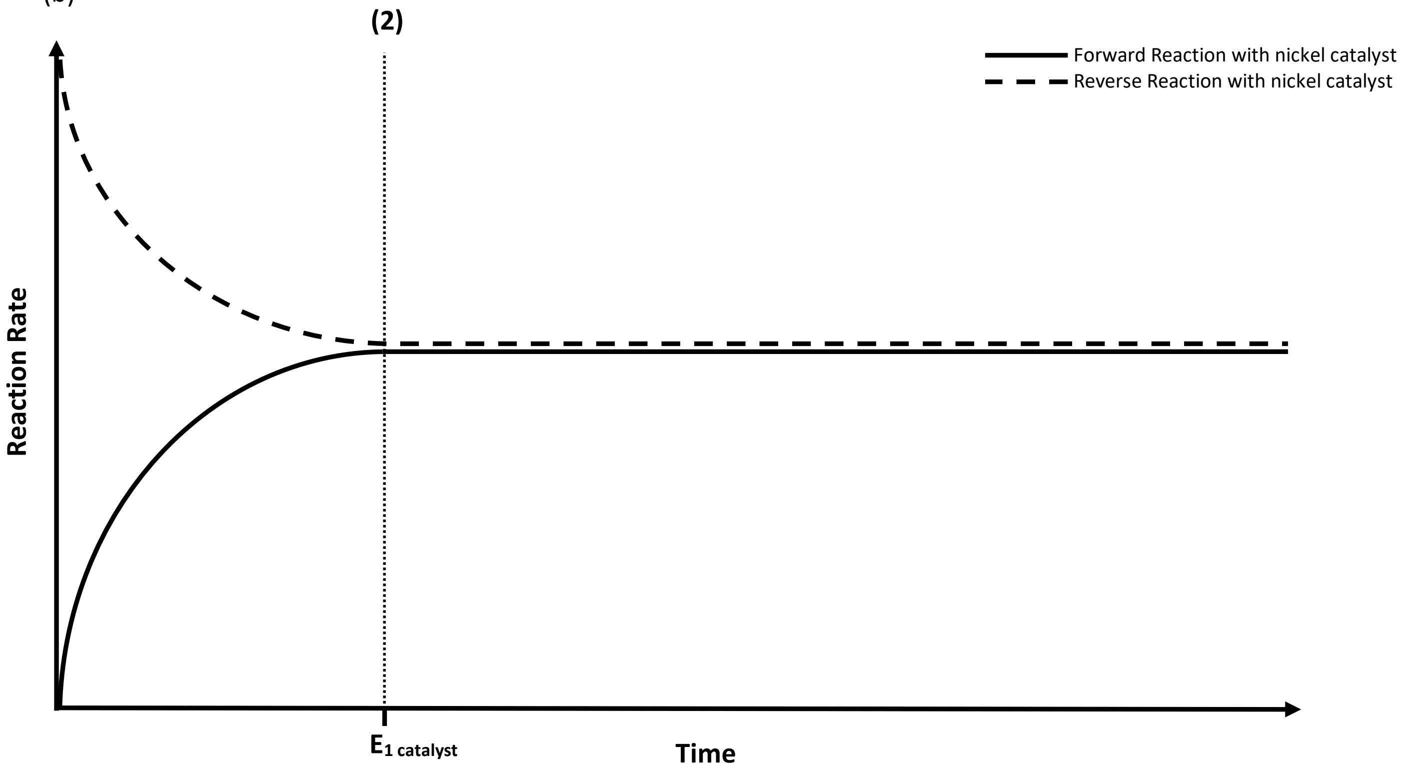
Marking Criteria	Marks Allocated
At T_1: • Temperature increase	1
At T_2: • Doubling the volume of the system • Addition of an inert gas at constant pressure to double the system volume	$1-2$
At T_4: • Addition of methane gas (CH_4)	1
Total	**4**
Note: deduct one mark at T_2 if no mention has been made that both changes have doubled the volume of the system	

1.7 **[11 marks]**

(a) $15{,}500 kPa$

Marking Criteria	Marks Allocated
• Correct pressure of $15{,}500 kPa$ stated	1
Total	**1**

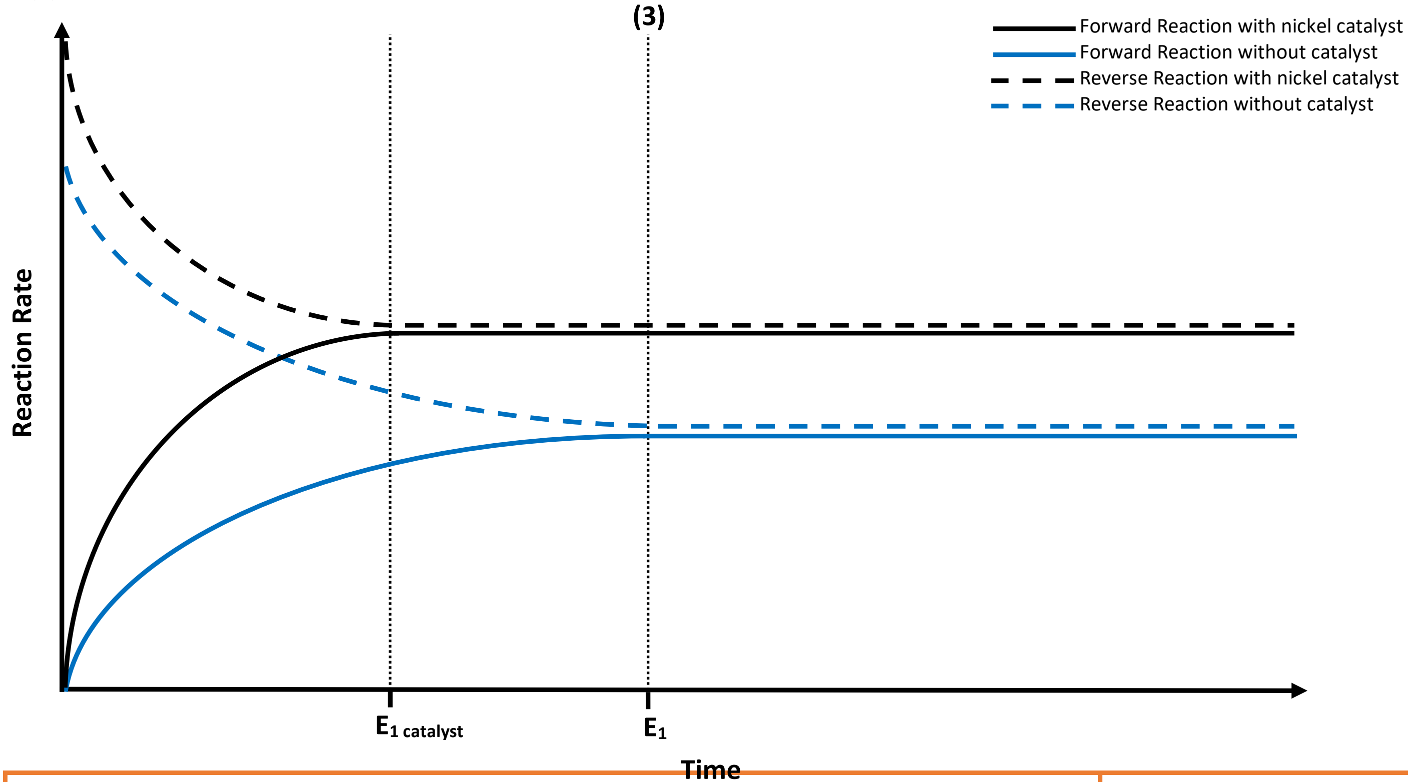
(b)



Marking Criteria	Marks Allocated
From T_1 to $E_{1\ catalyst}$: • Forward reaction curve starting at a zero reaction rate • Correct curvature and orientation for both curves to join at $E_{1\ catalyst}$	$1-2$
Total	**2**
Note: Deduct one mark for any missing/incorrect labels of T_1, $E_{1\ catalyst}$, axis labels etc.	

(c)

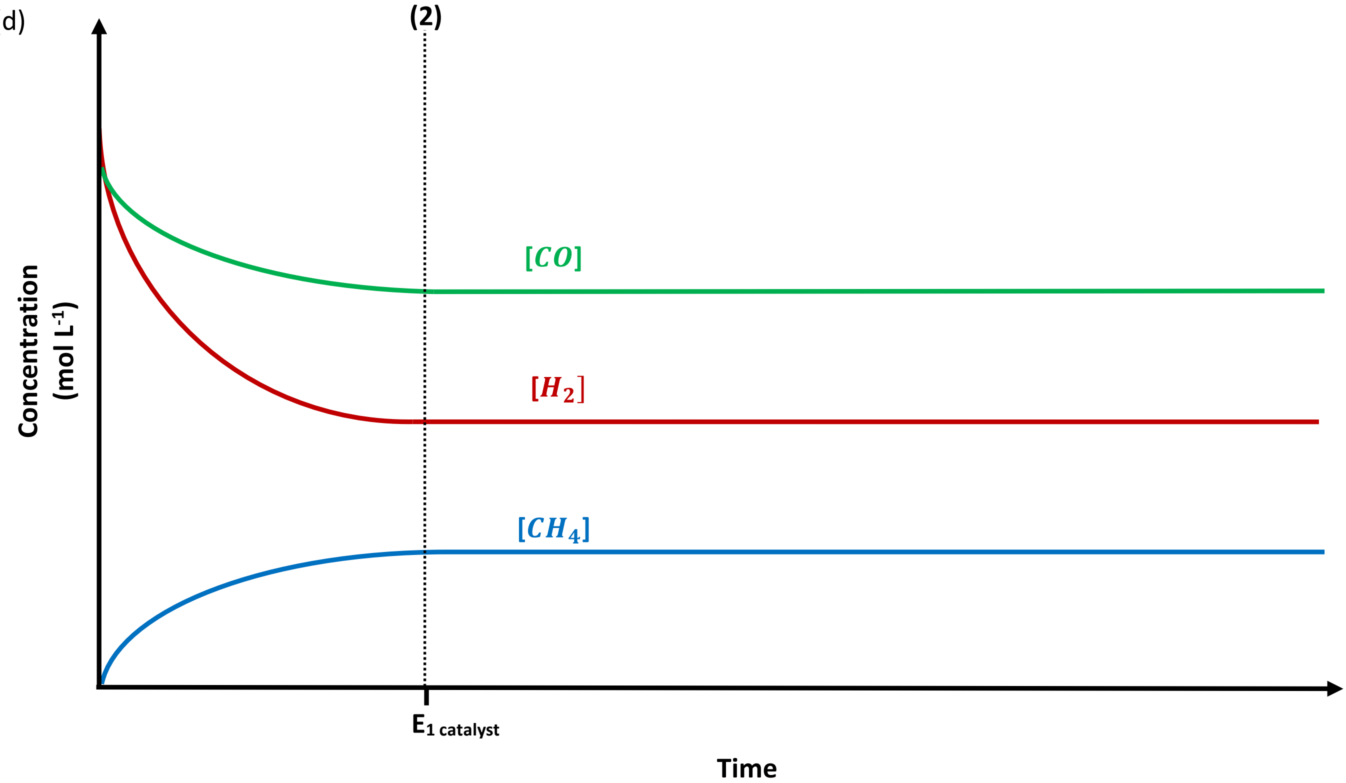
(3)



Marking Criteria	Marks Allocated
From T_1 to E_1: • Equilibrium established at a later point than $E_{1\ catalyst}$ • Equilibrium reaction rate lower than that of the catalysed reaction rate • Correct curvature and orientation for all curves to join at E_1	$1 - 3$
Total	**3**
Note: Deduct one mark for any missing/incorrect labels of T_1, $E_{1\ catalyst}$, axis labels etc.	

(d)

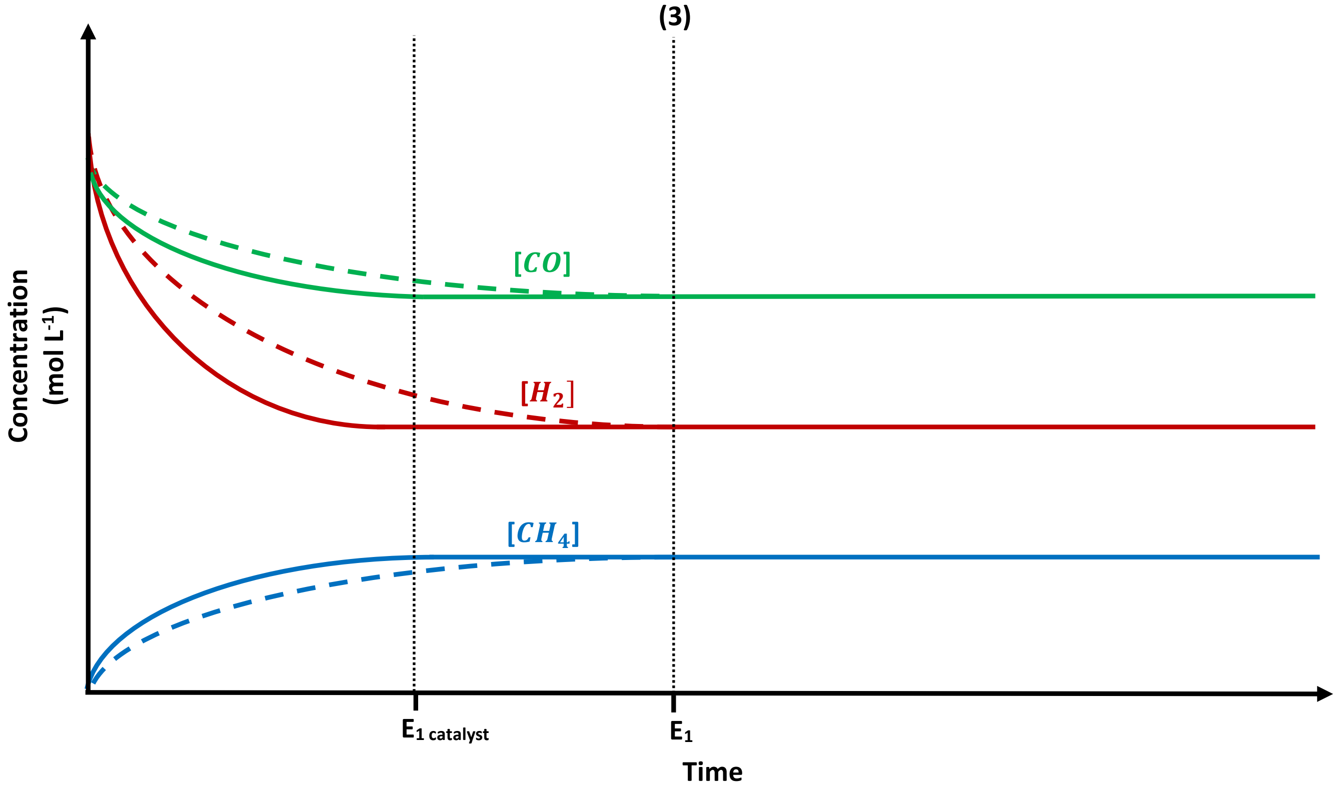
(2)



Marking Criteria	Marks Allocated
From T_0 to E_1: • Correct curvature and orientation of all curves, with $[CH_4]$ starting from a zero concentration • All curves reach equilibrium at $E_{1\ catalyst}$	$1-2$
Total	**2**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 1:1:3 ratio. Also can deduct a mark if the y-axis is labelled with 'Concentration' instead of 'Partial Pressure'	

(e)

(3)



Marking Criteria	Marks Allocated
From T_1 to E_1: • Equilibrium established at a later point than $E_{1\ catalyst}$ • All concentration curves reach the same concentration as the catalysed concentration curves • Correct curvature and orientation of all curves to establish equilibrium at E_1	$1-3$
Total	**3**
Note: Deduct one mark for any missing/incorrect labels of T_1, $E_{1\ catalyst}$, axis labels etc.	

1.71 **[4 marks]**

(a) Both a temperature increase and the addition of a catalyst will cause the reaction rates of both reactions to initially spike, however for the temperature increase the rate of the endothermic reaction will increase more than the rate of the exothermic reaction **(1)**, whereas for the catalyst both reaction rates will increase equally generating no net forward or reverse reaction **(1)**.

Marking Criteria	Marks Allocated
• The addition of a catalyst will cause both rates to instantaneously increase equally with no net forward or reverse reaction created • A temperature increase will cause both rates to instantaneously increase, however the endothermic rate will increase to a greater extent to create a net endothermic reaction	$1 - 2$
Total	**2**

(b) The addition of a catalyst will have no effect on the concentration graph, the concentration curves will all just continue to remain at equilibrium **(1)**. In a temperature increase scenario, there will be a net endothermic reaction so the concentrations of all reacting species will either increase or decrease over-time **(1)**.

Marking Criteria	Marks Allocated
• The addition of a catalyst will have no effect on the concentration curves • A temperature increase will cause the reacting species to increase/decrease as a result of a net endothermic reaction	$1 - 2$
Total	**2**

1.8 **[11 marks]**

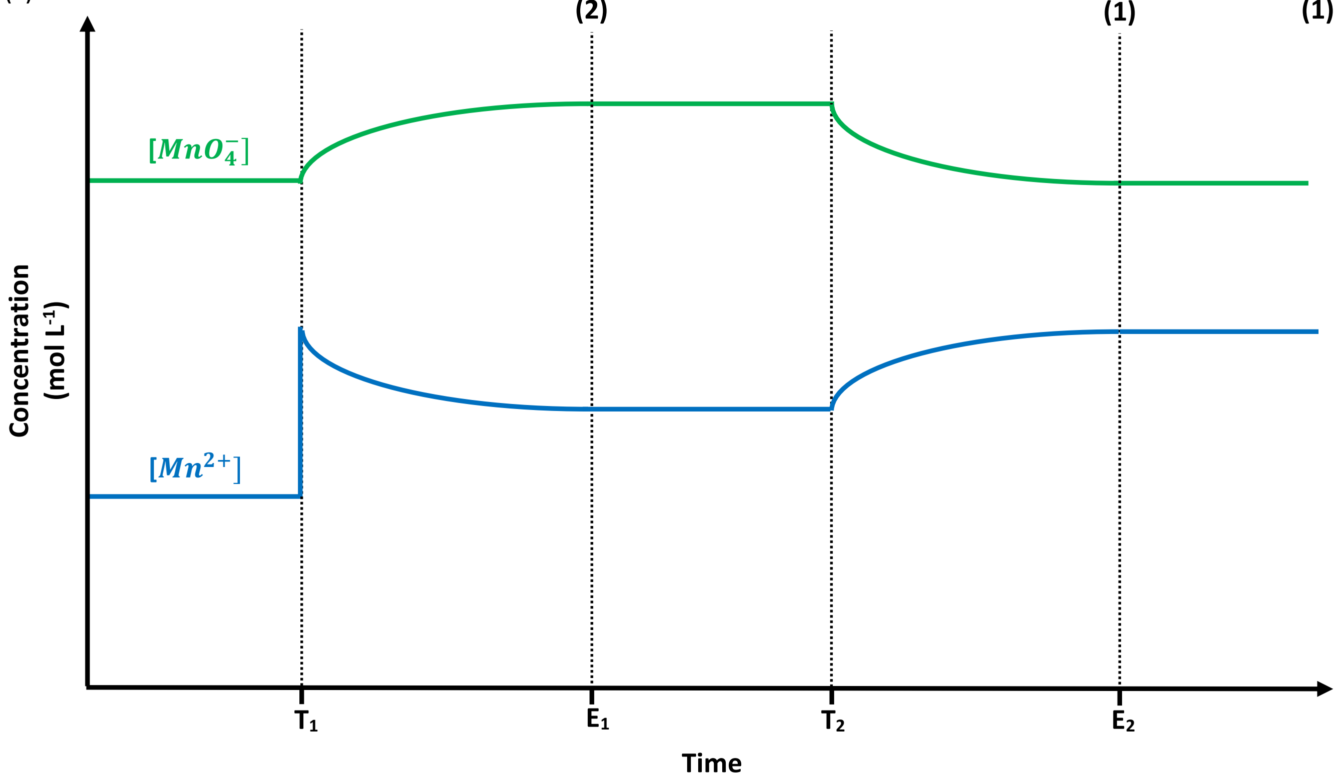
(a) The addition of some manganese ions (Mn^{2+})

Marking Criteria	Marks Allocated
• Correct statement that manganese ions are added or a solution containing manganese ions is added	1
Total	**1**

(b) The addition of some iron (II) ions (Fe^{2+})

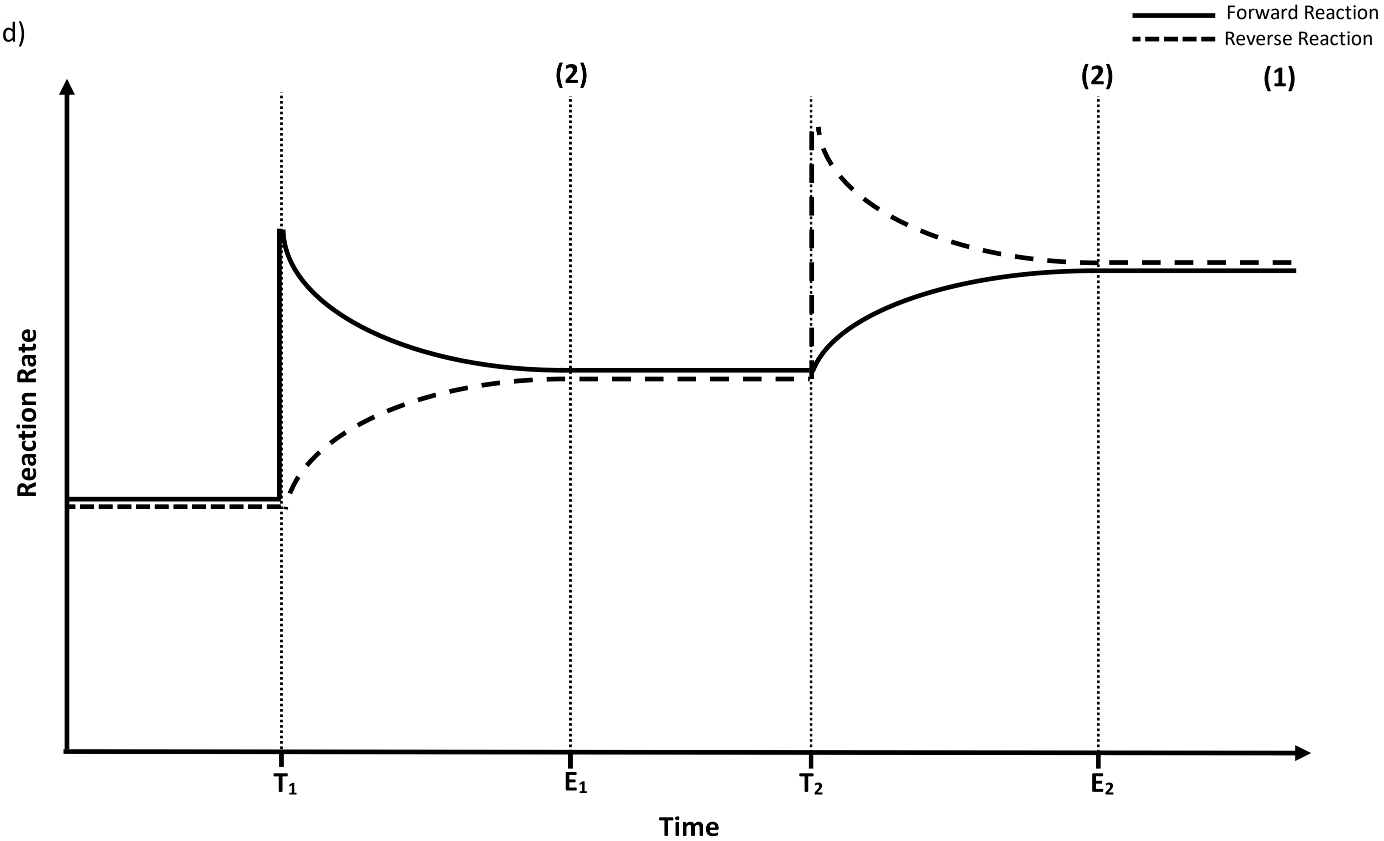
Marking Criteria	Marks Allocated
• Correct statement that iron (II) ions are added or a solution containing iron (II) ions is added	1
Total	**1**

(c)



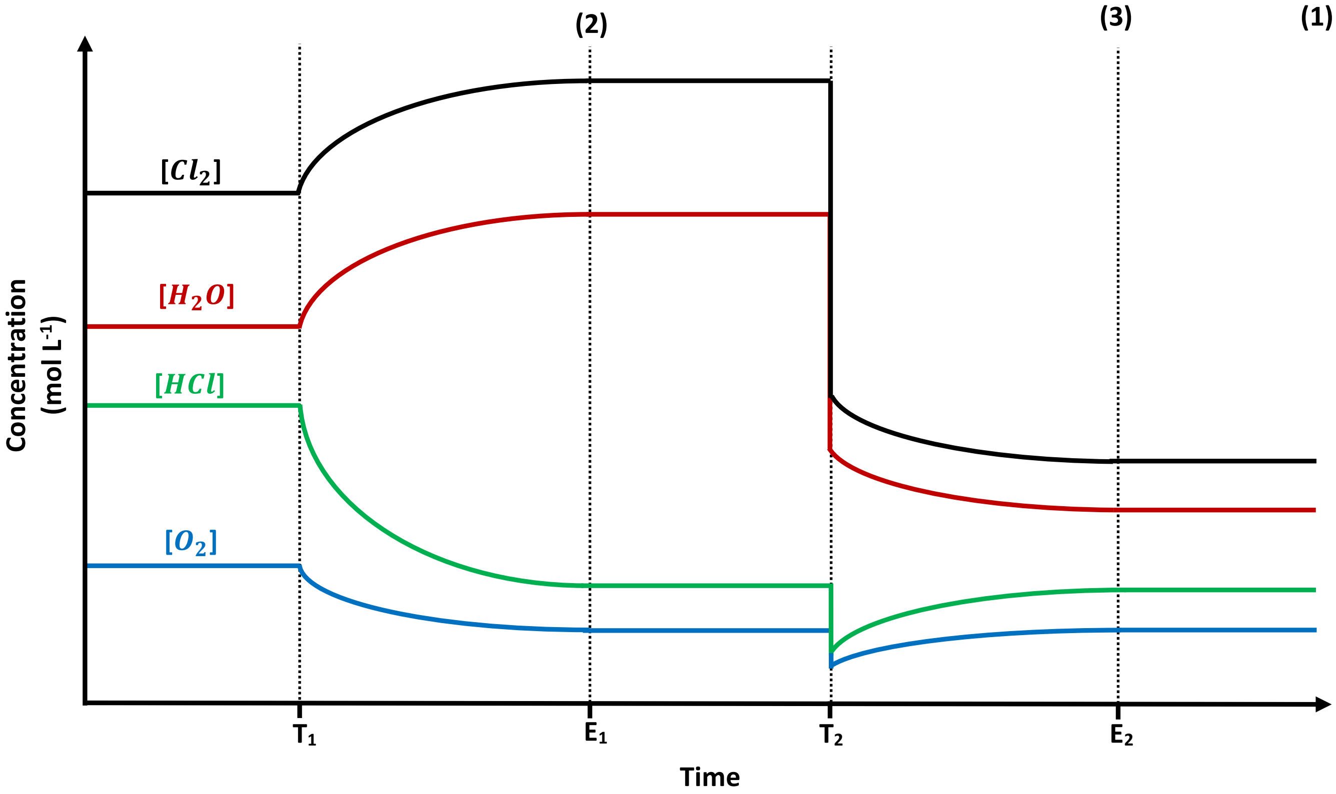
Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous spike in the $[Mn^{2+}]$ concentration curve at T_1 • Correct curvature and orientation for both curves to reach equilibrium at E_1	$1 - 2$
From T_2 to E_2: • Correct curvature and orientation for all curves to reach equilibrium at E_2	1
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
Total	**4**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 1:1 ratio.	

(d)



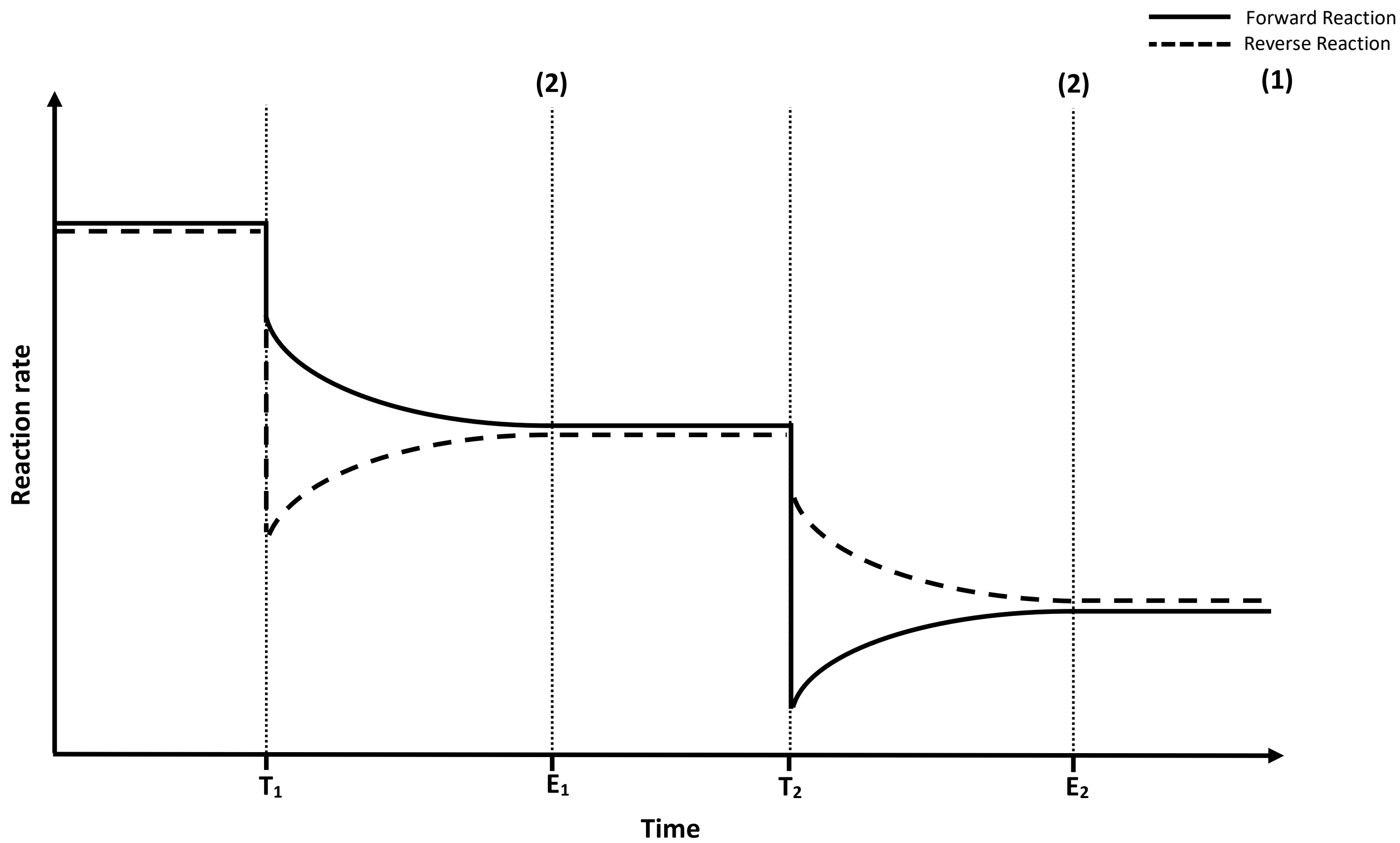
Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous spike of forward reaction curve at T_1 • Correct curvature and orientation for all curves to re-join at E_1	$1-2$
From T_2 to E_2: • Instantaneous spike of reverse reaction curve at T_2 • Correct curvature and orientation for all curves to re-join at E_2	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
Total	**5**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc.	

1.9 **[13 marks]**



Points to note: When you are drawing concentration graphs with three or four different concentration curves, you want to think about the order in which you put your lines initially so you can minimize the overlap that occurs for all of the lines.

Marking Criteria	Marks Allocated
From T_1 to E_1: • Correct curvature and orientation for both curves to reach equilibrium at E_1	1
From T_2 to E_2: • Instantaneous drop in all curves at T_2 • The instantaneous drop for all curves is to half their concentrations • Correct curvature and orientation for all curves to reach equilibrium at E_2	$1-3$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
Total	**5**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 4:1:2:2 ratio.	



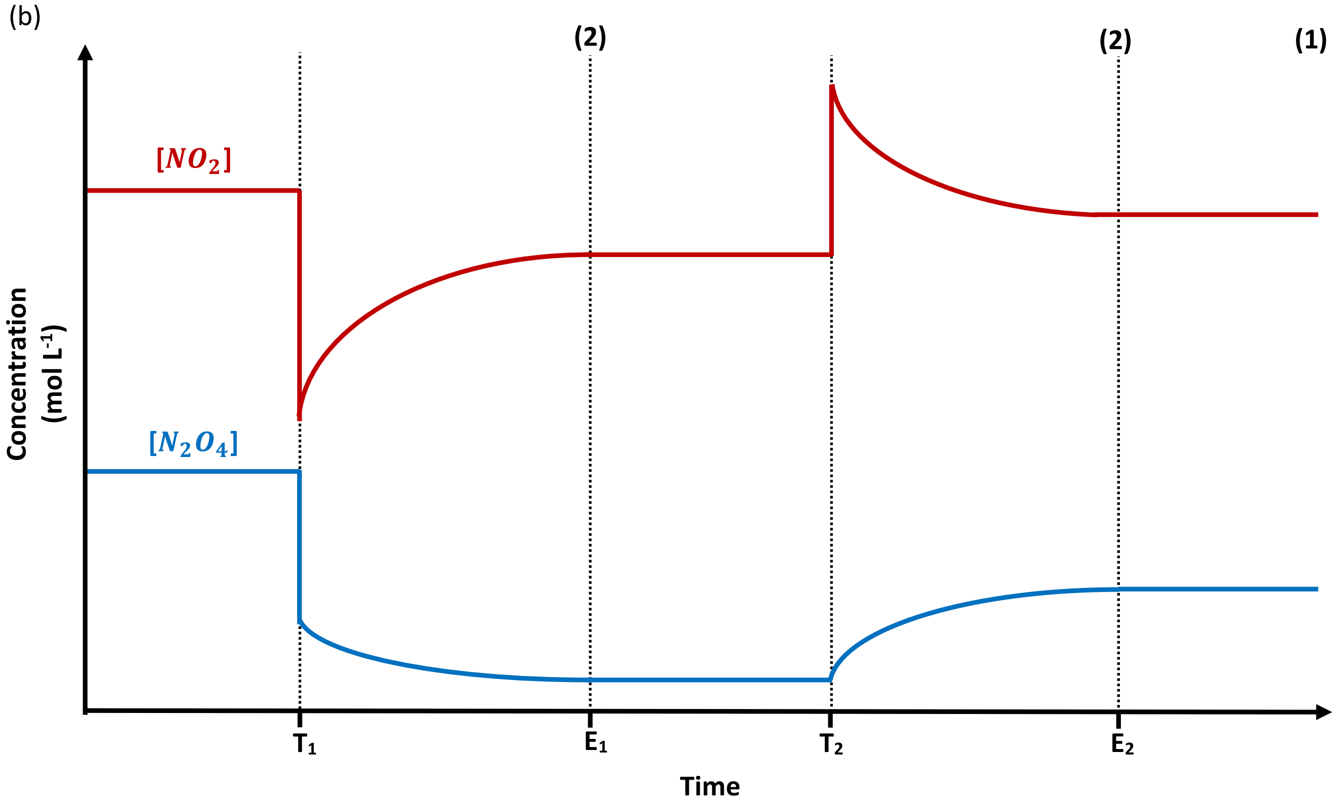
Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous drop in both curves at T_1, however a greater drop in the reverse reaction curve • Correct curvature and orientation for all curves to re-join at E_1	$1 - 2$
From T_2 to E_2: • Instantaneous drop in both curves at T_2, however a greater drop in the forward reaction curve • Correct curvature and orientation for all curves to re-join at E_2	$1 - 2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
Total	**5**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc.	

1.91 **[12 marks]**

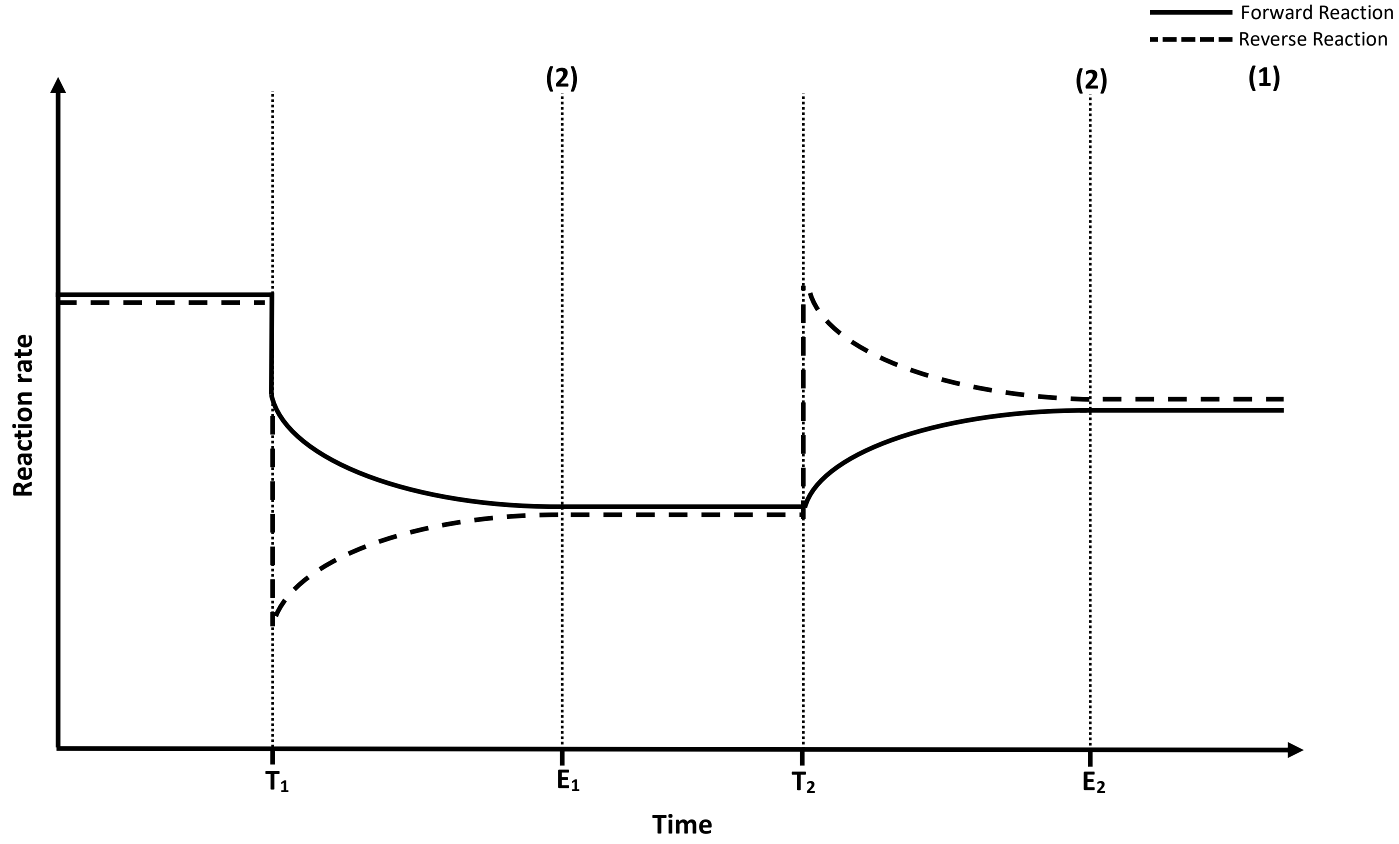
(a) When Rupert injects helium gas into the system, the volume of the system will instantaneously increase, decreasing the concentrations of both reacting species, turning the system to a lighter brown colour **(1)**. Over time, the system will return to a darker brown colour, however will still be a lighter brown than prior to the helium gas being added **(1)**.

Marking Criteria	Marks Allocated
• Adding an inert gas at constant pressure, increases the system volume causing an instantaneous drop in all concentrations, making the system turn a lighter brown colour • Over-time the system will become darker brown, however still remain a lighter brown than it was initially	$1 - 2$
Total	**2**

(b)

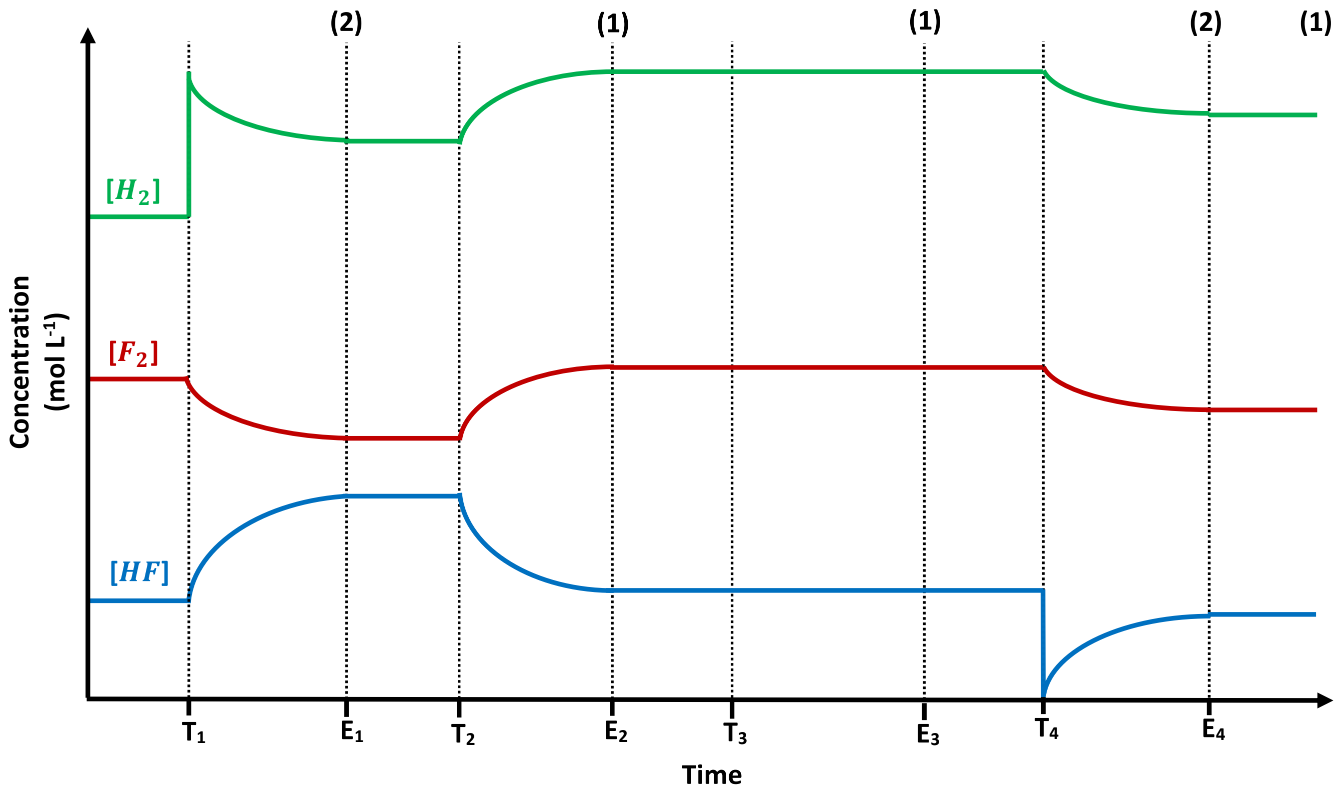


Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous drop in both curves at T_1, proportional to the 1:2 ratio • Correct curvature and orientation for both curves to reach equilibrium at E_1	$1-2$
From T_2 to E_2: • Instantaneous spike in $[NO_2]$ concentration curve • Correct curvature and orientation for all curves to reach equilibrium at E_2	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
Total	**5**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 1:2 ratio.	



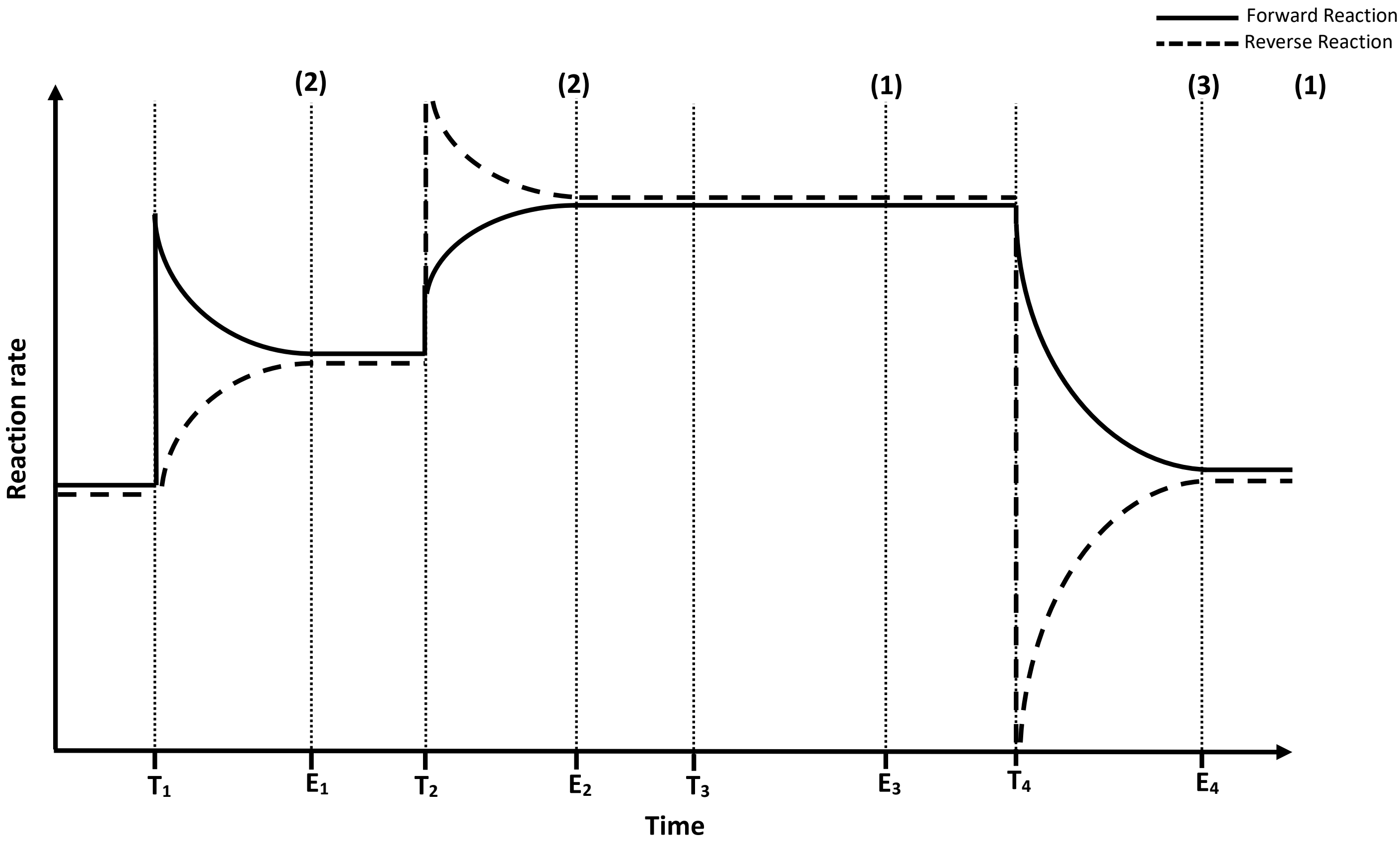
Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous drop in both curves at T_1, however a greater drop in the reverse reaction curve • Correct curvature and orientation for all curves to re-join at E_1	$1-2$
From T_2 to E_2: • Instantaneous spike for reverse reaction curve at T_2 • Correct curvature and orientation for all curves to re-join at E_2	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2 and E_2 onwards	1
Total	**5**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc.	

1.101 **[15 marks]**



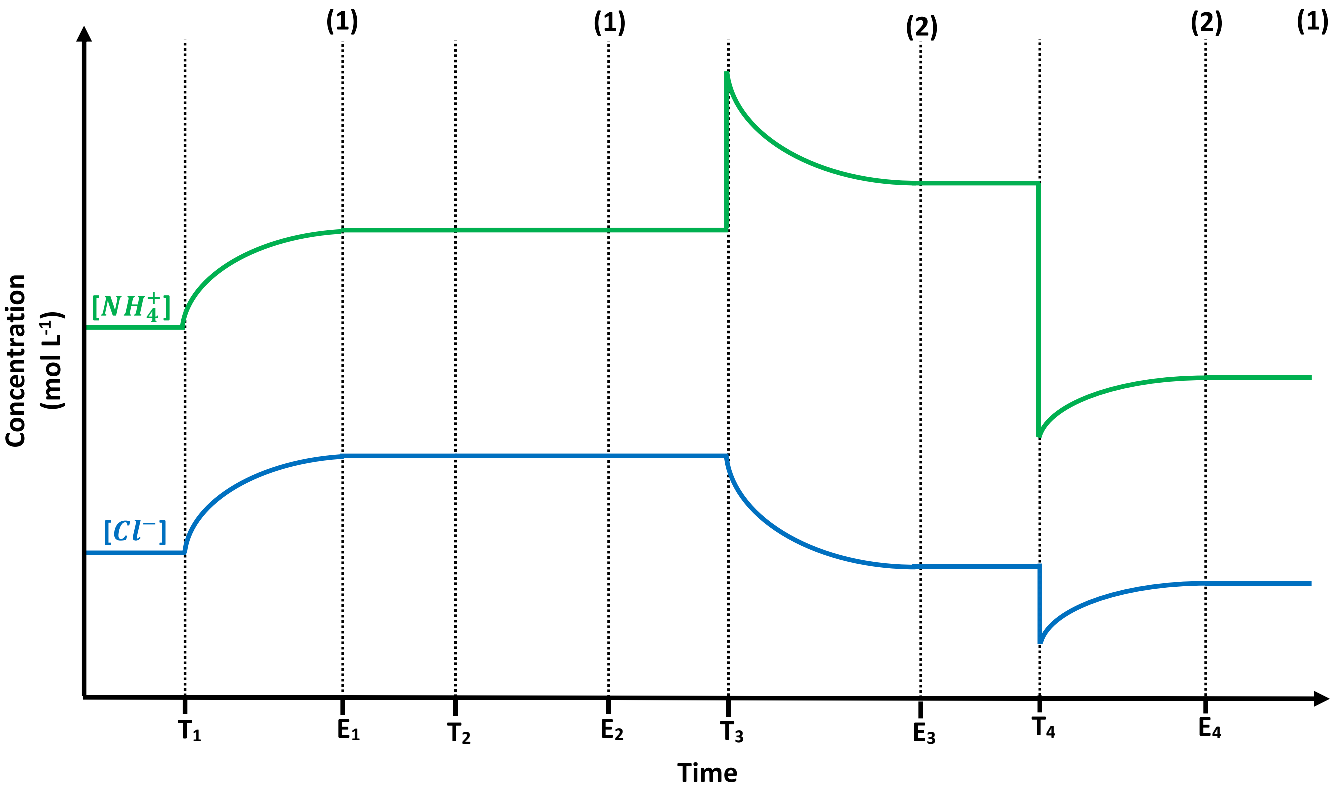
Points to note: It is unrealistic to expect to ever have to draw four different changes on a single concentration graph, however it is good practice none-the-less

Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous spike in the $[H_2]$ concentration curve at T_1 • Correct curvature and orientation for all curves to reach equilibrium at E_1	$1-2$
From T_2 to E_2: • Correct curvature and orientation for all curves to reach equilibrium at E_2	1
From T_3 to E_3: • Continuation of all equilibrium lines from T_3 to E_3	1
From T_4 to E_4: • Instantaneous drop in the $[HF]$ concentration to zero • Correct curvature and orientation for all curves to reach equilibrium at E_4	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2, E_2 to T_3, E_3 to T_4 and E_4 onwards	1
Total	**7**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 1:1:2 ratio	



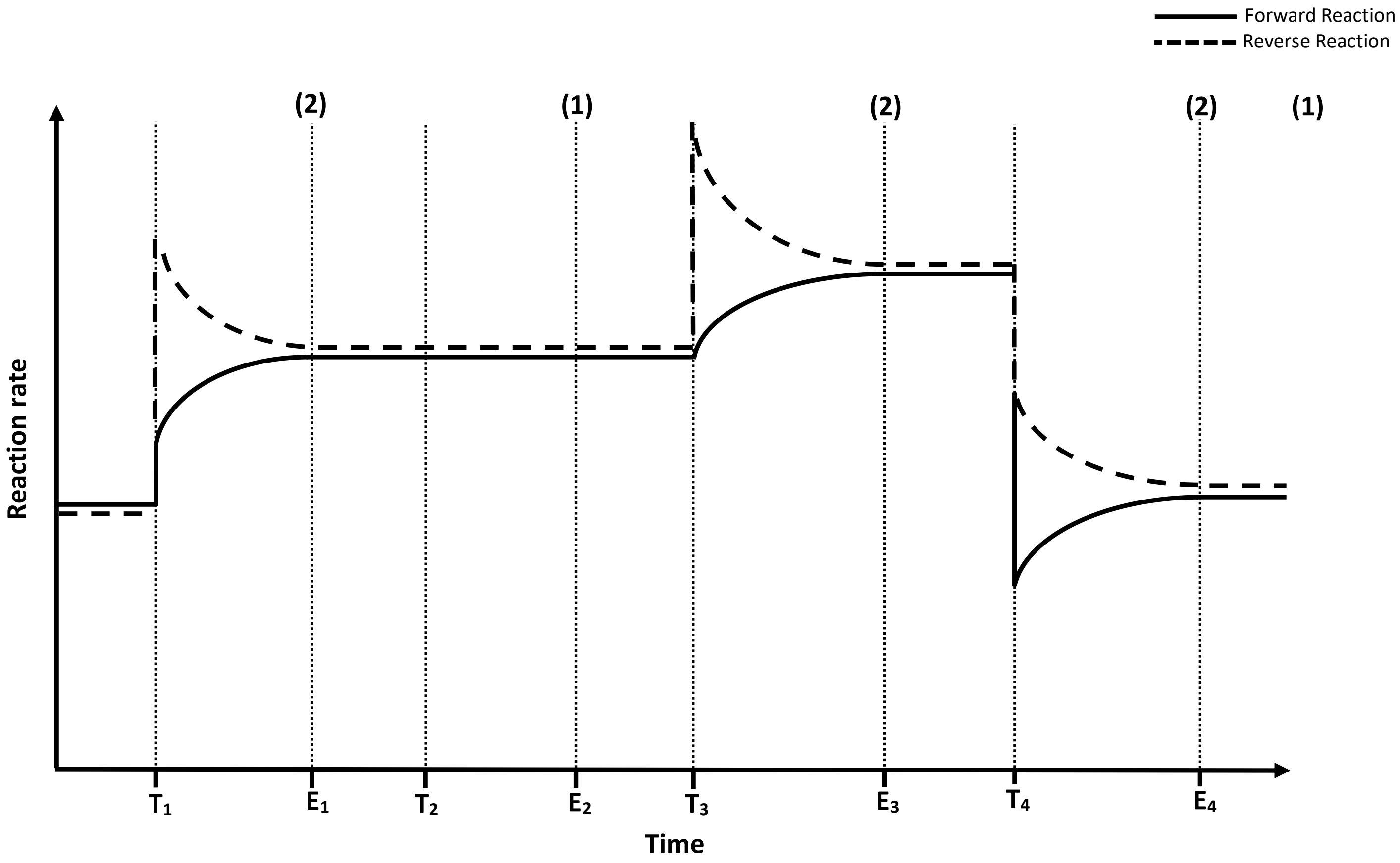
Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous spike of forward reaction curve at T_1 • Correct curvature and orientation for all curves to re-join at E_1	$1-2$
From T_2 to E_2: • Instantaneous spike in both curves at T_2, however a greater spike in the reverse reaction curve • Correct curvature and orientation for all curves to re-join at E_2	$1-2$
From T_3 to E_3: • Continuation of all equilibrium lines from T_3 to E_3	1
From T_4 to E_4: • Instantaneous drop of the reverse reaction curve at T_4 • Reverse reaction curve drops all the way to a zero reaction rate • Correct curvature and orientation for all curves to re-join at E_4	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2, E_2 to T_3, E_3 to T_4, and E_4 onwards	1
Total	**8**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc.	

1.102 **[15 marks]**



Points to note: At T_3 the reaction of ammonia gas with water, will produce some additional ammonium ions.

Marking Criteria	Marks Allocated
From T_1 to E_1: • Correct curvature and orientation for all curves to reach equilibrium at E_1	1
From T_2 to E_2: • Continuation of all equilibrium lines from T_2 to E_2	1
From T_3 to E_3: • Instantaneous spike in the $[NH_4^+]$ concentration curve at T_3 • Correct curvature and orientation for all curves to reach equilibrium at E_3	$1-2$
From T_4 to E_4: • Instantaneous drop in all curves to half their concentrations • Correct curvature and orientation for all curves to reach equilibrium at E_4	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2, E_2 to T_3, E_3 to T_4 and E_4 onwards	1
Total	**7**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc. and for not maintaining a 1:1:2 ratio	



Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous spike of reverse reaction curve at T_1 • Correct curvature and orientation for all curves to re-join at E_1	$1-2$
From T_2 to E_2: • Continuation of all equilibrium lines from T_2 to E_2	1
From T_3 to E_3: • Instantaneous spike of the reverse reaction curve at T_2 • Correct curvature and orientation for all curves to re-join at E_3	$1-2$
From T_4 to E_4: • Instantaneous drop in both curves at T_4, however a greater drop in the forward reaction curve • Correct curvature and orientation for all curves to re-join at E_4	$1-2$
Equilibrium lines • Equilibrium lines from T_0 to T_1, E_1 to T_2, E_2 to T_3, E_3 to T_4, and E_4 onwards	1
Total	**8**
Note: Deduct one mark for any missing/incorrect labels of T_1, E_1, axis labels etc.	

Concept 2

Ocean Equilibrium – Repetitive Questions Answers

2.1 **[15 marks]**

(a) When the concentration of atmospheric carbon dioxide is reduced, it will shift the carbon dioxide equilibrium shared with the ocean ($CO_{2(g)} \rightleftharpoons CO_{2(aq)}$) to the left, reducing the amount of carbon dioxide in the water **(1)**. This will reduce the amount of carbonic acid produced in the water because a decrease in the dissolved carbon dioxide concentration will cause the equilibrium position of the production of carbonic acid to shift to the left: $H_2O_{(l)} + CO_{2(aq)} \rightleftharpoons H_2CO_{3(aq)}$ **(1)**. With a decrease in the concentration of carbonic acid in the oceans, the concentration of hydronium ions will decrease and therefore will reduce the rate of ocean acidification **(1)**.

Points to note: With ocean equilibrium questions it is always a good tactic to state as many equations as necessary to get your point across; you will find you can usually accumulate marks just from stating the equations and then talking whatever nonsense you want. It is also easiest if you either start at the beginning or end of the ocean equilibrium process (i.e. $CO_{2(g)} \rightleftharpoons CO_{2(aq)}$ or $Ca^{2+}{}_{(aq)} + CO_3{}^{2-}{}_{(aq)} \rightleftharpoons CaCO_{3(s)}$) so you are grounded in your explanations.

Marking Criteria	Marks Allocated
• Decreasing the concentration of atmospheric carbon dioxide, will decrease the concentration of dissolved carbon dioxide ($CO_{2(g)} \rightleftharpoons CO_{2(aq)}$ optional) • A decreased concentration of dissolved carbon dioxide will shift the equilibrium position for the production of carbonic acid to the left: $H_2O_{(l)} + CO_{2(aq)} \rightleftharpoons H_2CO_{3(aq)}$ **(must use)** • A decrease in carbonic acid will decrease the hydronium ion concentration and therefore the rate of ocean acidification	$1-3$
Total	**3**

(b) With a decrease in the amount of carbonic acid in the water it will reduce the concentration of hydronium ions in the oceans, so the equilibrium position the second ionisation of carbonic acid: $HCO_3{}^{-}{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$ will shift to the right producing more carbonate ions **(1)**. This increased concentration of carbonate ions, will shift the equilibrium system for the production of calcium carbonate to the right: $Ca^{2+}{}_{(aq)} + CO_3{}^{2-}{}_{(aq)} \rightleftharpoons CaCO_{3(s)}$, meaning that there is more calcium carbonate available **(1)**. With more calcium carbonate particles present in our oceans, it will make the process for marine organisms to create their calcium carbonate shells a much easier process **(1)**.

Marking Criteria	Marks Allocated
• A decrease in the concentration of carbonic will reduce the hydronium ion concentration, causing the equilibrium position of the second ionisation of carbonic acid to shift to the right: $HCO_3{}^{-}{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$ producing more carbonate ions • An increased carbonate ion concentration, shifts the production of calcium carbonate to the right: $Ca^{2+}{}_{(aq)} + CO_3{}^{2-}{}_{(aq)} \rightleftharpoons CaCO_{3(s)}$ • This makes it easier for organisms to form their calcium carbonate shells because there is more calcium carbonate available	$1-3$

	Total	3

2.11 **[15 marks]**

(a)

Reaction	Direction of shift in equilibrium (←, → or no shift)
$CO_{2(g)} \rightleftharpoons CO_{2(aq)}$	→
$H_2O_{(l)} + CO_{2(aq)} \rightleftharpoons H_2CO_{3(aq)}$	→
$H_2CO_{3(aq)} + H_2O_{(l)} \rightleftharpoons HCO_3{}^-{}_{(aq)} + H_3O^+{}_{(aq)}$	→
$HCO_3{}^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$	←
$Ca^{2+}{}_{(aq)} + CO_3{}^{2-}{}_{(aq)} \rightleftharpoons CaCO_{3(s)}$	←

Points to note: when you get questions like these in exams, that are worth a fair few marks for very little work, you want to get both efficient in answering them to save time but also take a moment to double check that you have thought each answer through correctly, because it is not a place you want to be losing marks

Marking Criteria	Marks Allocated
• One mark for each correctly stated shift	$1-5$
Total	**5**

(b)

(i) Increase

Marking Criteria	Marks Allocated
• Correctly stating 'Increase'	1
Total	**1**
Note: No marks awarded for using any terms other than 'Increase'	

(ii) Increase

Marking Criteria	Marks Allocated
• Correctly stating 'Increase'	1
Total	**1**
Note: No marks awarded for using any terms other than 'Increase'	

(iii) No change

Points to note: no change occurs in the concentrations because the concentrations of solids are forever constant

Marking Criteria	Marks Allocated
• Correctly stating 'No Change'	1
Total	**1**
Note: No marks awarded for using any terms other than 'No Change'	

(iv) Increase

Points to note: Whilst HCO_3^- ions are consumed in $HCO_3{}^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$, this concentration increase is always only partially opposed. Thus there is a net increase in the hydrogen carbonate concentration.

Marking Criteria	Marks Allocated
• Correctly stating 'Increase'	1
Total	**1**
Note: No marks awarded for using any terms other than 'Increase'	

(v) Decrease

Points to note: Whilst carbonate ions are reproduced from $Ca^{2+}{}_{(aq)} + CO_3{}^{2-}{}_{(aq)} \rightleftharpoons CaCO_{3(s)}$ this only partially opposes the concentration decrease from $HCO_3{}^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$. Thus there is a net decrease in the carbonate ion concentration

Marking Criteria	Marks Allocated
• Correctly stating 'Decrease'	1
Total	**1**
Note: No marks awarded for using any terms other than 'Decrease'	