

---

# Chapter 1

---

## Chemical Equilibrium

### Answers

Problem Set 1 Progressive Answers – Chemical Equilibrium BTG .....	1
Problem Set 1 Repetitive Answers – Chemical Equilibrium BTG .....	4
Problem Set 2 Progressive Answers – Qualitative Chemical Equilibrium .....	7
Problem Set 2 Repetitive Answers – Qualitative Chemical Equilibrium .....	25
Problem Set 3 Progressive Answers – Visualising Chemical Equilibrium .....	70
Problem Set 3 Repetitive Answers – Visualising Chemical Equilibrium .....	87

# 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	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]

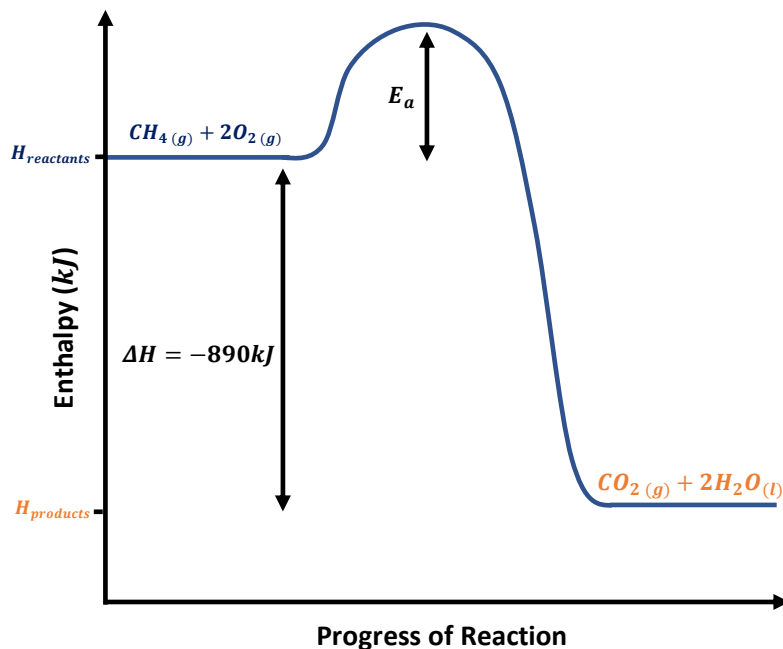
- (i) Endothermic      (ii) Endothermic      (iii) Exothermic      (iv) Endothermic

**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	4

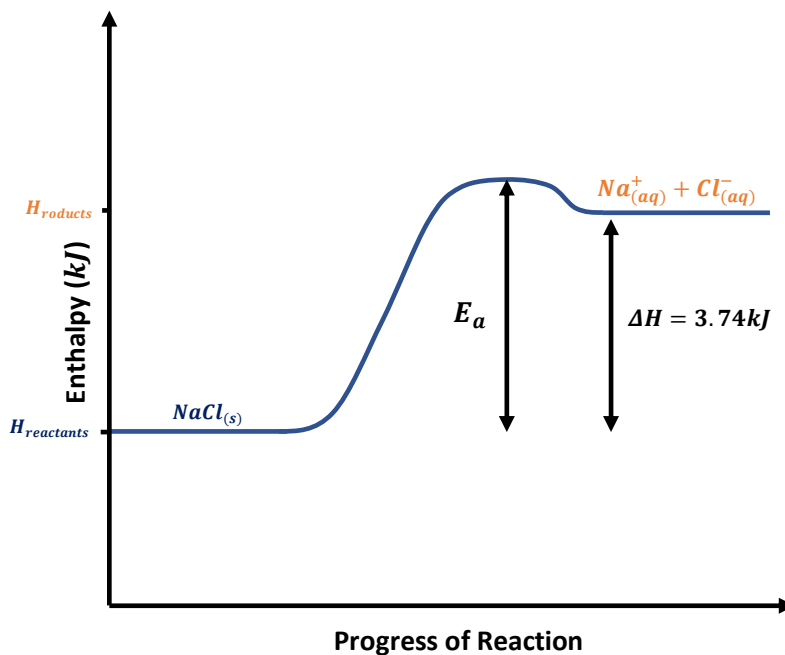
1 (a)

[20 marks]



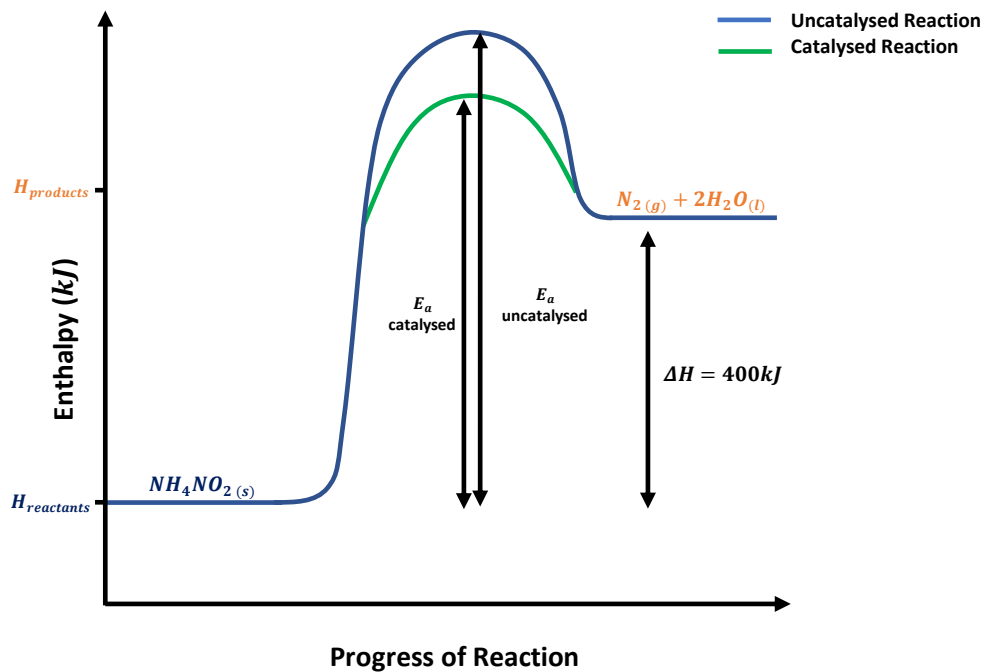
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Exothermic reaction curve</li> <li>Correct axis labels</li> <li>Correct <math>\Delta H</math> and <math>E_a</math> labels</li> <li>Reactants and products correctly labelled</li> </ul>	1 – 4
Total	4

(b)

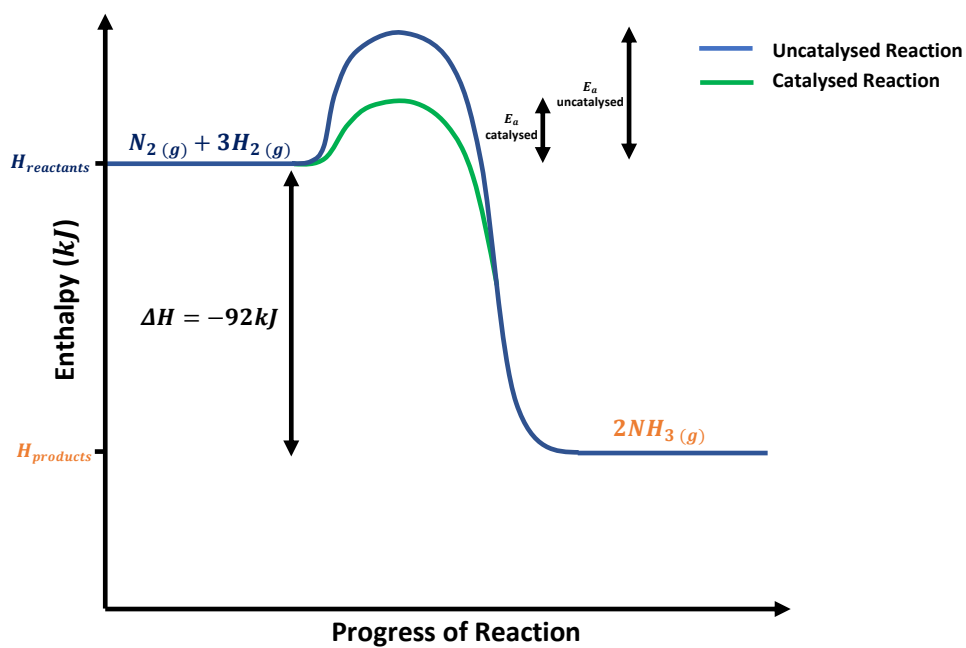


Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Endothermic reaction curve</li> <li>Correct axis labels</li> <li>Correct <math>\Delta H</math> and <math>E_a</math> labels</li> <li>Reactants and products correctly labelled</li> </ul>	1 – 4
Total	4

(c)



(d)



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>Exothermic reaction curve</li><li>Correct axis labels</li><li>Correct <math>\Delta H</math> label</li><li>Reactants and products correctly labelled</li><li>Appropriate catalyst curve</li><li>Activation energies appropriately labelled</li></ul>	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	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	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  $\Delta H$  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	4

1.21 [4 marks]

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

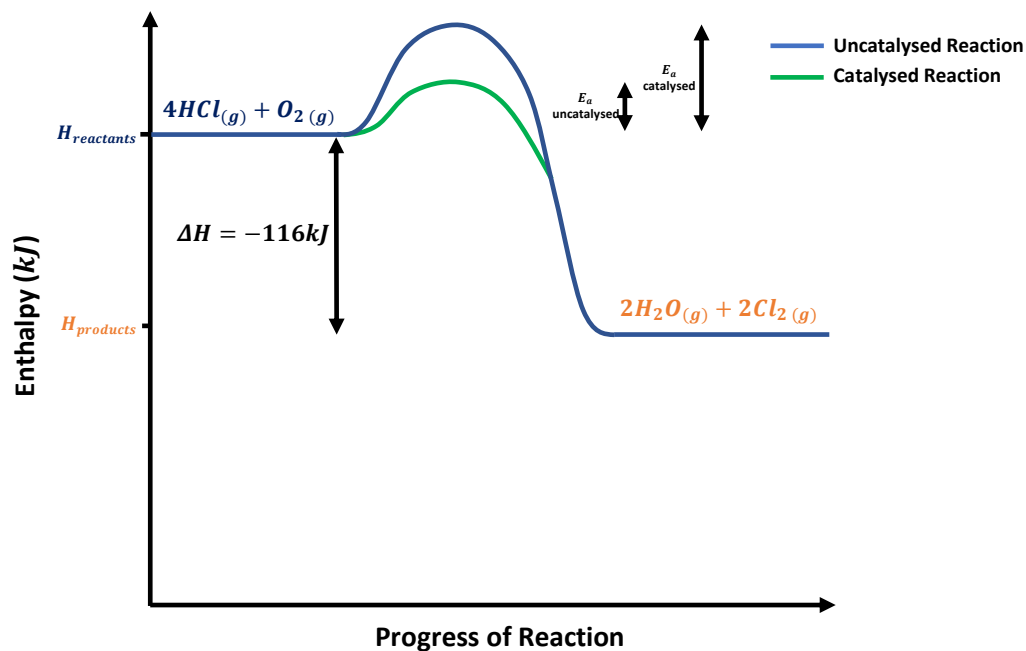
**Points to note:** For this question, the key point is to remember that exothermic reactions form products with more stable bonds (e.g. water to ice), whereas endothermic reactions form products with less stable bonds (e.g. water to water vapor).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correct determination of whether each reaction is endothermic or exothermic</li> </ul>	1 – 4
Total	4

1.3

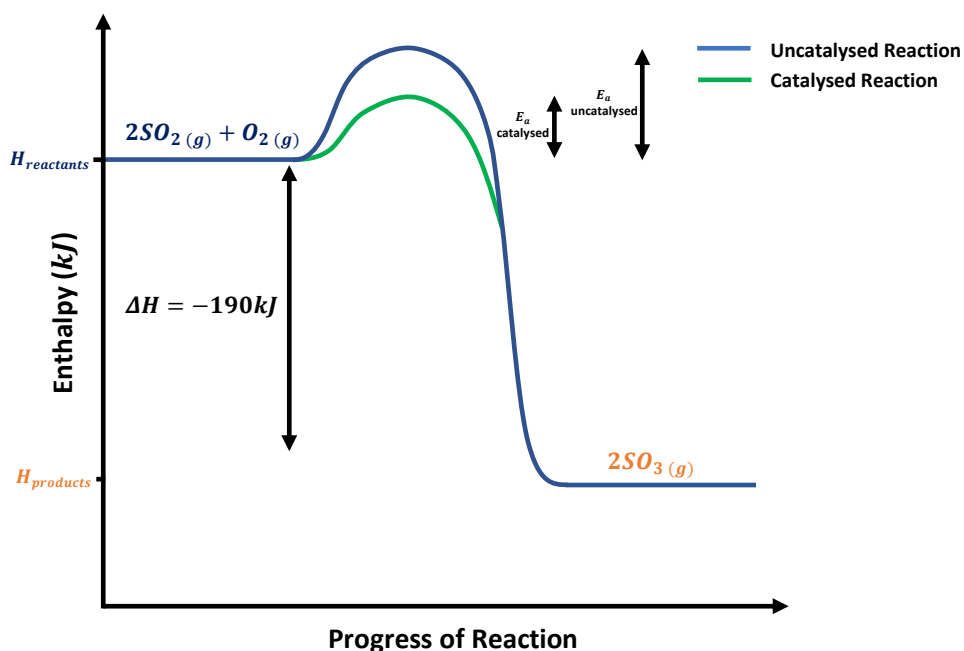
[18 marks]

(a)

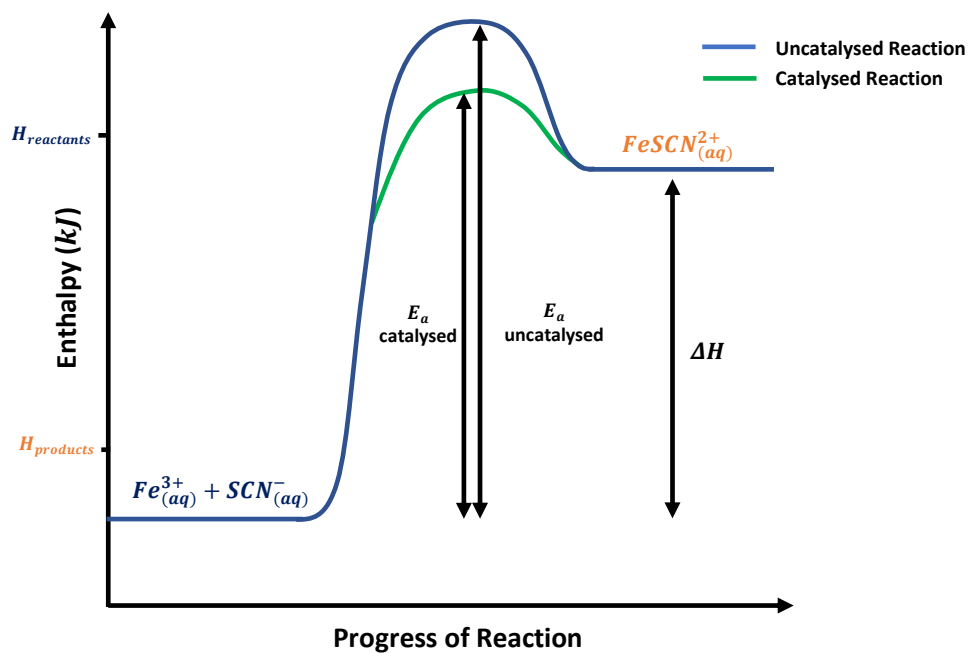


Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Exothermic reaction curve</li> <li>Correct axis labels</li> <li>Correct <math>\Delta H</math> label</li> <li>Reactants and products correctly labelled</li> <li>Appropriate catalyst curve</li> <li>Activation energies appropriately labelled</li> </ul>	1 – 6
Total	6

(b)



(c)



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>• Endothermic reaction curve</li><li>• Correct axis labels</li><li>• Correct <math>\Delta H</math> label</li><li>• Reactants and products correctly labelled</li><li>• Appropriate catalyst curve</li><li>• Activation energies appropriately labelled</li></ul>	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
<ul style="list-style-type: none"> <li>Correct equilibrium law calculation</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>
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
<ul style="list-style-type: none"> <li>One mark for each correct comment made about the extent of the reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

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
<ul style="list-style-type: none"> <li>Correct equilibrium constant</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
Note: deduct one mark if ' $K_c =$ ' is not used	

3.

[8 marks]

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

$$K_c = \frac{[H_2][CO_2]}{[H_2O][CO]} \qquad K_c = \frac{[NO_2]^2}{[N_2O_4]}$$

$$K_c = \frac{[0.91][0.56]}{[0.1][0.17]} \qquad K_c = \frac{[0.0015]^2}{[0.81]}$$

$$= 30 \qquad (1) \qquad = 2.8 \times 10^{-6} \qquad (1)$$

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  $2.8 \times 10^{-6}$  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
<ul style="list-style-type: none"> <li>Correct equilibrium constant calculation with appropriate workings</li> </ul>	1 – 2
<ul style="list-style-type: none"> <li>Correct comment made about the extent of each reaction</li> </ul>	1 – 2
<b>Total</b>	<b>4</b>

(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
<ul style="list-style-type: none"> <li>Stating that an increasing the temperature, increases the average kinetic energy of particles</li> <li>Application of Le Chatelier's Principle to state that endothermic reaction will be favoured in each system</li> </ul>	1 – 2
<ul style="list-style-type: none"> <li>One mark for each correct comment made about how the extent of the reaction will change with the changing temperature</li> </ul>	1 – 2
<b>Total</b>	<b>4</b>
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	<b>Forward</b>	<b>Increase</b>	<b>Decrease</b>	<b>Increase</b>
2. Some $H_2$ is removed	<b>Reverse</b>	<b>Increase</b>	<b>Decrease</b>	<b>Decrease</b>
3. Some $NH_3$ is added	<b>Reverse</b>	<b>Increase</b>	<b>Increase</b>	<b>Increase</b>
4. Temperature is increased	<b>Reverse</b>	<b>Increase</b>	<b>Increase</b>	<b>Decrease</b>
5. Temperature is decreased	<b>Forward</b>	<b>Decrease</b>	<b>Decrease</b>	<b>Increase</b>
6. Pressure is increased	<b>Forward</b>	<b>Increase</b>	<b>Increase</b>	<b>Increase</b>
7. Volume is increased	<b>Reverse</b>	<b>Decrease</b>	<b>Decrease</b>	<b>Decrease</b>
8. Argon gas (inert) is added at constant pressure	<b>Reverse</b>	<b>Decrease</b>	<b>Decrease</b>	<b>Decrease</b>

**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
<ul style="list-style-type: none"> <li>1 mark for each correct row</li> </ul>	1 – 8
<b>Total</b>	<b>8</b>
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
<b>Total</b>	<b>5</b>
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
<b>Total</b>	<b>3</b>
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
<b>Total</b>	<b>1</b>

(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
<b>Total</b>	<b>4</b>
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
------------------	-----------------

<ul style="list-style-type: none"> <li>• A temperature decrease, decreases the average kinetic energy of the system particles</li> <li>• According to Le Chatelier's Principle, the system will shift to favour the exothermic reaction, which will reproduce some of the consumed heat</li> <li>• A favoured reverse reaction will consume some <math>NO_2</math> making the system a lighter brown colour</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

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
<ul style="list-style-type: none"> <li>• Stating that the additional concentration increases the concentration of the reactants for the forward reaction, accounting for the initial 'darker yellow' colour change</li> <li>• Applying LCP to state the system will act to consume some of the added chromate ions</li> <li>• Correct conclusion that the system will favour the forward reaction and the system will return to 'orangey-yellow', however more yellow than initially</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>• Stating that the volume increase causes a concentration decrease, resulting in a lighter orangey-yellow colour</li> <li>• Applying LCP to state the system will act to favour the reaction that produces more moles of aqueous product</li> <li>• Correct conclusion that the system will favour the reverse reaction and the system is a more yellow but lighter colour than initially</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

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  $\text{NaOH}$  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
<ul style="list-style-type: none"> <li>Determining that <math>\text{NaOH}</math> will react with hydrogen ions: <math>\text{OH}^-_{(aq)} + \text{H}_3\text{O}^+_{(aq)} \rightleftharpoons 2\text{H}_2\text{O}_{(l)}</math> thus decreasing the hydrogen ion concentration in the system</li> <li>Applying LCP to state the act to reproduce some of the lost hydrogen ions</li> <li>Correct conclusion that the reverse reaction will be favoured, and the system will become darker yellow</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
Note: The equation $\text{OH}^-_{(aq)} + \text{H}_3\text{O}^+_{(aq)} \rightleftharpoons 2\text{H}_2\text{O}_{(l)}$ 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
<ul style="list-style-type: none"> <li>Stating that the addition of water vapour will increase the concentration of reactants for the reverse reaction</li> <li>Applying LCP to state system will act to consume some of the added water vapour</li> <li>Correct conclusion that the system will favour the reverse reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Stating that the ammonia partial pressure increase will increase the concentration of reactants for the forward reaction</li> <li>Applying LCP to state system will act to consume some of the added ammonia gas</li> <li>Correct conclusion that the system will favour the forward reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Applying LCP to state system will act to favour the reaction that produces less moles of gaseous product</li> <li>Correct conclusion that the system will favour the forward reaction</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(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
<ul style="list-style-type: none"> <li>Stating that the temperature decrease will decrease the average KE of reacting particles</li> <li>Applying LCP to state system will act to replace some of the lost energy by favouring the exothermic reaction</li> <li>Correct conclusion that the system will favour the reverse reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>Stating that adding the inert gas at a constant pressure will increase the volume of the system</li> <li>Applying LCP to state system will act to favour the reaction that produces more moles of gaseous product</li> <li>Correct conclusion that the system will favour the reverse reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

### Tricky aqueous system questions: Q7

7.

[4 marks]

When excess sodium carbonate 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
<ul style="list-style-type: none"> <li>Determining that the carbonate ions will react with the cobalt ions to produce cobalt carbonate: <math>Co_{(aq)}^{2+} + CO_{3(aq)}^{2-} \rightarrow CoCO_{3(s)}</math></li> <li>Stating that the cobalt ion concentration will decrease</li> <li>Applying LCP to state system will act to reproduce some of the lost cobalt ions</li> <li>Correct conclusion that the system will favour the reverse reaction</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
Note: The equation $Co_{(aq)}^{2+} + CO_{3(aq)}^{2-} \rightarrow CoCO_{3(s)}$ 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
------------------	-----------------

<ul style="list-style-type: none"> <li>One mark for each correct comment made about the change to the yield of the reaction</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>Determining that the water will dilute the system, causing it to <b>initially</b> turn a lighter blue</li> <li>Applying LCP to state system will act to favour the reaction that produces more moles of aqueous product</li> <li>Correct conclusion that the system will favour the reverse reaction</li> <li>Correct conclusion that the system will turn a light pink colour</li> </ul>	1 – 4
<ul style="list-style-type: none"> <li>Correct comments about the validity of each of the three statements given by Alex, Jamie and Dylan</li> </ul>	1 – 2
<b>Total</b>	<b>6</b>
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
<ul style="list-style-type: none"> <li>1 mark for each correct application of Le Chatelier's Principle to each change</li> </ul>	1 – 3
<ul style="list-style-type: none"> <li>Correct comment about the changes that will occur to the concentration of oxygen gas</li> </ul>	1 – 3
<b>Total</b>	<b>6</b>
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
<ul style="list-style-type: none"> <li>1 mark for each correct application of Le Chatelier's Principle to each change</li> </ul>	1 – 3
<ul style="list-style-type: none"> <li>Correct comment about the changes that will occur to the concentration of oxygen gas</li> </ul>	1 – 3
<b>Total</b>	<b>6</b>
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

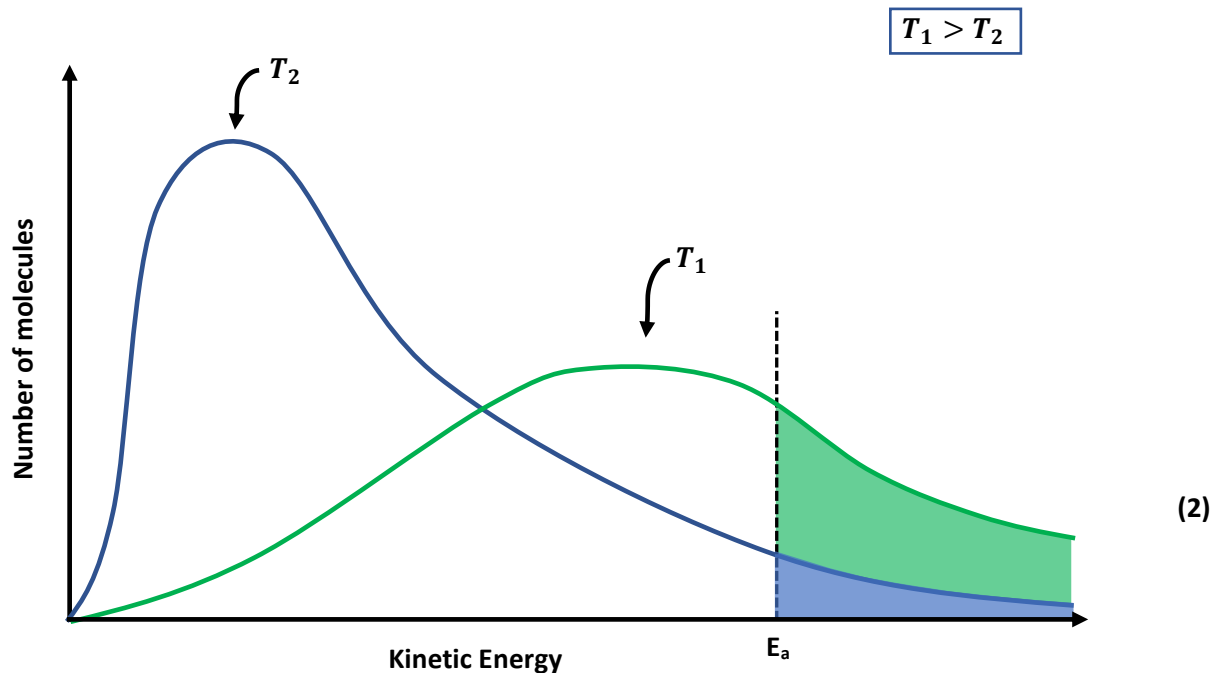
### Concept 3

## Collision Theory – Progressive Questions Answers

### Non-Reversible Reaction Questions: Q1

1.

[7 marks]



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
<ul style="list-style-type: none"> <li>Clearly drawn Maxwell Boltzmann Curve with appropriate labels</li> </ul>	1 – 2
<ul style="list-style-type: none"> <li>Temperature decrease, decreases average kinetic energy of particles</li> <li>Therefore, particles moving at a slower velocity, so collision frequency decreases</li> <li>Also, the average kinetic energy decrease will decrease the proportion of successful collisions with sufficient energy to overcome the activation energy</li> <li>Mention of Maxwell Boltzmann Curve to support this decrease in the proportion of successful collisions</li> <li>Combination of both factors have dramatic effect on reaction rate decrease</li> </ul>	1 – 5
<b>Total</b>	<b>7</b>
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
<ul style="list-style-type: none"><li>• Correct determination that copper carbonate is a green solid</li><li>• Correct determination that copper ions are blue</li></ul>	1 – 2
<b>Total</b>	<b>2</b>
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
<ul style="list-style-type: none"><li>• Carbonate ion concentration increase will increase the reverse reactant collision frequency, so reverse reaction will increase</li><li>• As no forward reactant particles have been added, the forward reaction rate will initially remain unchanged</li><li>• Thus there will be a net reverse reaction</li><li>• Reverse reaction rate will decrease over-time and the forward reaction rate will increase until their rates become equal and equilibrium is established</li></ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>Stating that the copper carbonate concentration will remain unchanged because copper carbonate is a solid</li> <li>Forward reaction rate will therefore remain unchanged</li> <li>Concluding there is neither a net forward nor reverse reaction since there is also no change in reverse reaction rate</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

### 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
<ul style="list-style-type: none"> <li>Determining that <math>H_{2(g)}</math> was the gas added to the system</li> <li>Stating that initial the forward and reverse reaction rates are equal</li> <li>The injection of hydrogen gas increases the forward reactant collision frequency and therefore forward reaction rate</li> <li>Forward reaction rate will decrease until equal to reverse reaction rate/equilibrium is re-established</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
Note: no marks awarded for information that does not fit the criteria above	

(b) Same rate

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Stating reaction rate is stays the same</li> </ul>	1
<b>Total</b>	<b>1</b>

(c) Higher

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Stating reaction rate is higher</li> </ul>	1
<b>Total</b>	<b>1</b>

## 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
<ul style="list-style-type: none"><li>A temperature increase, increases the average kinetic energy of particles</li><li>Particles moving faster so collision frequency will increase for both forward and reverse reactions to the same extent</li><li>Both reactions will have a higher proportion of particles with sufficient energy to overcome the activation energy, therefore both rates increase</li><li>However, endothermic reverse reaction will have a greater increase in the proportion of successful collisions, creating a net reverse reaction</li><li>Concluding a net reverse reaction will produce more <math>SCN^-</math> ions making the solution a pale brown colour</li></ul>	1 – 5
<b>Total</b>	<b>5</b>
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
<ul style="list-style-type: none"><li>A volume increase will decrease the reaction rates whilst increasing the yield</li></ul>	1 – 5

<ul style="list-style-type: none"> <li>• A volume increase makes particles become spaced further apart, so both reaction rates will decrease</li> <li>• Forward reaction will decrease less than reverse reaction due to a 1:2 gaseous molar ratio</li> <li>• Thus, there will be a net forward reaction</li> <li>• 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</li> </ul>	
<b>Total</b>	<b>6</b>
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
<ul style="list-style-type: none"> <li>• A catalyst provides an alternate reaction pathway with a lower activation energy</li> <li>• This will increase the proportion of collisions with sufficient energy to overcome the activation energy equally both reactions</li> <li>• The forward and reverse reactions will therefore increase equally</li> <li>• No net forward or reverse reaction will be created, so the yield will remain unchanged</li> <li>• Generalised comment about Lachlan's statement being only partially correct</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>
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
<ul style="list-style-type: none"> <li>A volume increase will decrease the reaction rates of both reaction rates from a collision frequency decrease</li> <li>The reverse reaction rate will decrease more than forward reaction due to a 1:2 gaseous molar ratio</li> <li>Thus, there will be a net forward reaction</li> <li>More ammonium and hydroxide ions will be produced and some ammonia will be consumed as a result of this net forward reaction</li> <li>Must mention <b>yield of <math>NH_4^+</math> will increase</b></li> </ul>	1 – 5
<b>Total</b>	<b>5</b>
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
<ul style="list-style-type: none"> <li>Option '(iii) Constant Temperature' chosen</li> <li>Option '(i) Constant Volume' chosen</li> </ul>	1/2 for each
<b>Total</b>	<b>1</b>
Note: no wording is necessary other than '(iii) Constant Temperature'	

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

Marking Criteria	Marking Criteria
<ul style="list-style-type: none"> <li>Deduced no changes to either partial pressures</li> </ul>	1
<b>Total</b>	<b>1</b>
Note: no wording necessary other than 'No changes'	

ii. Yes

Marking Criteria	Marking Criteria
<ul style="list-style-type: none"> <li>Option 'Yes' chosen</li> </ul>	1
<b>Total</b>	<b>1</b>
Note: no wording is necessary other than 'Yes'	

iii. No

Marking Criteria	Marking Criteria
<ul style="list-style-type: none"> <li>Option 'No' chosen</li> </ul>	1
<b>Total</b>	<b>1</b>
Note: no wording is necessary other than 'No'	

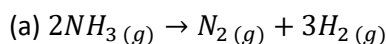
iv. Neither

Marking Criteria	Marking Criteria
<ul style="list-style-type: none"><li>Option 'Neither' chosen</li></ul>	1
<b>Total</b>	<b>1</b>
Note: no wording is necessary other than 'Neither'	

### Initial Equilibrium Establishment questions: Q9

9.

[7 marks]



Marking Criteria	Marking Criteria
<ul style="list-style-type: none"><li>Forward reaction shows the decomposition of ammonia into nitrogen gas and hydrogen gas: <math>2NH_3(g) \rightarrow N_2(g) + 3H_2(g)</math></li></ul>	1
<b>Total</b>	<b>1</b>
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
<ul style="list-style-type: none"><li>Presence of the reverse reaction which reproduces some of the ammonia initially injected</li><li>Conclusion that the reverse reaction prevents the forward reaction from ever going to completion/it establishes an equilibrium system</li></ul>	1 – 2
<b>Total</b>	<b>2</b>
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
<ul style="list-style-type: none"><li>When ammonia is added, the frequency of collisions for the forward reaction will increase, so the forward reaction rate will increase</li></ul>	1 – 5



<ul style="list-style-type: none"> <li>As no reverse reactant particles have been added, the reverse reaction rate will initially remain unchanged</li> <li>Thus there will be a net forward reaction</li> <li>Forward reaction rate will decrease over-time and the reverse reaction rate will increase until their rates become equal and equilibrium is established</li> </ul>	
<b>Total</b>	<b>5</b>

**‘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”		✓
<b>Explanation (if you ticked ‘False’):</b> 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”	✓	
<b>Explanation (if you ticked ‘False’):</b>		
“Adding an inert gas to a system increases the frequency of collisions between reacting molecules, thus increasing the partial pressures of all reacting molecules”		✓
<b>Explanation (if you ticked ‘False’):</b> 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”	✓	
<b>Explanation (if you ticked ‘False’):</b>		

Marking Criteria	Marking Criteria
<ul style="list-style-type: none"> <li>1 mark for each correctly ticked box</li> </ul>	1 – 4
<ul style="list-style-type: none"> <li>1 mark for each correctly given explanation to false statement</li> </ul>	1 – 2
<b>Total</b>	<b>6</b>
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
<ul style="list-style-type: none"> <li>One mark for each correct equilibrium constant determined</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>The equilibrium constants indicate that both reaction rates occur to a reasonable extent, with both reactants and products present</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

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
<ul style="list-style-type: none"> <li>One mark for each correct equilibrium constant determined</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>
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
<ul style="list-style-type: none"> <li>A moderate equilibrium constant for reaction (i) indicates similar amounts of products and reactants are present</li> <li>A very small equilibrium constant for reaction (iv) indicates negligible reaction occurs, so mostly present as reactants</li> <li>A large equilibrium constant for reaction (v) indicates the reaction occurs to near completion, so mostly products are present</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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  $K = ^\circ C + 273$ .

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>One mark for each correct equilibrium constant determined</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Applying Le Chatelier's Principle to state that the system will act to partially oppose a temperature increase by favouring the endothermic reaction</li> <li>Concluding the size of <math>K_c</math> will increase from the forward reaction being favoured</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

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
<ul style="list-style-type: none"> <li>Applying Le Chatelier's Principle to state that the system will act to counter a temperature decrease by favouring the exothermic reaction</li> <li>Concluding the size of <math>K_c</math> will decrease from the reverse reaction being favoured</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

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
<ul style="list-style-type: none"> <li>Stating the drop in <math>K_c</math> at 500K is due to a reactant turning from liquid to gas</li> <li>Identifying the overall trend that <math>K_c</math> is increasing with an increasing temperature</li> <li>Applying Le Chatelier's Principle to state that the system will act to counter a temperature decrease by favouring the exothermic reaction</li> </ul>	1 – 3
<ul style="list-style-type: none"> <li>Recognising the value of <math>K_c</math> is increasing so the forward reaction is favoured</li> <li>Concluding the forward reaction is therefore endothermic</li> </ul>	1 – 2
<b>Total</b>	<b>5</b>

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
<b>Total</b>	<b>7</b>
Note: No half-marks awarded for getting half of the row correct	

1.33

[3 marks]

Using molar ratios:

$$\begin{aligned}
 [H_2O] &= 2 \times [N_2] \\
 &= 2 \times 2 \\
 &= 4 \text{ mol L}^{-1} \quad \mathbf{(1)}
 \end{aligned}$$

$$\begin{aligned}
 K_c &= [N_2][H_2O] \\
 &= [2][4] \\
 &= 8 \quad \mathbf{(1)}
 \end{aligned}$$

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
<ul style="list-style-type: none"><li>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'</li></ul>	1
<b>Total</b>	<b>1</b>

(b) Right

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>Equilibrium position shift correctly stated</li></ul>	1
<b>Total</b>	<b>1</b>

(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
<ul style="list-style-type: none"><li>Stating that diluting the system will decrease the concentration of all ions</li><li>Applying LCP to state the system will act to favour the reaction that produces more moles of aqueous product</li><li>Correct conclusion that the system will favour the forward reaction, shifting the equilibrium position to the right</li></ul>	1 – 3
<b>Total</b>	<b>3</b>

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
<ul style="list-style-type: none"> <li>Stating the addition of hydrogen gas will increase the hydrogen gas concentration</li> <li>Applying LCP to state the system will act to consume some of the added reactant</li> <li>Correct conclusion that the system will favour the reverse reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>Stating the carbon monoxide decrease in partial pressure will also decrease its partial pressure</li> <li>Applying LCP to state the system will act to reproduce some of the lost carbon monoxide</li> <li>Correct conclusion that the system will favour the forward reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>Applying LCP to state system will act to favour the reaction that produces more moles of gaseous product</li> <li>Correct conclusion that the system will favour the forward reaction</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(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
<ul style="list-style-type: none"> <li>Stating that the temperature decrease will decrease the average KE of reacting particles</li> <li>Applying LCP to state the system will act to replace some of the lost energy by favouring the exothermic reaction</li> <li>Correct conclusion that the system will favour the reverse reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>Applying LCP to state the system will not act to partially oppose the change since there has been no equilibrium position shift</li> <li>Correct conclusion that the system will not favour either reaction</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(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
<ul style="list-style-type: none"> <li>Stating that adding the neon gas at a constant pressure will increase the volume of the system</li> <li>Applying LCP to state the system will act to favour the reaction that produces more moles of gaseous product</li> <li>Correct conclusion that the system will favour the forward reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

**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
<b>Total</b>	<b>8</b>
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
<b>Total</b>	<b>4</b>
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
<b>Total</b>	<b>4</b>
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
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Must correctly identify both reaction (I) and (V)</li> </ul>	2
<b>Total</b>	<b>2</b>
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
<ul style="list-style-type: none"> <li>One mark for each colour change that is correctly stated</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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 &amp; 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
<ul style="list-style-type: none"> <li>One mark for each colour change correctly described</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
Note: Can be fairly lenient as long as it is along the lines of the correct colour change	

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
<ul style="list-style-type: none"> <li>One mark for each predicted cause appropriately identified</li> </ul>	1 – 4
<ul style="list-style-type: none"> <li>One mark for correct application of Le Chatelier's Principle</li> <li>One mark for linking it to the observed colour change or pH change</li> </ul>	1 – 8
<b>Total</b>	<b>12</b>

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

(a) Endothermic

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>One mark for correctly determining reverse reaction is endothermic</li> </ul>	1

<b>Total</b>	<b>1</b>
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
<ul style="list-style-type: none"> <li>Stating that the temperature increase will increase the average KE of reacting particles</li> <li>Applying LCP to state the system will act to replace consume some of the added thermal energy by favouring the endothermic reaction</li> <li>Correct conclusion that the system will favour the reverse reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Stating the removal of sulfur trioxide will decrease its concentration</li> <li>Applying LCP to state the system will act to reproduce some of the lost sulfur trioxide</li> <li>Correct conclusion that the system will favour the forward reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Stating that the oxygen gas partial pressure increase will increase the concentration of oxygen gas</li> <li>Applying LCP to state the system will act to consume some of the added oxygen gas</li> <li>Correct conclusion that the system will favour the forward reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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 forward reaction will be favoured **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Stating that the temperature increase will increase the average KE of reacting particles</li> <li>Applying LCP to state the system will act to replace consume some of the added energy by favouring the endothermic reaction</li> <li>Correct conclusion that the system will favour the forward reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>Applying LCP to state the system will not act to partially oppose the change since there has been no equilibrium position shift</li> <li>Correct conclusion that the system will not favour either reaction</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(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
<ul style="list-style-type: none"> <li>Correctly stating both alterations (i) and (iii)</li> </ul>	2
<b>Total</b>	<b>2</b>
Note: no marks awarded if alteration (ii) is included, or if only one correct alteration is included	

(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
<ul style="list-style-type: none"> <li>Stating that the temperature decrease will decrease the average KE of reacting particles</li> <li>Applying LCP to state the system will act to replace some of the lost energy by favouring the exothermic reaction</li> <li>Correct conclusion that the system will favour the forward reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>Applying LCP to state the system will act to favour the reaction that produces more moles of gaseous product</li> <li>Correct conclusion that the system will favour the reverse reaction</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(c) When the partial 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
<ul style="list-style-type: none"> <li>Stating that a decrease in the partial pressure of carbon monoxide and hydrogen gas will cause a decrease for both concentrations</li> <li>Applying LCP to state the system will act to reproduce some of the lost reactants for both</li> <li>Correct conclusion that the system will favour the reverse reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>Stating that adding carbon monoxide will increase the concentration of carbon monoxide</li> </ul>	1 – 3

<ul style="list-style-type: none"> <li>Applying LCP to state the system will act to consume some of the added carbon monoxide</li> <li>Correct conclusion that the system will favour the forward reaction</li> </ul>	
<b>Total</b>	<b>3</b>

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
<ul style="list-style-type: none"> <li>Applying LCP to state the system will act to favour the reaction that produces more moles of gaseous product</li> <li>Comment made that both sides contain equal moles of gaseous product</li> <li>Correct conclusion that the system will favour neither reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>Stating that increasing the volume will decrease the concentration of all reacting particles</li> <li>Applying LCP to state the system will act to favour the reaction that produces more moles of aqueous product</li> <li>Comment made that both sides contain equal moles of gaseous product</li> <li>Correct conclusion that the system will favour neither reaction</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

(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
<ul style="list-style-type: none"> <li>Stating that adding the inert gas at a constant volume will have no concentration effect</li> <li>Applying LCP to state the system will not partially oppose the change</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(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
<ul style="list-style-type: none"> <li>• Stating that as the water depth increases, the system pressure will increase</li> <li>• Applying LCP to state the system will act to favour the reaction that produces less moles of gaseous product</li> <li>• Correct conclusion that the system will favour the forward reaction</li> <li>• Comment made this will result in more nitrogen dioxide being dissolve into the system</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>• Stating that as the water depth increase, the system pressure will decrease</li> <li>• Applying LCP to state the system will act to favour the reaction that produces more moles of gaseous product</li> <li>• Correct conclusion that the system will favour the reverse reaction</li> <li>• Comment made that more gas will be produced than what can be expelled</li> <li>• A concluding statement about the accumulation of bubbles in tissue and bloodstream that causes decompression sickness</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>

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

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
<ul style="list-style-type: none"> <li>Stating that diluting the system will decrease the concentration of all ions</li> <li>Applying LCP to state the system will act to favour the reaction that produces more moles of aqueous product</li> <li>Correct conclusion that the system will favour the forward reaction, restoring some <math>Fe^{3+}</math> and <math>SCN^{-}</math> ions</li> <li>Comment about how there is still a net concentration decrease for all ions</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>Stating the chlorine powder will dissolve, increasing the <math>OCl^{-}</math> ion concentration</li> <li>Applying LCP to state system II will act to consume some of the added <math>OCl^{-}</math> ions</li> <li>Correct conclusion that the system will favour the forward reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>Stating the favoured forward reaction will also consume some hydronium ions</li> <li>Stating the hydronium ion concentration will decrease as a result of adding chlorine powder</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(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
<ul style="list-style-type: none"> <li>Generalised statement about how the pH will increase as a result of adding chlorine powder</li> </ul>	1
<b>Total</b>	<b>1</b>

Imposed Change	Concentration at the Point of Change		Final Concentrations	
	$[Ba^{2+}_{(aq)}]$	$[OH^{-}_{(aq)}]$	$[Ba^{2+}_{(aq)}]$	$[OH^{-}_{(aq)}]$
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
<b>Total</b>	<b>10</b>

Note: no half-marks are awarded for getting half of a concentration change correct

### Yield questions: Qs: 2.8, 2.81

(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	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>Stating that as the ammonia is removed, the concentration of ammonia will be zero</li> <li>Applying LCP to state the system will act to favour the reaction that produces more ammonia</li> <li>Correct conclusion that the system will favour the forward reaction</li> <li>Comment made this will result increase the yield of ammonia</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>One mark for a generalised statement about the effect the change has on the equilibrium</li> <li>One mark for applying Le Chatelier's principle to determine which reaction is favoured</li> <li>One mark for linking back to how the favoured reaction optimises yield</li> </ul>	(1 – 3) × 6
<b>Total</b>	<b>18</b>

(c) High temperature and removing carbon dioxide gas

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>One mark for stating both high temperature and removal of carbon dioxide gas</li> </ul>	1
<b>Total</b>	<b>1</b>

### 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
<ul style="list-style-type: none"> <li>Stating that adding a base will decrease the hydronium ion concentration:  <math>OH_{(aq)}^- + H_3O_{(aq)}^+ \rightarrow 2H_2O_{(l)}</math></li> <li>Applying LCP to state the system will act to replace some of the hydronium ions</li> <li>Correct conclusion that the system will favour the forward reaction not the reverse reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
<ul style="list-style-type: none"> <li>Note: the equation <math>OH_{(aq)}^- + H_3O_{(aq)}^+ \rightarrow 2H_2O_{(l)}</math> is not necessary to attain full marks</li> </ul>	

(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
<ul style="list-style-type: none"> <li>Stating that adding the inert gas at a constant pressure will increase the volume of the system</li> <li>Applying LCP to state the system will act to favour the reaction that produces more moles of gaseous product</li> <li>Correct conclusion that the statement is incorrect because the system does not favour the side with less moles</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
------------------	-----------------

<ul style="list-style-type: none"> <li>Stating that adding the inert gas at a constant volume will have no concentration effect</li> <li>Applying LCP to state the system will not partially oppose the change</li> <li>Concluding the statement is incorrect because the system does not favour the side with less moles</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>Stating that the temperature decrease will decrease the average KE of reacting particles</li> <li>Applying LCP to state the system will act to replace some of the lost energy by favouring the exothermic reaction</li> <li>Correct conclusion that the system will favour the reverse reaction making the system more yellow not orange</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

**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
<ul style="list-style-type: none"> <li>Explaining that this 2:1 ratio will only occur when no changes have occurred other than the initial injection of <math>NOCl</math> gas</li> <li>Providing an example of when Jane's statement is not correct</li> <li>Concluding that Jane's statement is only partially correct</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

**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
<ul style="list-style-type: none"> <li>Stating that adding the <math>AgNO_3</math> will decrease the chloride ion concentration</li> <li>Applying LCP to state the system will act to replace some of the chloride ions</li> <li>Correct conclusion that the system will favour the reverse reaction and linking it to producing more <math>Co(H_2O)_6^{2+}</math> ions</li> <li>Concluding that Peter is correct and Luke is incorrect</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>Stating that the temperature increase will increase the average KE of reacting particles</li> <li>Applying LCP to state the system will act to replace consume some of the added energy by favouring the endothermic reaction</li> <li>Correct conclusion that the system will favour the forward reaction and linking it to producing more <math>CoCl_4^{2-}</math> ions</li> <li>Concluding that Luke is wrong and Peter is correct</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>Stating that adding the <math>AgNO_3</math> will decrease the chloride ion concentration</li> <li>Applying LCP to state the system will act to replace some of the chloride ions</li> <li>Correct conclusion that the system will favour the reverse reaction and linking it to producing more <math>Co(H_2O)_6^{2+}</math> ions</li> <li>Concluding that the <math>CoCl_4^{2-}</math> ions is blue by deducing that the <math>Co(H_2O)_6^{2+}</math> ions are pink</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>Stating that the temperature increase will increase the average KE of reacting particles</li> <li>Applying LCP to state the system will act to replace consume some of the added energy by favouring the endothermic reaction</li> <li>Correct conclusion that the system will favour the forward reaction and linking it to producing more <math>CoCl_4^{2-}</math> ions</li> <li>Concluding that the <math>CoCl_4^{2-}</math> ions must be blue</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>One mark for each correctly stated change that shifts the equilibrium position to the left</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>



### 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
<ul style="list-style-type: none"><li>Stating the concentration of water molecules will remain unchanged</li></ul>	1
<b>Total</b>	<b>1</b>

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

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>Stating the collision frequency of water will remain unchanged</li></ul>	1
<b>Total</b>	<b>1</b>

(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
<ul style="list-style-type: none"><li>When water is added it reduces the reactant particle concentration</li><li>Reactant particles become spaced further apart and therefore collision frequency decreases</li></ul>	1 – 2
<b>Total</b>	<b>2</b>

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

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>Stating the proportion of successful collisions will remain unchanged</li></ul>	1
<b>Total</b>	<b>1</b>

(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
<ul style="list-style-type: none"><li>A decrease in collision frequency, decreases the rate of successful collisions</li><li>As a result the reaction rate decreases</li></ul>	1 – 2
<b>Total</b>	<b>2</b>

## 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
<ul style="list-style-type: none"> <li>By definition, the state of subdivision is a state in which a solid is divided into smaller pieces</li> <li>It applies to any reactions that have at least one solid reactant</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(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 fine 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
<ul style="list-style-type: none"> <li>Collisions can only take place at the surface of a reacting solid</li> <li>An increased surface area increases the frequency of collisions</li> <li>An increased collision frequency, increases the rate of successful collisions, which increases the reaction rate</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>Adding/removing solid reactant has no effect on reaction rate because the concentration of a solid is always constant</li> </ul>	1
<b>Total</b>	<b>1</b>

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

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Surface area has no effect on the amount of product that will be produced, it only affects the reaction rate</li> </ul>	1
<b>Total</b>	<b>1</b>

## 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
<ul style="list-style-type: none"> <li>A temperature increase will increase the average kinetic energy of all reacting particles</li> <li>Particles will be moving faster so collision frequency will increase equally for both forward and reverse reactions</li> <li>Both reactions will have a higher proportion of particles with sufficient energy to overcome the activation energy</li> <li>However, endothermic reverse reaction will have a greater increase in the proportion of successful collisions, thus creating a net reverse reaction</li> <li>Concluding a net reverse reaction will produce more hydrogen peroxide and thus increasing its concentration</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>
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
<ul style="list-style-type: none"> <li>A volume increase will decrease the reaction rates of both reaction rates from a collision frequency decrease on both sides</li> <li>The reverse reaction rate will decrease less than forward reaction due to a 1:0 aqueous molar ratio</li> <li>Thus there will be a net reverse reaction</li> <li>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</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

(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
<ul style="list-style-type: none"> <li>The removal of oxygen gas will decrease the rate of the reverse reaction from a decrease in the frequency of collisions</li> <li>The rate of the forward reaction will remain initially unchanged from no particles being added/removed, thus creating a net forward reaction</li> <li>Some hydrogen peroxide will be consumed and some oxygen gas and water will be produced, thus decreasing the hydrogen peroxide concentration</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>Stating flask 1 is an open system</li> </ul>	1
<b>Total</b>	<b>1</b>

(b) Closed system

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Stating flask 2 is a closed system</li> </ul>	1
<b>Total</b>	<b>1</b>

(c) Flask 1

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Stating flask 1 had the greatest water loss</li> </ul>	1
<b>Total</b>	<b>1</b>

(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
<ul style="list-style-type: none"> <li>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</li> <li>The rate of evaporation remains unchanged, creating a net forward reaction</li> <li>This net forward reaction will cause the water levels to decrease</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Flask 2 is a closed system, so the wind will have no effect on the water vapour</li> <li>The rate of condensation will equal the rate of evaporation, leaving the system in equilibrium</li> <li>Thus there won't be any significant water level changes</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Flask 1 will have a vapor pressure equal to the atmospheric pressure</li> <li>Flask 2 will have a vapour pressure that stayed the same</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

**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
<ul style="list-style-type: none"> <li>The addition of chlorine gas will increase the rate of the forward reaction from an increase in the frequency of collisions</li> <li>The rate of the reverse reaction will remain initially unchanged from no particles being added/removed</li> <li>Correct conclusion that there will be a net forward reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>A volume increase will decrease the reaction rates of both reaction rates from a collision frequency decrease</li> <li>The forward reaction rate will decrease less than reverse reaction due to a 1:2 gaseous molar ratio</li> <li>Correct conclusion that there will be a net forward reaction</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Combining carbon powder into large chunks will decrease the surface area of carbon</li> <li>This will decrease the frequency of collisions between forward reactant particles creating a net reverse reaction</li> <li>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</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Adding oxygen gas will increase the forward reaction rate from an increase in the frequency of collisions</li> <li>The rate of the reverse reaction will remain initially unchanged from no particles being added/removed, thus creating a net forward reaction</li> <li>Some carbon monoxide will be produced from this net forward reaction, therefore increasing the reverse reaction rate/rate at which carbon monoxide is consumed</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>A volume decrease will increase the reaction rates of both reaction rates from a collision frequency increase on both sides</li> <li>However, the forward reaction rate will increase more than reverse reaction due to a 3:2 gaseous molar ratio</li> <li>Correct conclusion that there is a net forward reaction</li> <li>More carbon monoxide will be produced from this net reverse reaction, therefore decreasing the reverse reaction rate/rate at which carbon monoxide is consumed</li> <li>However, there will still be a net increase in the carbon monoxide consumption, because the initial reverse reaction increase is only partially opposed.</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>
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
<ul style="list-style-type: none"> <li>Removing chlorine gas will turn the system a lighter greenish-yellow initially</li> <li>The removal of chlorine gas will also cause the rate of the forward reaction to decrease from a decreased collision frequency</li> <li>The rate of the reverse reaction will remain initially unchanged from no particles being added/removed, thus creating a net reverse reaction</li> <li>This will reproduce some chlorine gas, however the system will still remain a lighter greenish-yellow because the concentration drop is only partially restored</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>Stating the concentration of dichromate ions/<math>Cr_2O_7^{2-}</math> increases</li> </ul>	1
<b>Total</b>	<b>1</b>

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

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Stating the concentration of chromate ions/<math>CrO_4^{2-}</math> increases</li> </ul>	1
<b>Total</b>	<b>1</b>

(iii) Increase the concentration of hydrogen ions

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Stating the concentration of hydrogen ions increases</li> </ul>	1
<b>Total</b>	<b>1</b>

(iv) Increase the concentration of hydrogen ions

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Stating the concentration of hydrogen ions increases</li> </ul>	1
<b>Total</b>	<b>1</b>

(v) Decrease the concentration of hydrogen ions



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Stating the concentration of hydrogen ions decreases</li> </ul>	1
<b>Total</b>	<b>1</b>

(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
<ul style="list-style-type: none"> <li>Stating there are no changes to the concentrations of any ions</li> </ul>	1
<b>Total</b>	<b>1</b>

(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
<ul style="list-style-type: none"> <li>Adding potassium dichromate will increase the dichromate ion concentration</li> <li>This will cause the rate of the forward reaction to increase from an increased collision frequency</li> <li>The rate of the reverse reaction will remain initially unchanged from no particles being added/removed, thus creating a net forward reaction</li> <li>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</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
------------------	------------------

<ul style="list-style-type: none"> <li>• Adding sodium hydroxide will consume some of the hydrogen ions, thus decreasing the hydrogen ion concentration</li> <li>• This will cause the rate of the reverse reaction to decrease from a decreased collision frequency</li> <li>• The rate of the forward reaction will remain initially unchanged from no particles being added/removed, thus creating a net forward reaction</li> <li>• 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</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>• Adding water will decrease the concentration of all ions, making the system a lighter purple</li> <li>• This concentration drop will cause the rates of the forward and reverse reactions to both decrease from the decreased collision frequency</li> <li>• However, the reverse reaction will decrease more than the forward reaction due to a 14:6 aqueous molar ratio</li> <li>• Correct conclusion there is a net reverse reaction</li> <li>• 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</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>
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
<ul style="list-style-type: none"> <li>• Temperature increase will cause a net forward reaction, so rate of evaporation is faster than rate of condensation</li> <li>• Gaseous area will become a darker reddish-colour and reddish-brown water levels will decrease</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>
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
<ul style="list-style-type: none"> <li>• Volume decrease will make gaseous area become darker reddish-brown colour</li> <li>• Volume decrease will also cause a net reverse reaction, so rate of condensation is faster than rate of evaporation</li> <li>• The gaseous area becomes a lighter reddish-brown colour and reddish-brown water levels decrease</li> <li>• However gaseous area is still a darker reddish-brown colour since initial change is only partially opposed</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>• Volume decrease will make gaseous area become darker reddish-brown colour</li> <li>• Volume decrease will also cause a net reverse reaction, so rate of condensation is faster than rate of evaporation</li> <li>• The gaseous area becomes a lighter reddish-brown colour and reddish-brown water levels decrease</li> </ul>	1 – 4

<ul style="list-style-type: none"> <li>• However gaseous area is still a darker reddish-brown colour since initial change is only partially opposed</li> </ul>	
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>• The volume decrease will increase the rate of the reverse reaction from increasing collision frequency</li> <li>• Rate of the forward reaction is not gaseous, so will remain unchanged initially, thus creating net reverse reaction</li> <li>• More bromine water will be produced until equilibrium is re-established</li> <li>• However since bromine water is a liquid, its concentration will remain forever unchanged so the rate of evaporation will forever remain unchanged</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>• Determining that <math>294kJ</math> of energy will be released</li> </ul>	1
<b>Total</b>	<b>1</b>

(b) Decreasing the temperature

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Stating that decreasing the temperature will increase the yield</li> </ul>	1
<b>Total</b>	<b>1</b>

(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
<ul style="list-style-type: none"> <li>A temperature decrease, decreases the average kinetic energy of particles</li> <li>Particles moving slower so collision frequency will decrease to the same extent for both reactions</li> <li>Both reactions will have a lower proportion of particles with sufficient energy to overcome the activation energy</li> <li>Exothermic forward reaction has a smaller decrease in proportion of successful collisions, thus creating a net forward reaction</li> <li>Over-time the rate of the forward reaction will decrease and the reverse reaction will increase until equilibrium is re-established</li> <li>This net forward reaction will produce more sulfur trioxide, therefore increasing the yield of the reaction</li> </ul>	1 – 6
<b>Total</b>	<b>6</b>

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
<ul style="list-style-type: none"> <li>A temperature decrease, decreases the average kinetic energy of particles</li> <li>Particles moving slower so collision frequency so collision frequency decreases and proportion of particles with sufficient energy to overcome activation energy will decrease</li> <li>This will decrease the rate of successful collisions and therefore reaction rate</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

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
<ul style="list-style-type: none"> <li>A temperature decrease, decreases the average kinetic energy of particles</li> <li>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</li> <li>This will decrease the rate of successful collisions and therefore reaction rate to a greater extent</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>A net forward reaction will produce more calcium hydroxide/ <math>Ca(OH)_2</math></li> <li>This will increase the yield of the reaction</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

**3.52** **[8 marks]**

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

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Stating the rates of the forward and reverse reactions are equal</li> </ul>	1
<b>Total</b>	<b>1</b>

(b) The concentration for both reactions will remain unchanged

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>No initial concentration changes for both reactions</li> </ul>	1
<b>Total</b>	<b>1</b>

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

Marking Criteria	Marks Allocated
------------------	-----------------

<ul style="list-style-type: none"> <li>Stating the frequency of collisions will increase equally</li> </ul>	1
<b>Total</b>	<b>1</b>

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

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Proportion of successful collisions will increase for both reactions</li> <li>However the proportion will increase more for reverse reaction</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

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

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correct conclusion the reverse reaction rate is higher than forward reaction rate</li> </ul>	1
<b>Total</b>	<b>1</b>

(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
<ul style="list-style-type: none"> <li>A temperature increase will increase the average kinetic energy of all reacting particles</li> <li>Particles will be moving faster so collision frequency will increase equally for both forward and reverse reactions</li> <li>Both reactions will have a higher proportion of particles with sufficient energy to overcome the activation energy</li> <li>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</li> <li>Concluding a net reverse reaction will gradually decrease the reverse reaction rate and gradually increase the forward reaction rate until equilibrium is re-established</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>
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
<ul style="list-style-type: none"> <li>Concentrations of nitrogen gas and hydrogen gas will be higher than initially</li> <li>Concentration of ammonia will be lower than initially</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

**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
<ul style="list-style-type: none"> <li>At zero kelvin, all particles will have a zero kinetic energy</li> <li>Therefore no collisions will occur, so the reaction rates will both be decreased to zero</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

**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
<ul style="list-style-type: none"> <li>A minimised <math>NH_4NO_2(s)</math> decomposition will occur from a low system temperature</li> <li>A temperature decrease, decreases the average kinetic energy of particles</li> <li>Particles moving slower so collision frequency will decrease for both forward and reverse reactions and therefore their rates</li> <li>Both reactions will have a lower proportion of particles with sufficient energy to overcome the activation energy</li> <li>Exothermic forward reaction will have a smaller decrease in proportion of successful collisions, thus creating a net reverse reaction</li> <li>Concluding a net reverse reaction will reduce the amount of decomposition that occurs, since yield of <math>NH_4NO_2(s)</math> decreases</li> </ul>	1 – 6
<b>Total</b>	<b>6</b>

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
<ul style="list-style-type: none"> <li>The addition of catalyst will provide an alternate reaction pathway with a lower activation energy</li> <li>This will increase the proportion of collisions with sufficient energy to overcome the activation energy equally for both the forward and reverse reactions</li> <li>Thus the reaction rates for the forward and reverse reactions will increase equally</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Increasing the system temperature</li> <li>Addition of hydrogen gas</li> <li>Addition of iodine gas</li> <li>Removing hydrogen iodine gas</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

## 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: <ul style="list-style-type: none"> <li>Decreasing the volume of the system</li> <li>Adding nitrogen dioxide (<math>NO_2</math>) gas to the system</li> <li>Increasing the pressure of the system</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

### 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
<ul style="list-style-type: none"> <li>1 mark for each correct row</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>A volume increase will decrease the reaction rates of both reaction rates from a collision frequency decrease on both sides</li> </ul>	1 – 4

<ul style="list-style-type: none"> <li>The forward reaction rate will decrease more than reverse reaction due to a 2:1 aqueous molar ratio</li> <li>Thus creating a net reverse reaction</li> <li>Over time the reverse reaction rate will gradually decrease and the forward reaction rate will gradually increase until equilibrium is re-established</li> </ul>	
<b>Total</b>	<b>4</b>
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
<ul style="list-style-type: none"> <li>Dichromate ion/<math>Cr_2O_7^{2-}</math> concentration is decreased</li> </ul>	1
<b>Total</b>	<b>1</b>

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
<ul style="list-style-type: none"> <li>A volume decrease will increase the reaction rates of both reaction rates from a collision frequency increase on both sides</li> <li>The reverse reaction rate will increase more than forward reaction due to a 2:3 molar ratio</li> <li>Thus creating a net reverse reaction</li> <li>Over time the reverse reaction rate will gradually decrease and the forward reaction rate will gradually increase until equilibrium is re-established</li> <li>This will cause concentration changes that shift the equilibrium position to the left</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>
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
<ul style="list-style-type: none"> <li>A constant pressure was maintained</li> </ul>	1
<b>Total</b>	<b>1</b>

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

Marking Criteria	Marking Criteria
<ul style="list-style-type: none"> <li>No</li> </ul>	1
<b>Total</b>	<b>1</b>

(c) Right

Marking Criteria	Marking Criteria
<ul style="list-style-type: none"> <li>Equilibrium position will shift to the right</li> </ul>	1
<b>Total</b>	<b>1</b>

(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
<ul style="list-style-type: none"> <li>The volume increase will initially make the system a lighter brown colour</li> <li>Over time colour will return to a darker brown, however still lighter than before the neon gas was added</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(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)**.

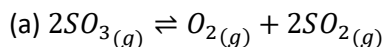
Marking Criteria	Marking Criteria
<ul style="list-style-type: none"> <li>Adding an inert gas at a constant pressure will increase the system volume</li> <li>A volume increase will decrease the reaction rates of both reaction rates from a collision frequency decrease on both sides</li> <li>The reverse reaction rate will decrease more than forward reaction due to a 1:2 gaseous molar ratio</li> <li>Thus creating a net forward reaction</li> </ul>	1 – 5

<ul style="list-style-type: none"> <li>Over time the forward reaction rate will gradually decrease and the reverse reaction rate will gradually increase until equilibrium is re-established</li> </ul>	
<b>Total</b>	<b>5</b>

### Initial Equilibrium Establishment questions: Qs: 3.9

3.9

[11 marks]



Marking Criteria	Marking Criteria
<ul style="list-style-type: none"> <li>Co-efficients of 2, 1 and 2: <math>2SO_{3(g)} \rightleftharpoons O_{2(g)} + 2SO_{2(g)}</math></li> </ul>	1
<b>Total</b>	<b>1</b>

(b) When sulfur trioxide is injected into 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
<ul style="list-style-type: none"> <li>Adding sulfur trioxide will increase the sulfur trioxide concentration from zero</li> <li>This will increase the frequency of collisions between forward reactant particles and therefore the forward reaction rate will increase</li> <li>Some of this sulfur trioxide will be consumed, gradually decreasing the forward reaction rate until equilibrium is re-established</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>The reverse reactant particles will initially stay at a concentration of zero</li> <li>As sulfur trioxide is consumed, oxygen gas and sulfur dioxide will be produced, increasing the reverse reactant collision frequency</li> <li>The reverse reaction rate will gradually increase until equilibrium is established</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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 consumed (**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
<ul style="list-style-type: none"> <li>The vanadium oxide catalyst will provide an alternate reaction pathway with a lower activation energy</li> <li>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</li> <li>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</li> <li>Thus the vanadium oxide catalyst increases the rate at which equilibrium is established</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

### '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
<ul style="list-style-type: none"> <li>Stating that the statements made by Jane, Dylan and Alex are all only partially correct</li> </ul>	1
<ul style="list-style-type: none"> <li>A catalyst will provide an alternate reaction pathway with a lower activation energy</li> <li>There will be an increase the proportion of collisions with sufficient energy to overcome the activation energy equally</li> <li>Thus the rate of both reactions will increase equally and there will be no net forward or reverse reaction</li> </ul>	1 – 3
<ul style="list-style-type: none"> <li>One mark for each person that is correctly corrected</li> </ul>	1 – 3
<b>Total</b>	<b>7</b>

# Problem Set 3 – Visualising Chemical Equilibrium

## Progressive Questions

### Concept 1

## Concentration and Reaction Rate Graphs – Progressive Questions

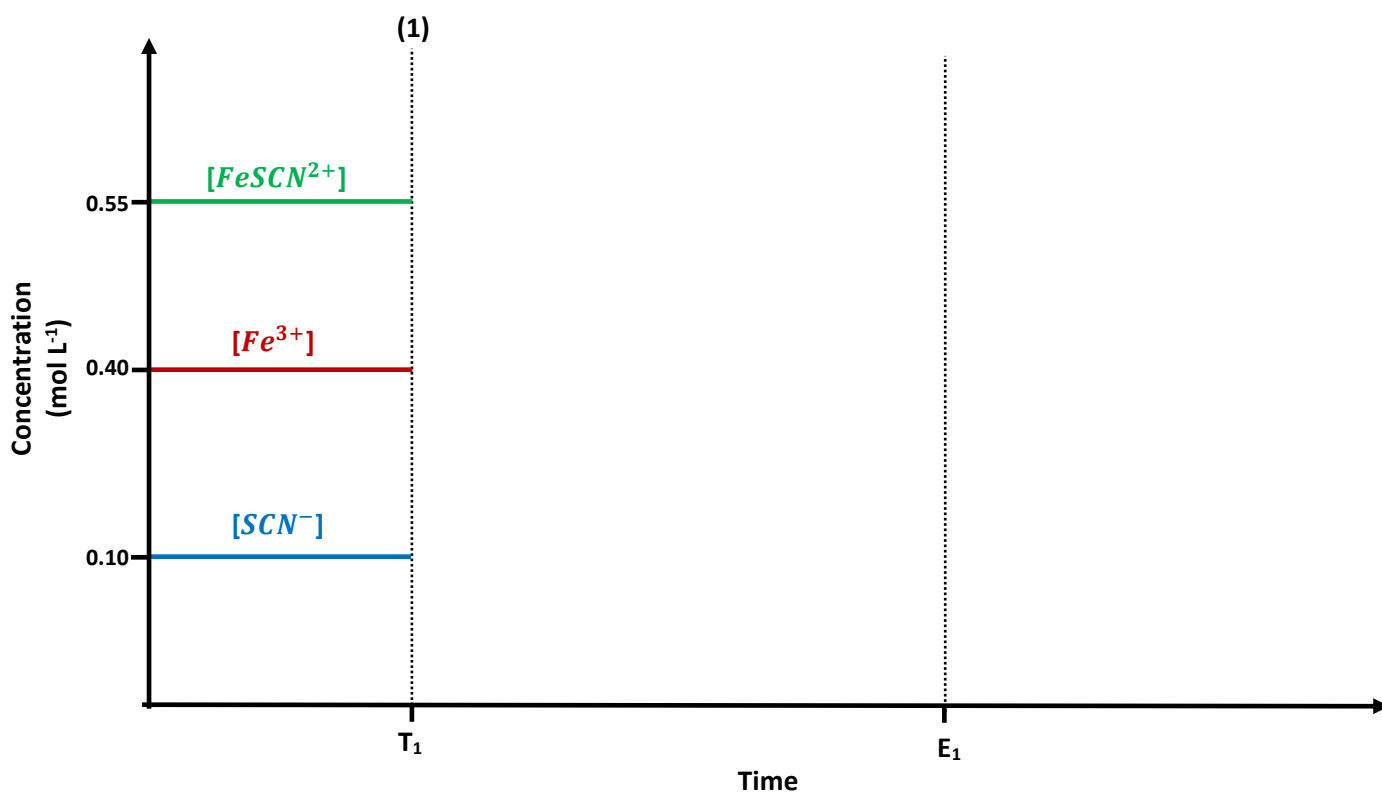
### Answers

Drawing concentration graphs with given concentrations: Q1

1.

[9 marks]

(a)



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correct positioning and labelling of initial concentration curves such that <math>[FeSCN^{2+}] &gt; [Fe^{3+}] &gt; [SCN^-]</math></li> </ul>	1
<b>Total</b>	<b>1</b>

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

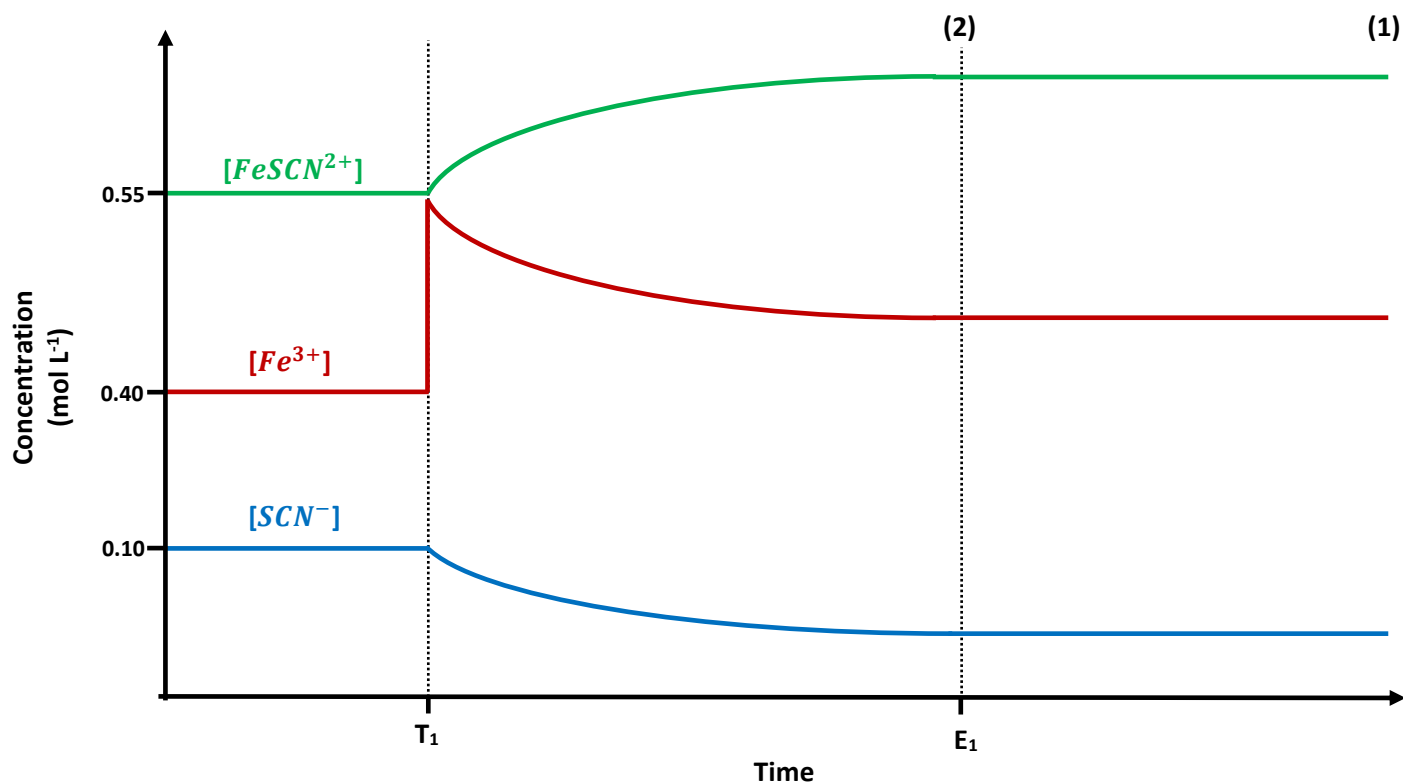
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>A solution of <math>Fe^{3+}</math> ions was added</li> </ul>	1

<b>Total</b>	<b>1</b>
--------------	----------

(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
<ul style="list-style-type: none"> <li>Stating that the concentration increase of the <math>Fe^{3+}</math> ions will make the solution a darker brown colour</li> <li>Applying LCP to state the system will act to consume some of the added <math>Fe^{3+}</math> ions</li> <li>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 <math>FeSCN^{2+}</math> ion concentration increase</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
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
<b>From T<sub>1</sub> to E<sub>1</sub>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike in <math>[Fe^{3+}]</math> concentration curve</li> </ul>	1 – 2

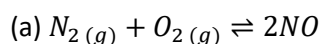


<ul style="list-style-type: none"> <li>Correct curvature and orientation of all curves to establish equilibrium at <math>E_1</math></li> </ul>	
<b>Equilibrium lines</b>	1
<ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math> and <math>E_1</math> onwards</li> </ul>	
<b>Total</b>	<b>4</b>
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	

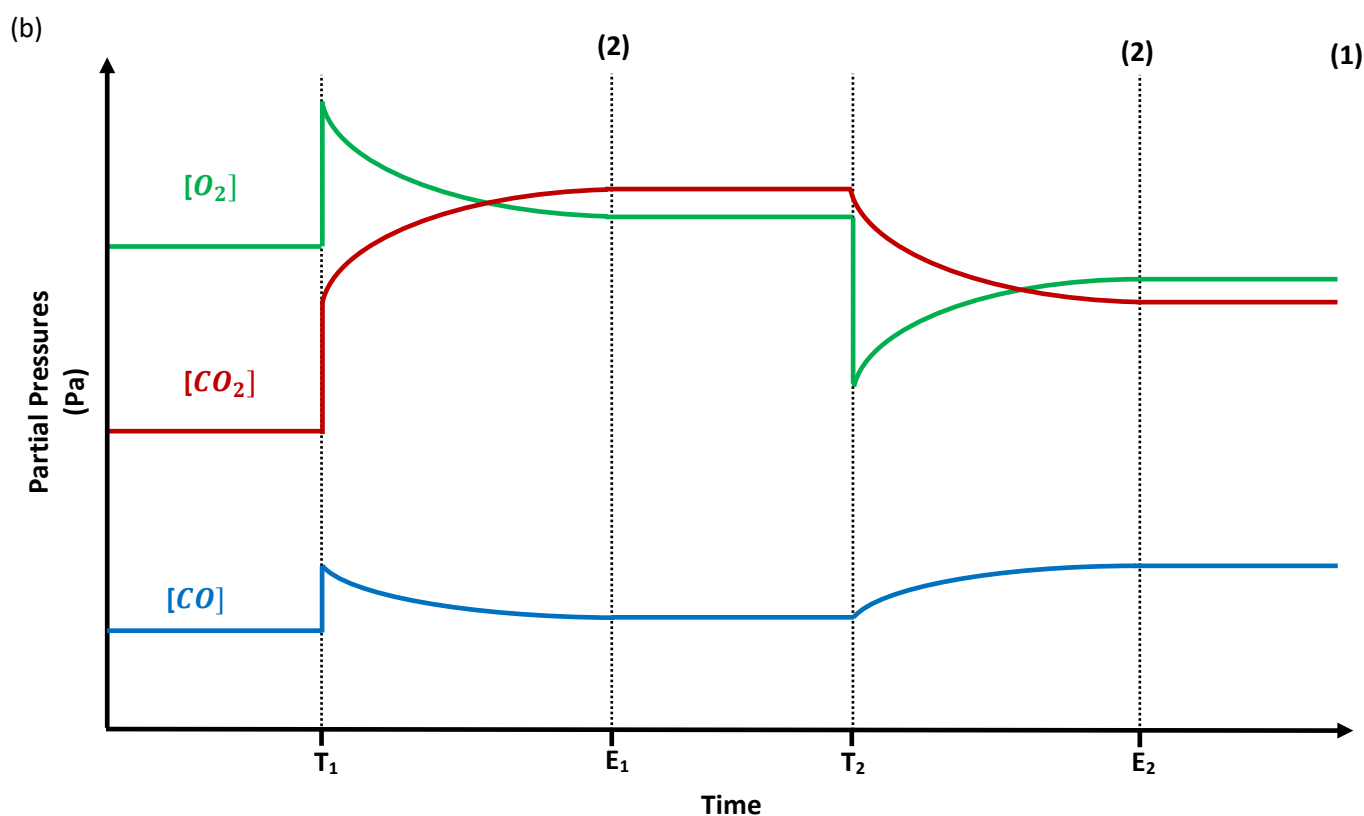
## Illustrating gas changes on concentration graphs: Q2

2.

[6 marks]



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li><math>N_2(g) + O_2(g) \rightleftharpoons 2NO</math></li> </ul>	1
<b>Total</b>	<b>1</b>



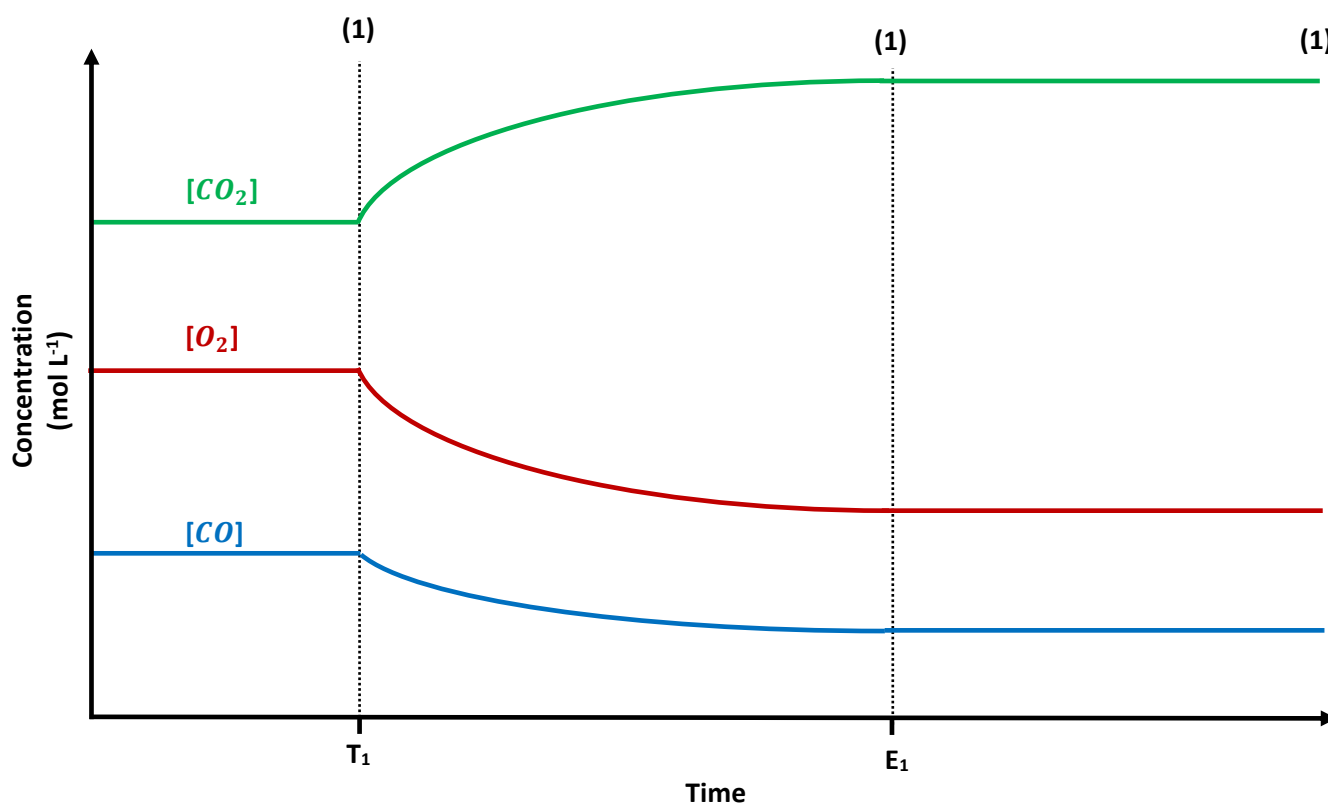
**Points to note:** At  $T_2$ , when the 'fresh-air' is added the nitrogen gas will react with the oxygen gas, so the concentration of oxygen will drop at  $T_2$ . It also important to label the y-axis with partial pressure rather than concentration, because the question specifically asks us to

Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b>	1 – 2
<ul style="list-style-type: none"> <li>Correct upward spike of all partial pressure curves at <math>T_1</math></li> <li>Correct curvature and orientation of all curves moving towards <math>E_1</math></li> </ul>	

<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>• Correct downward spike of <math>[O_2]</math> partial pressure curve at <math>T_2</math></li> <li>• Correct curvature and orientation of all curves from <math>T_2</math> to <math>E_2</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>• Equilibrium lines from <math>E_1</math> to <math>T_2</math> and <math>E_2</math> onwards</li> </ul>	1
<b>Total</b>	<b>5</b>
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
<b>From <math>T_0</math> to <math>T_1</math>:</b> <ul style="list-style-type: none"> <li>• Correct positioning and labelling of initial concentration curves such that <math>[CO_2] &gt; [O_2] &gt; [CO]</math></li> </ul>	1
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>• Correct curvature and orientation of all curves moving towards <math>E_1</math></li> </ul>	1
<b>From <math>E_1</math> onwards:</b> <ul style="list-style-type: none"> <li>• Equilibrium lines from <math>T_0</math> to <math>T_1</math> and <math>E_1</math> onwards</li> </ul>	1
<b>Total</b>	<b>3</b>
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
<ul style="list-style-type: none"> <li>Partial pressure will remain constant because system is initially in equilibrium from <math>T_0</math> to <math>T_1</math></li> </ul>	1
<b>Total</b>	<b>1</b>

(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
<ul style="list-style-type: none"> <li>Establishing a temperature decrease is the change made at <math>T_1</math></li> <li>A temperature decrease will decrease the concentrations curves of both <math>H_2O</math> and <math>N_2</math> without causing any initial spikes/drops, which matches the shape of the curves given</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(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
<ul style="list-style-type: none"> <li>Establishing a volume decrease is the change made at <math>T_2</math></li> <li>A temperature decrease will spike the concentrations of both <math>H_2O</math> and <math>N_2</math> initially and then cause them to decrease over-time, which matches the shape of the curves given</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

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
<ul style="list-style-type: none"> <li>Establishing the addition of a catalyst <b>or</b> the addition of an inert gas at constant volume are the two possible changes made at <math>T_3</math></li> </ul>	1 – 2

<ul style="list-style-type: none"> <li>Both changes will not create any spikes/drops or any inert forward/reverse reactions, which matches the continued equilibrium lines shown</li> </ul>	
<b>Total</b>	<b>2</b>
Note: Must state <b>both</b> 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
<ul style="list-style-type: none"> <li>The reaction rate graphs indicates that the temperature is decreased and that the forward reaction is favoured</li> <li>According to Le Chatelier's Principle, the system will act to favour the exothermic reaction</li> <li>Correct conclusion that the forward reaction is exothermic</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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)**.

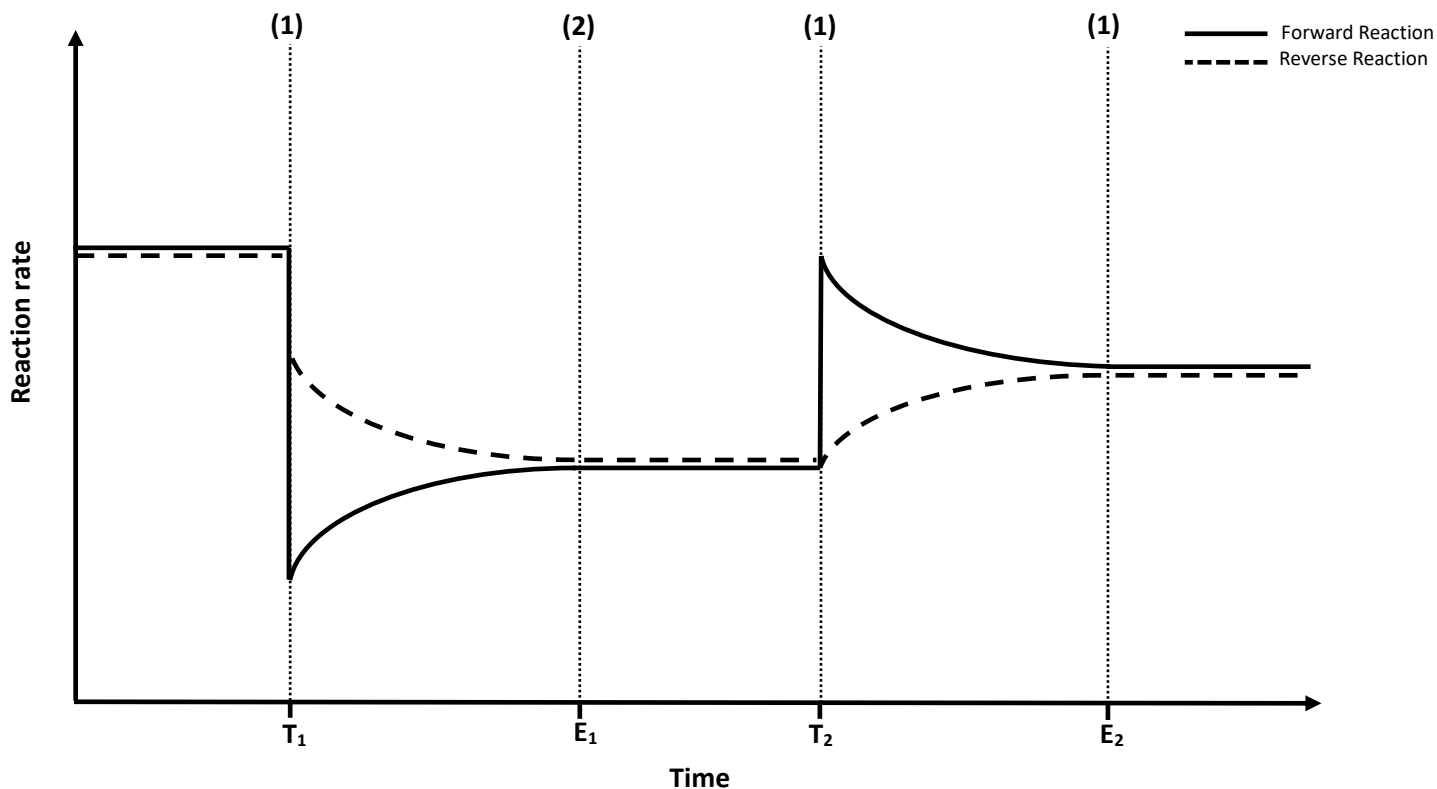
**Points to note:** a common trick is just stating volume increase without also stating the addition of an inert gas a constant pressure

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>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:</li> <li>A volume increase; or</li> <li>The addition of inert gas at a constant pressure</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

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

6.

[5 marks]

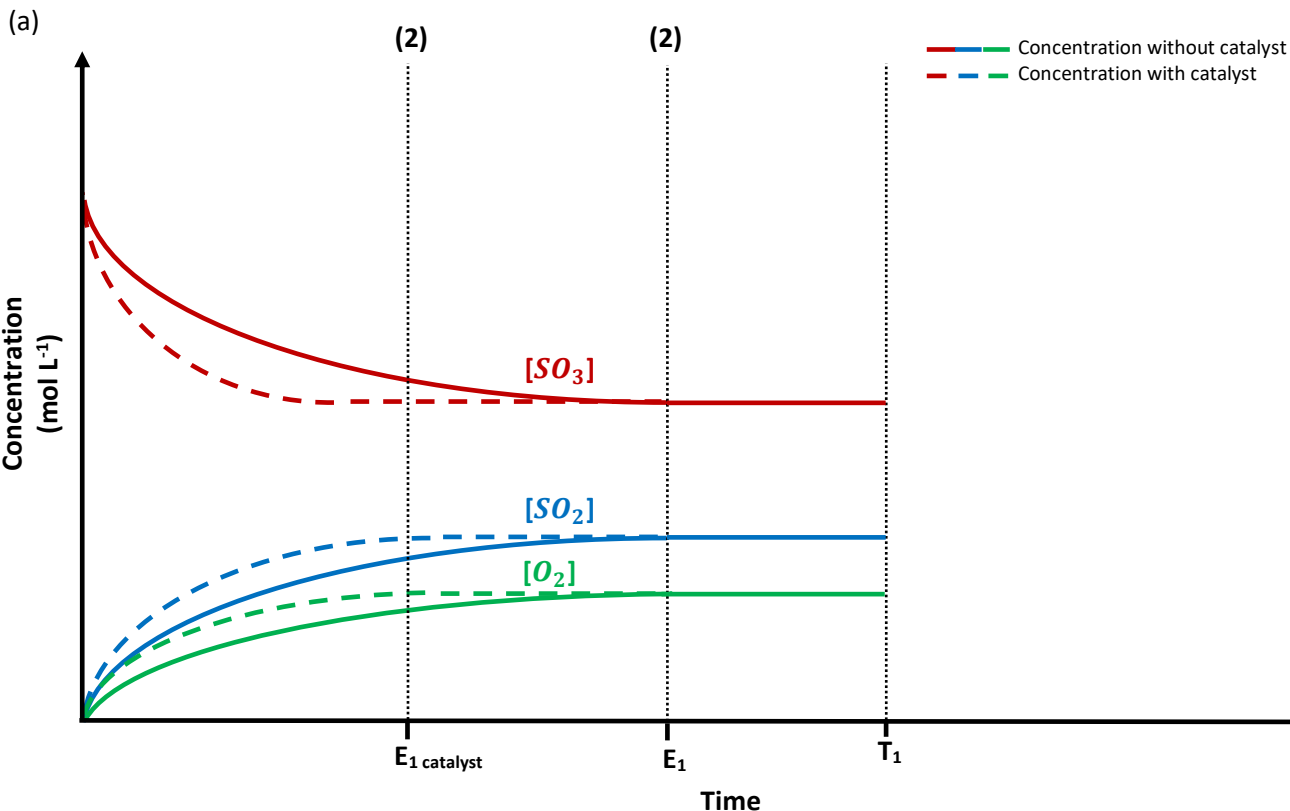


Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in both curves, however greater drop in the forward reaction curve at <math>T_1</math></li> <li>Correct curvature and orientation of both curves to re-join at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike in the forward reaction curve at <math>T_2</math></li> <li>Correct curvature and orientation of both curves to re-join at <math>E_2</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math> and <math>E_2</math> onwards</li> </ul>	1
<b>Total</b>	<b>5</b>
Note: Deduct one mark for any missing/incorrect labels of $T_1$ , $E_1$ , axis labels etc.	

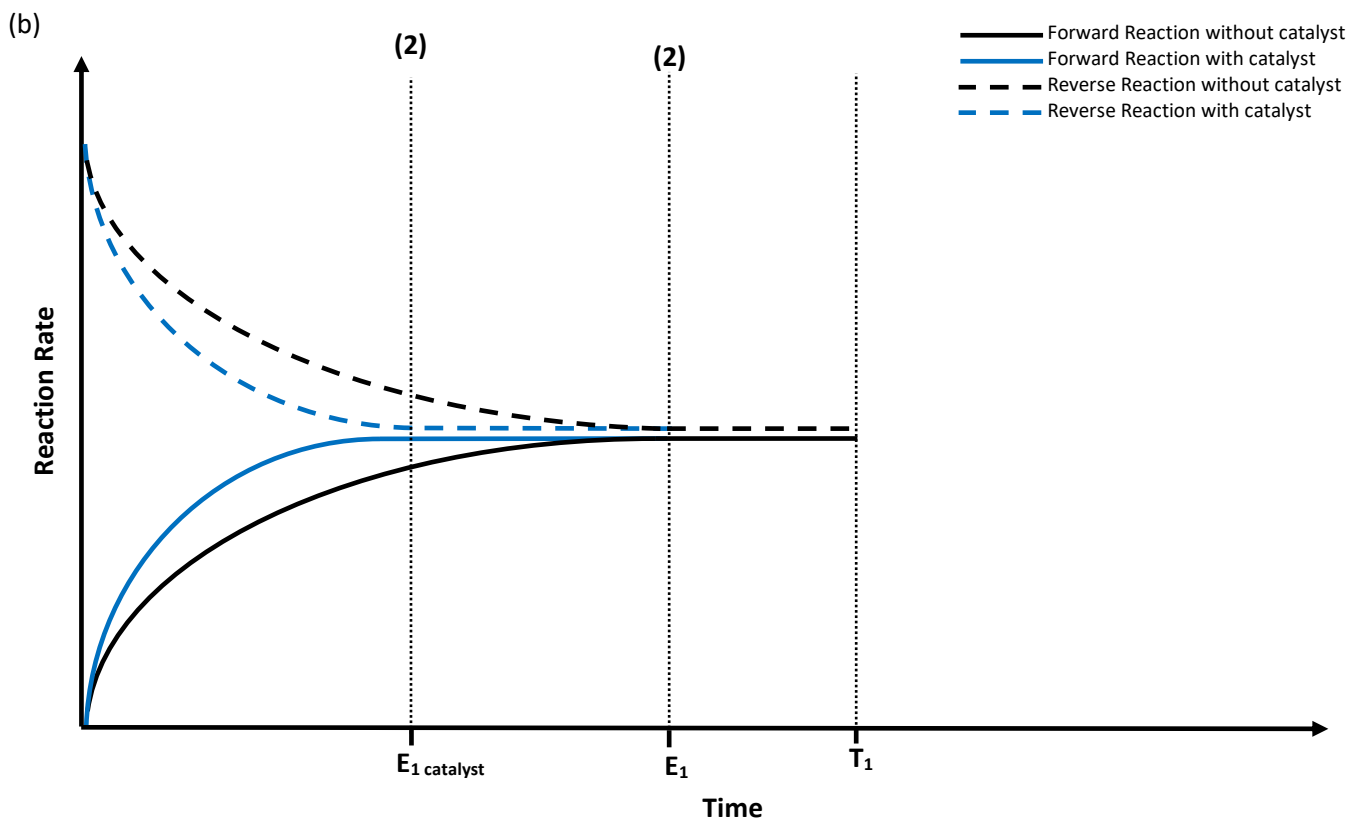
Concentration and reaction rate combination questions (WACE exam level): Q7, Q8 & Q9

7.

[11 marks]



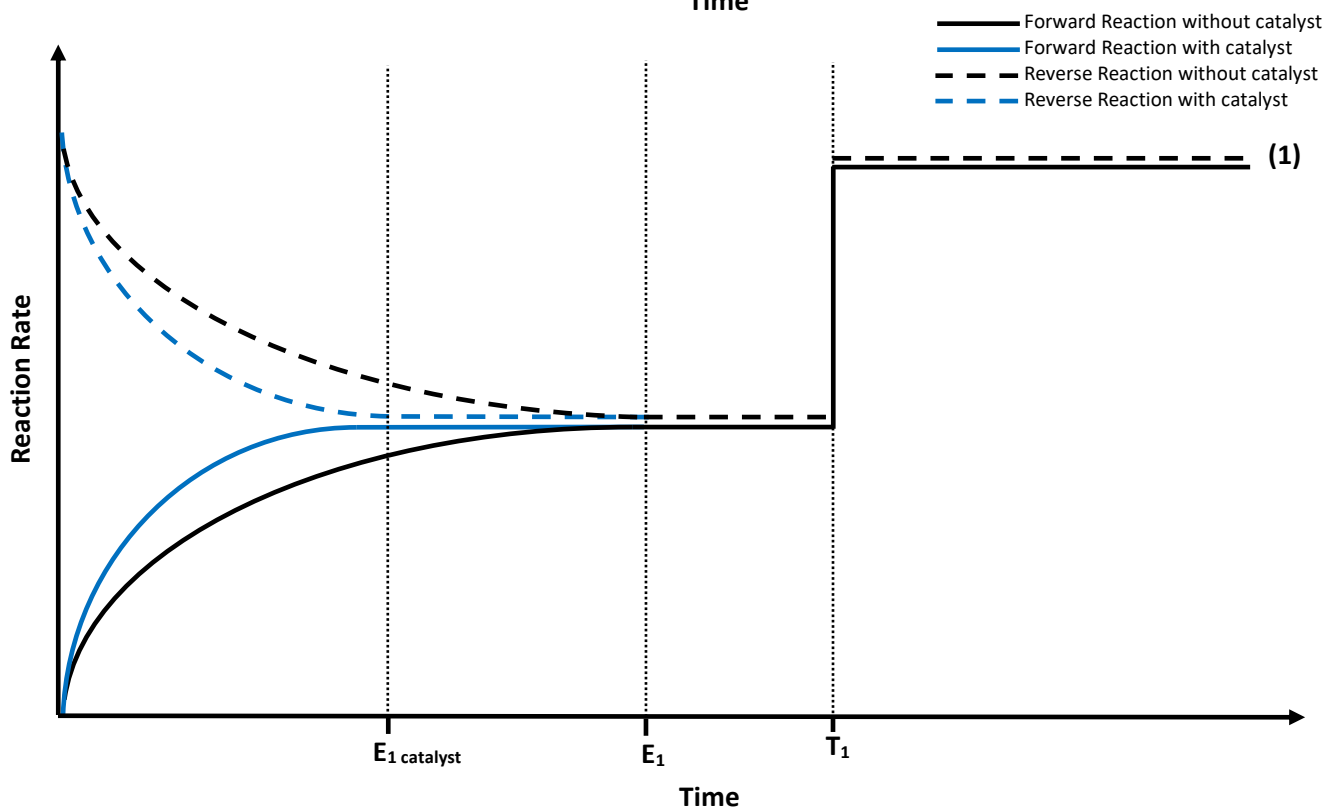
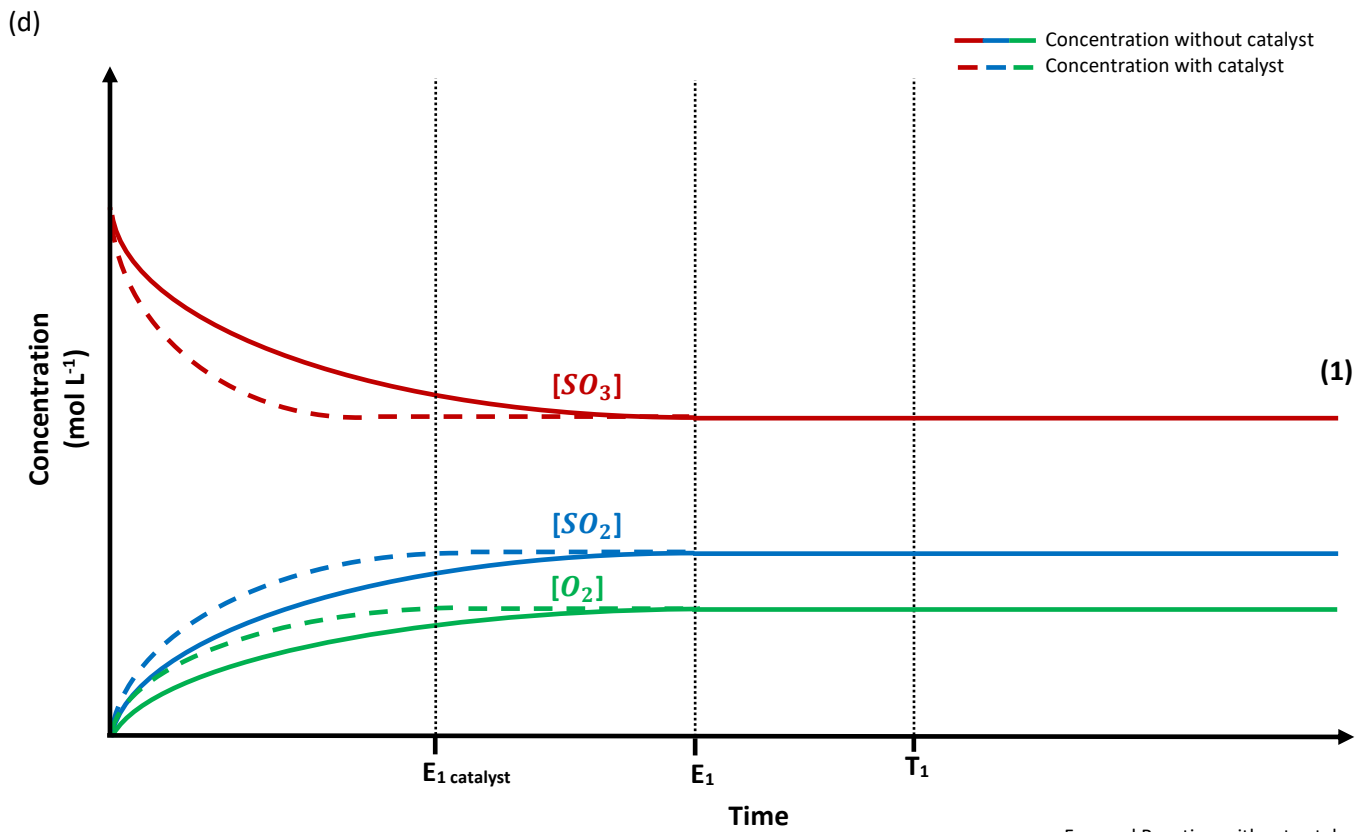
Marking Criteria	Marks Allocated
<b>Catalyst absent concentration curves:</b> <ul style="list-style-type: none"> <li>• Correct curvature and orientation of all curves, with [SO<sub>2</sub>] and [O<sub>2</sub>] starting from a zero concentration</li> <li>• All curves reach equilibrium at E<sub>1</sub></li> </ul>	1 – 2
<b>Catalyst concentration curves</b> <ul style="list-style-type: none"> <li>• Correct orientation and shape of all curves, with [SO<sub>2</sub>] and [O<sub>2</sub>] starting from a zero concentration</li> <li>• All curves reach equilibrium at E<sub>1 catalyst</sub></li> </ul>	1 – 2
<b>Total</b>	<b>4</b>
Note: Deduct one mark for not maintaining 1:2:2 ratio and deduct one mark if no legend is used	



Marking Criteria	Marks Allocated
<b>Catalyst absent concentration curves:</b> <ul style="list-style-type: none"> <li>• Correct orientation and shape of both curves, with forward reaction rate starting from zero</li> <li>• Both curves re-join to reach equilibrium at <math>E_1</math></li> </ul>	1 – 2
<b>Catalyst concentration curves</b> <ul style="list-style-type: none"> <li>• Correct orientation and shape of both curves, with catalysed forward reaction rate starting from zero</li> <li>• Both curves re-join to reach equilibrium at <math>E_{1 \text{ catalyst}}</math></li> </ul>	1 – 2
<b>Total</b>	<b>4</b>
Note: Deduct one mark if no legend is used	

(c) Vanadium oxide has the molecular formula of  $V_2O_5$

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Correct molecular formula of <math>V_2O_5</math></li> </ul>	1
<b>Total</b>	<b>1</b>



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Correct continuation of horizontal concentration lines for concentration graph</li> <li>• Correct spike and then horizontal continuation for reaction rate graph</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

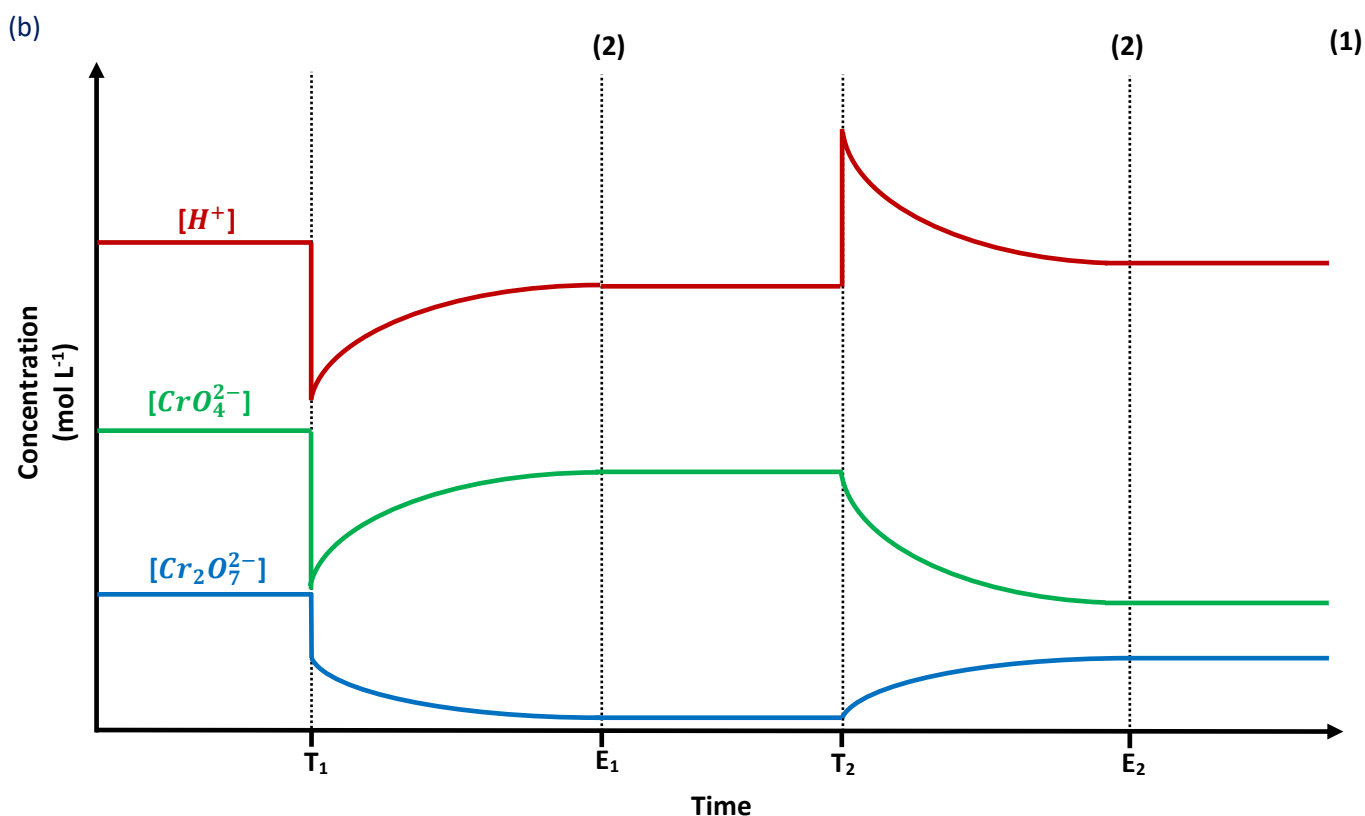


8.

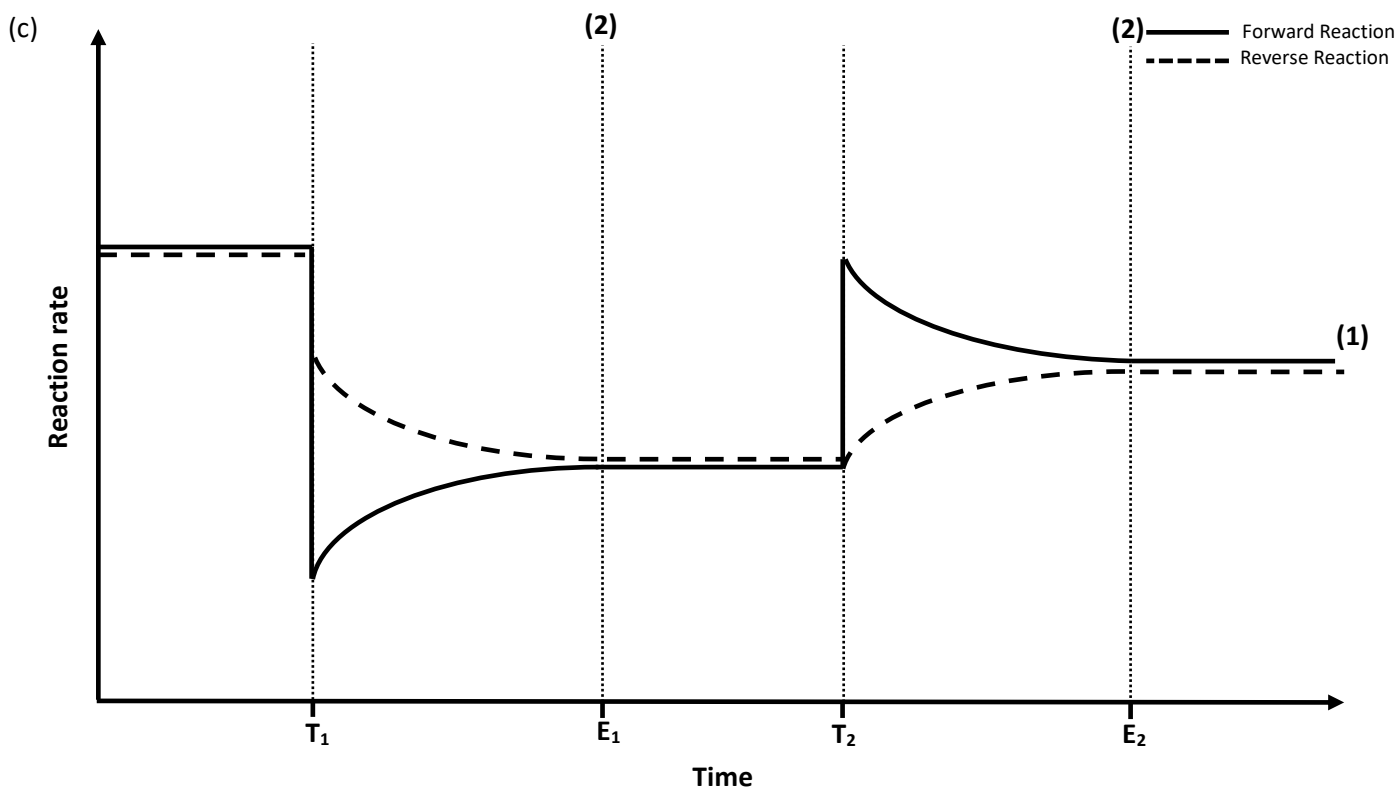
[16 marks]

(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
<ul style="list-style-type: none"> <li>Water should not be included on the concentration graph</li> <li>Solids and liquids will always maintain a constant concentration, so there is no reason to include them</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>



Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in all curves, proportional to 2:2:1 ratio</li> <li>Correct curvature and orientation of all curves to reach equilibrium at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike in the concentration of <math>H^+</math></li> <li>Correct curvature and orientation of all curves to reach equilibrium at <math>E_2</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math> and <math>E_2</math> onwards</li> </ul>	1
<b>Total</b>	<b>5</b>
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	



Marking Criteria	Marks Allocated
<b>From T<sub>1</sub> to E<sub>1</sub>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in both curves, however greater drop for the forward reaction curve at T<sub>1</sub></li> <li>Correct curvature and orientation of both curves to re-join at E<sub>1</sub></li> </ul>	1 – 2
<b>From T<sub>2</sub> to E<sub>2</sub>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike in the forward reaction curve at T<sub>2</sub></li> <li>Correct curvature and orientation of both curves to re-join at E<sub>2</sub></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from T<sub>0</sub> to T<sub>1</sub>, E<sub>1</sub> to T<sub>2</sub> and E<sub>2</sub> onwards</li> </ul>	1
<b>Total</b>	<b>5</b>
Note: Deduct one mark for any missing/incorrect labels of T <sub>1</sub> , E <sub>1</sub> , axis labels etc.	

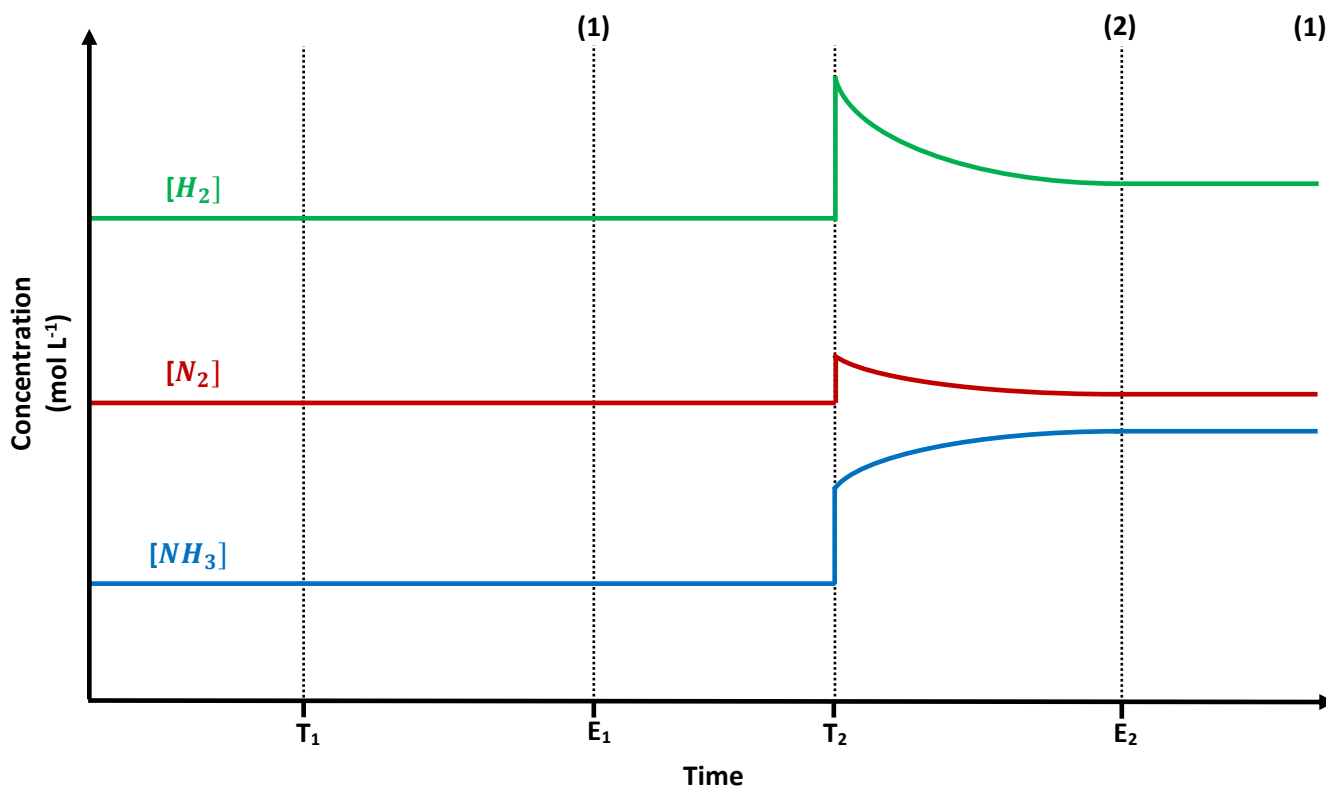
(d) At T<sub>1</sub> when the water is added, the solution will go from a yellow colour to a lighter yellow colour, since there will be a concentration drop of all ions (1). As shown in the rate graph, this will produce a net reverse reaction which over time will increase the chromate ion ( $CrO_4^{2-}$ ) concentration turning the solution back to a yellow colour that is lighter than it was initially (1). At T<sub>2</sub> 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
<b>Changes at T<sub>1</sub>:</b> <ul style="list-style-type: none"> <li>When water is added, solution will turn to a light yellow from concentration drop</li> <li>A net reverse reaction will produce more chromate ions, to turn it to a lighter yellow colour than it was initially</li> </ul>	1 – 2

<b>Changes at <math>T_2</math>:</b>	
<ul style="list-style-type: none"> <li>Increasing the hydrogen ion concentration will create a net forward reaction, producing more dichromate ions and consuming some chromate ions</li> <li>This will turn the solution to a more orangy-yellowish colour</li> </ul>	1 – 2
<b>Total</b>	<b>4</b>
Note: Must reference the concentration and reaction rate graphs at least once each to attain full marks, otherwise deduct 1 – 2 marks	

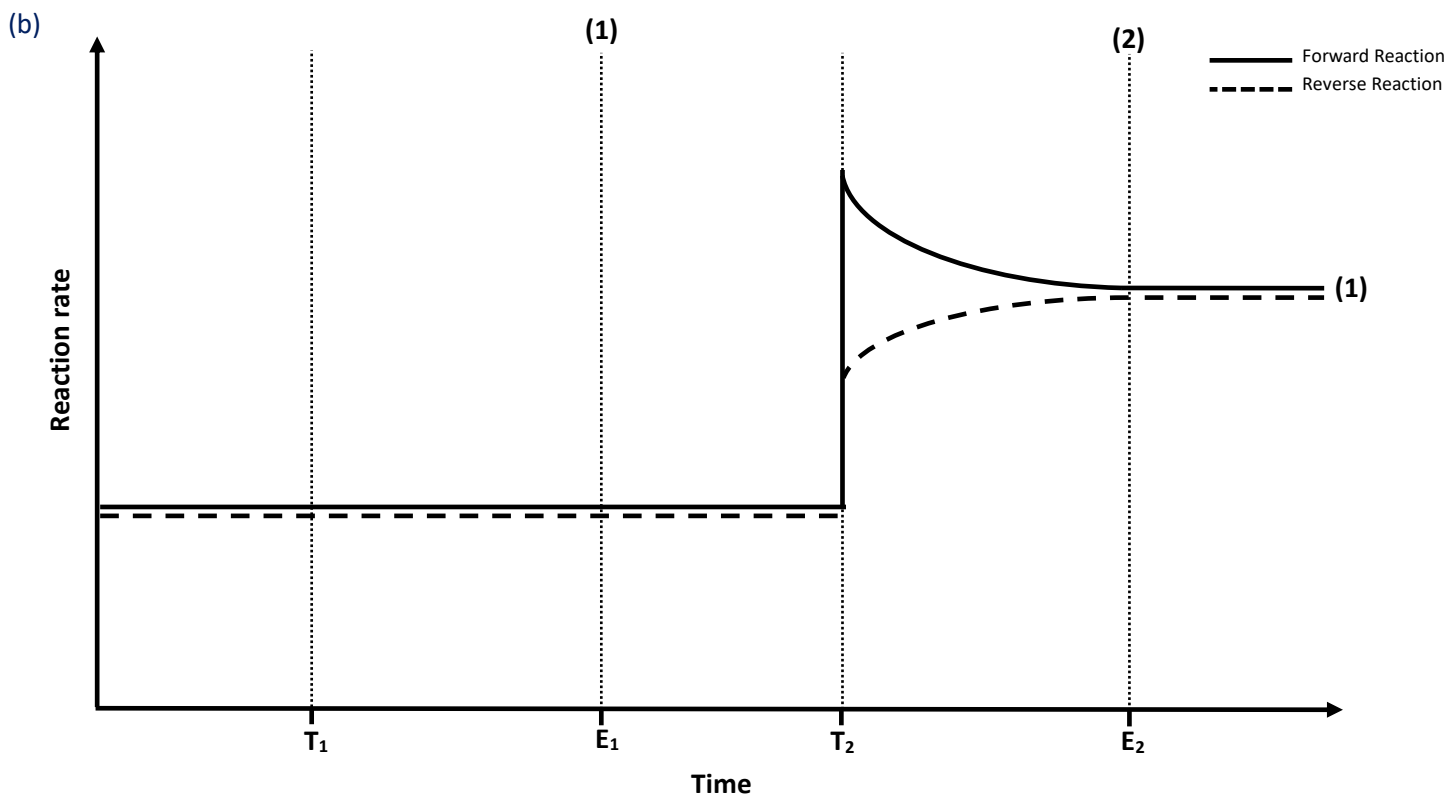
9.

[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
<b>From <math>T_1</math> to <math>E_1</math>:</b>	1
<ul style="list-style-type: none"> <li>Equilibrium lines continued for all curves</li> </ul>	
<b>From <math>T_2</math> to <math>E_2</math>:</b>	1 – 2
<ul style="list-style-type: none"> <li>Instantaneous spike for all curves, maintaining a 1:3:2 ratio</li> <li>Correct curvature and orientation of both curves to re-join at <math>E_2</math></li> </ul>	
<b>Equilibrium lines</b>	1
<ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math> and <math>E_2</math> onwards</li> </ul>	
<b>Total</b>	<b>4</b>
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	

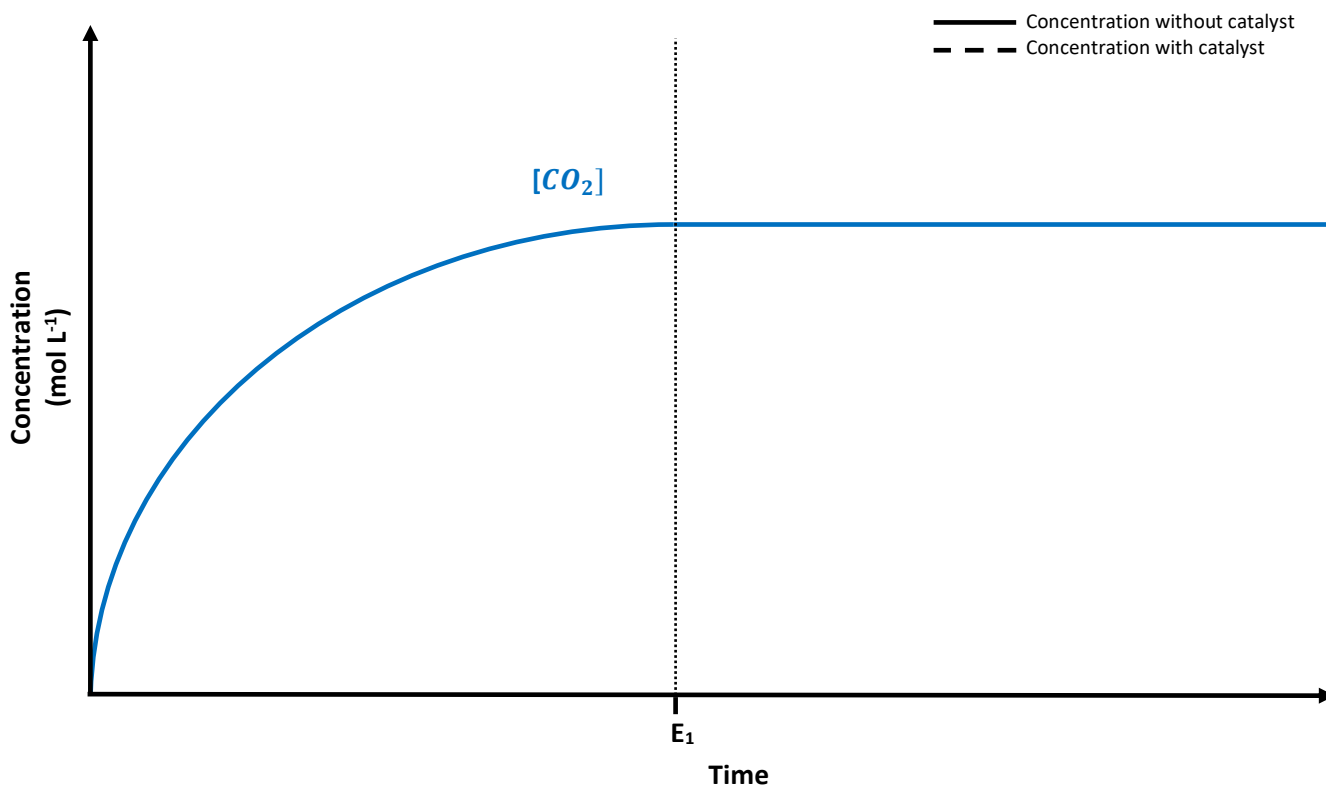


Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Reaction rate lines kept constant</li> </ul>	1
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike in both curves, however greater increase in the forward reaction curve at <math>T_2</math></li> <li>Correct curvature and orientation of both curves to re-join at <math>E_2</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math> and <math>E_2</math> onwards</li> </ul>	1
<b>Total</b>	<b>4</b>
Note: Deduct one mark for any missing/incorrect labels of $T_1$ , $E_1$ , axis labels etc.	

10.

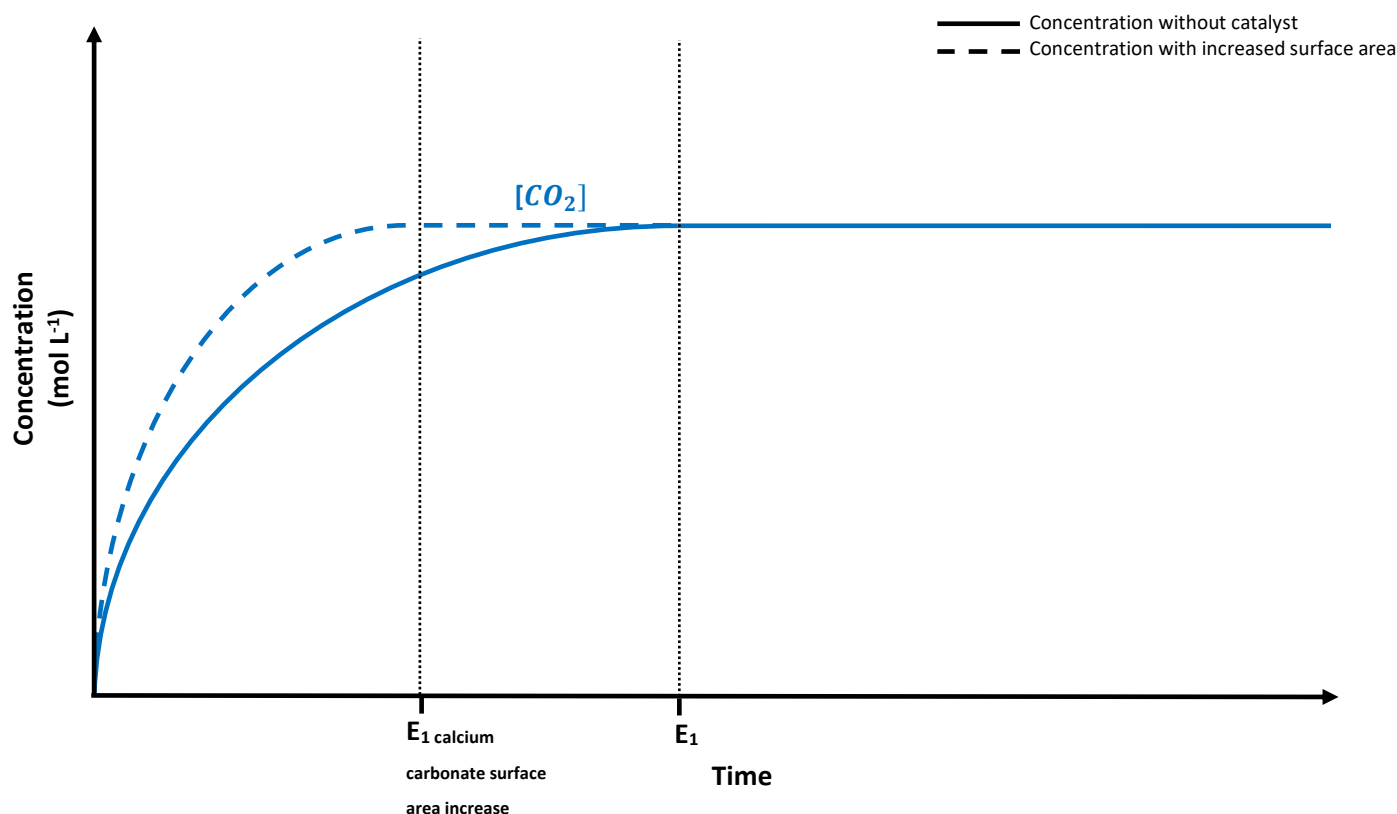
[4 marks]

(a)



Marking Criteria	Marks Allocated
<b>From <math>T_0</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>• Correct curvature and orientation of curve, with <math>[CO_2]</math> starting from a zero concentration</li> <li>• Equilibrium established at <math>E_1</math></li> </ul>	1 – 2
<b>Total</b>	<b>2</b>
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<sub>2</sub> concentration curve.

Marking Criteria	Marks Allocated
<b>From T<sub>0</sub> to E<sub>1</sub>:</b> <ul style="list-style-type: none"><li>• Correct curvature and orientation of surface area curve</li><li>• Equilibrium established at E<sub>1</sub> calcium carbonate surface area increase</li></ul>	1 – 2
<b>Total</b>	<b>2</b>
Note: Deduct one mark for any missing/incorrect labels of T <sub>1</sub> , E <sub>1</sub> , 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
<ul style="list-style-type: none"> <li>Increasing the concentration of atmospheric carbon dioxide will increase the concentration of dissolved carbon dioxide: <math>CO_{2(g)} \rightleftharpoons CO_{2(aq)}</math></li> <li>A increased concentration of dissolved carbon dioxide will shift the equilibrium position for the production of carbonic acid to the right: <math>H_2O_{(l)} + CO_{2(aq)} \rightleftharpoons H_2CO_{3(aq)}</math></li> <li>An increased carbonic acid concentration will shift the equilibrium position for the ionisation of carbonic acid to the right: <math>H_2CO_{3(aq)} + H_2O_{(l)} \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)</math> increasing the hydronium ion concentration</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>An increased hydronium ion concentration will shift the equilibrium position of the second ionisation of carbonic acid to the left: <math>HCO_3^-(aq) + H_2O_{(l)} \rightleftharpoons H_3O^+(aq) + CO_3^{2-}(aq)</math></li> <li>This will consume some of the carbonate ions, thus decreasing the carbonate ion concentration</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(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
<ul style="list-style-type: none"> <li>A decreased carbonate ion concentration will shift equilibrium position of the production of calcium carbonate to the left: <math>Ca^{2+}(aq) + CO_3^{2-}(aq) \rightleftharpoons CaCO_{3(s)}</math></li> <li>This will reduce the amount of calcium carbonate available in our oceans</li> <li>A loss of calcium carbonate makes it harder for coral reefs to gather calcium carbonate particles to form their calcium carbonate bodies</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

# Problem Set 3 – Visualising Chemical Equilibrium

## Progressive Questions

### Concept 1

### Concentration and Reaction Rate Graphs – Repetitive Questions

### Answers

1.1

[9 marks]

(a)

Time ( <i>t</i> )	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	<b>(0.80)</b>
$T_2$	(The temperature is raised)	<b>(1.10)</b>	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
<ul style="list-style-type: none"><li>• Correct determination of <math>[NH_3] = 0.80 \text{ mol L}^{-1}</math> at <math>T_1</math></li><li>• Correct determination of <math>[Cu^{2+}] = 1.10 \text{ mol L}^{-1}</math> at <math>T_2</math></li></ul>	1 – 2
<b>Total</b>	<b>2</b>

(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)**.

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

$$K_c \text{ initially} = \frac{[1.20]}{[0.4][1]^4}$$

$$K_c \text{ initially} = 3$$

$$K_c \text{ after } T_1 = \frac{[1.25]}{[1.02][0.8]^4}$$

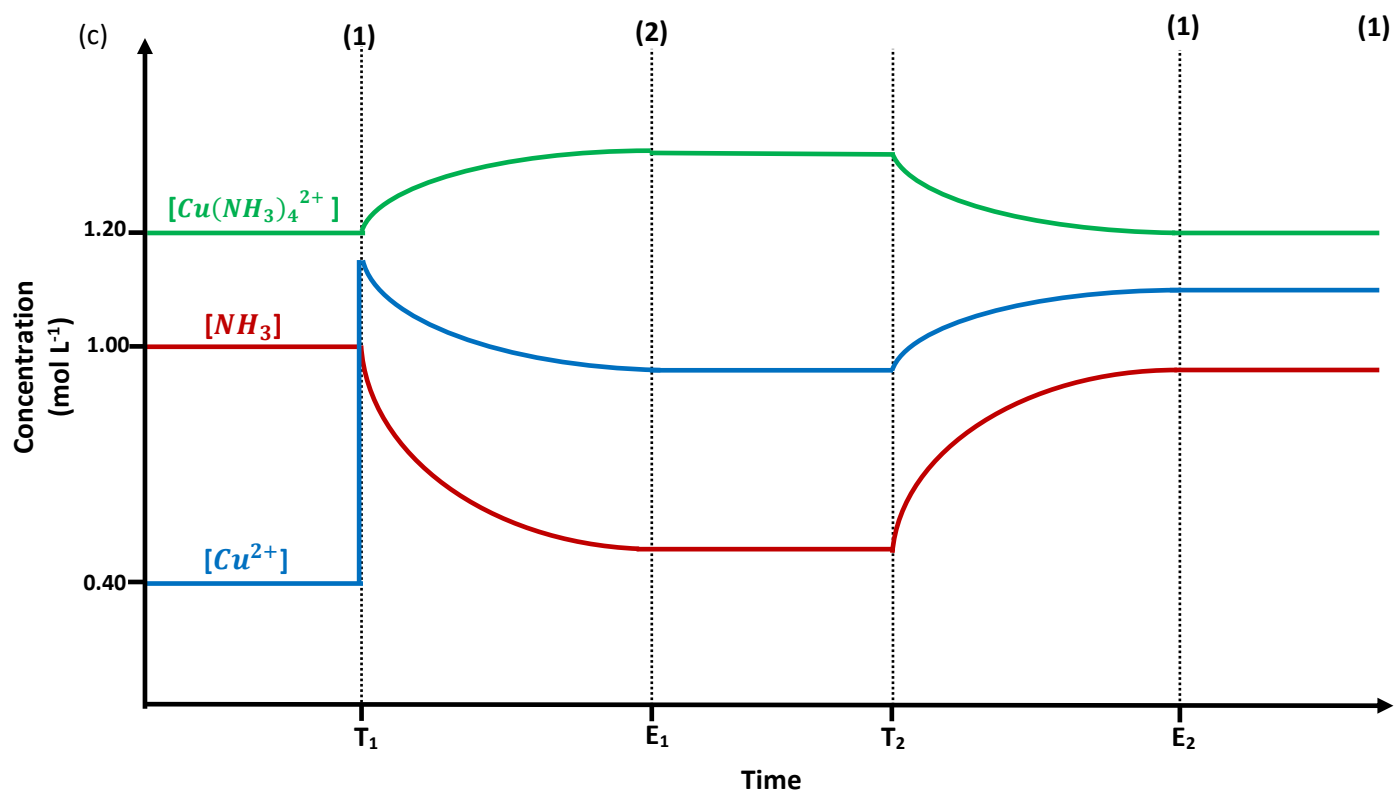
$$K_c \text{ after } T_1 = 3$$

**(1)**

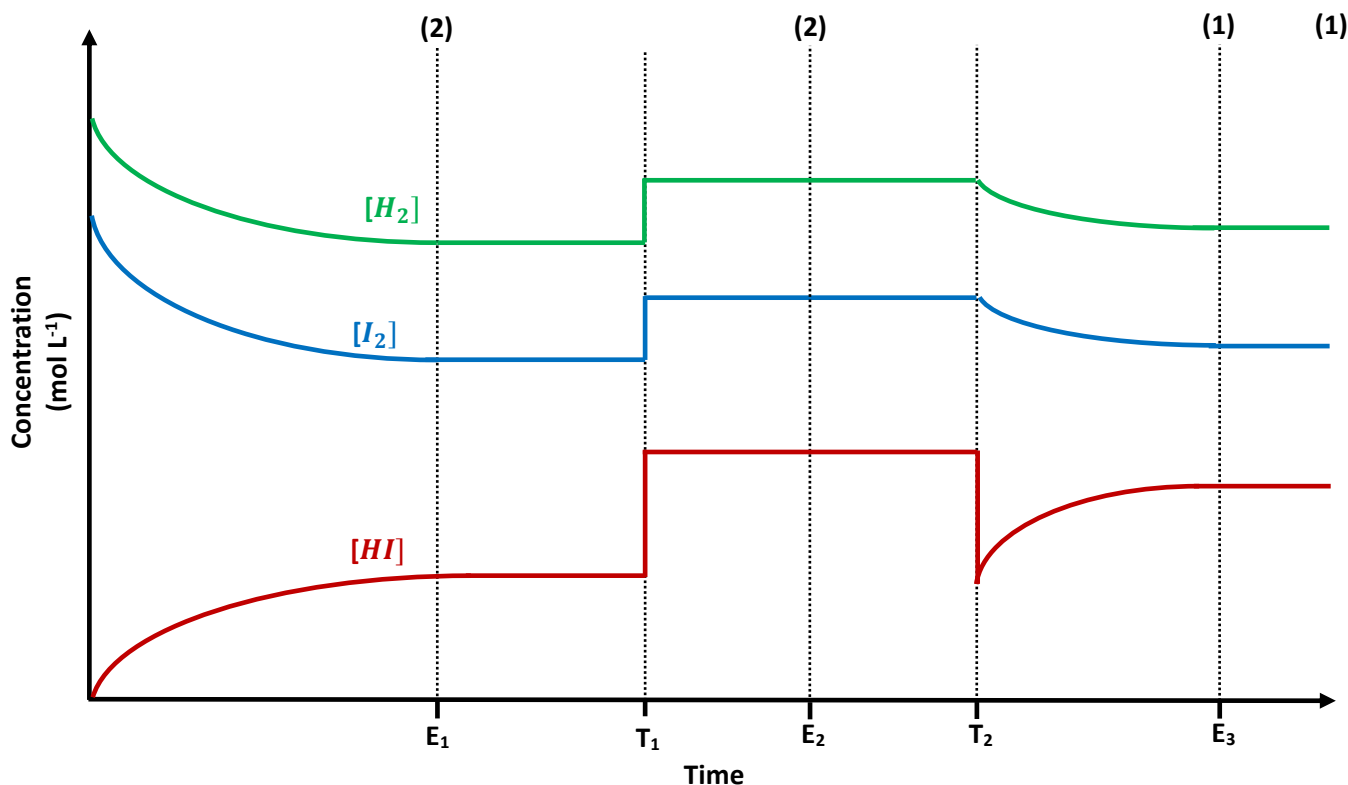
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>• Stating that the <math>K_c</math> values should be equal before and after the change at <math>T_1</math></li><li>• Correct determination that both <math>K_c</math> values equal 3</li></ul>	1 – 2
<b>Total</b>	<b>2</b>

Note: Deduct one mark for any errors made in workings

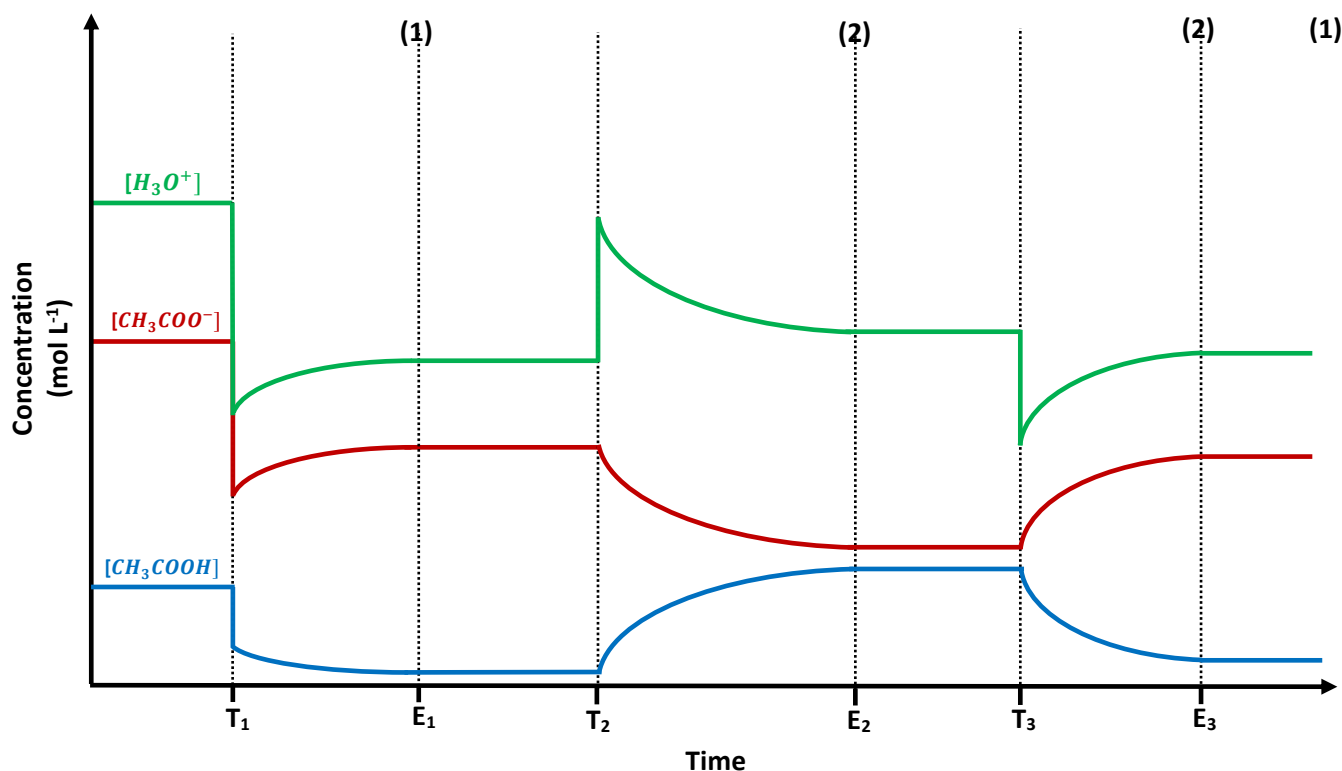




Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike for copper ions at <math>T_1</math></li> <li>Correct curvature and orientation for all curves to reach equilibrium at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Correct curvature and orientation for all curves to reach equilibrium at <math>E_2</math></li> </ul>	1
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math> and <math>E_2</math> onwards</li> </ul>	1
<ul style="list-style-type: none"> <li>Correct concentration labels of <math>[Cu^{2+}_{(aq)}] = 0.40</math>, <math>[NH_{3(aq)}] = 1.00</math>, <math>[Cu(NH_3)_4^{2+}_{(aq)}] = 1.20</math> on the y-axis</li> </ul>	1
<b>Total</b>	<b>5</b>
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	

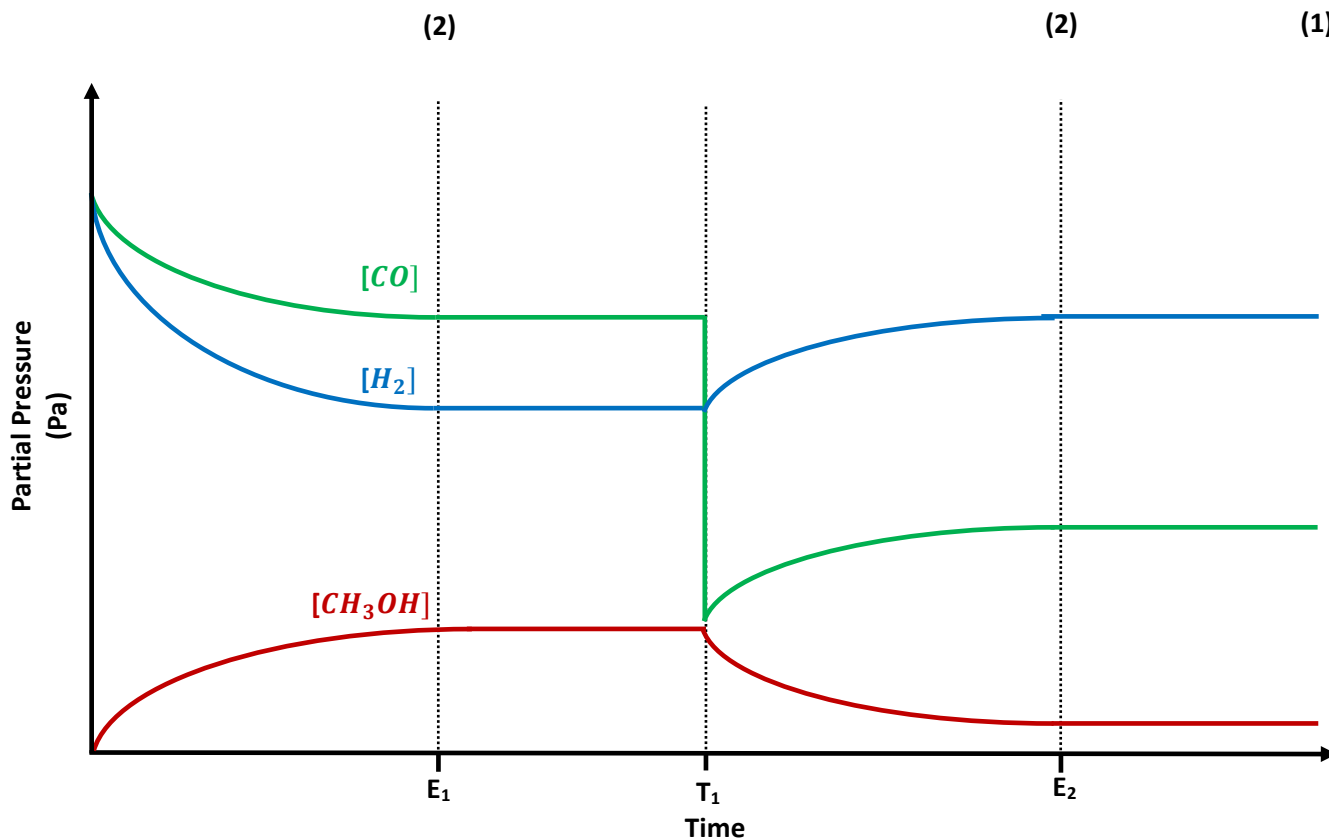


Marking Criteria	Marks Allocated
<b>From T<sub>0</sub> to E<sub>1</sub>:</b> <ul style="list-style-type: none"> <li>• Correct curvature and orientation of all curves, with <math>[HI]</math> starting from a zero concentration</li> <li>• All curves reach equilibrium at E<sub>1</sub></li> </ul>	1 – 2
<b>From T<sub>1</sub> to E<sub>2</sub>:</b> <ul style="list-style-type: none"> <li>• Instantaneous spike for all curves, proportional to 1:1:2 ratio</li> <li>• Continuation of equilibrium lines from T<sub>1</sub> to E<sub>2</sub></li> </ul>	1 – 2
<b>From T<sub>2</sub> to E<sub>3</sub>:</b> <ul style="list-style-type: none"> <li>• Correct curvature and orientation for all curves to reach equilibrium at E<sub>2</sub></li> </ul>	1
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>• Equilibrium lines from E<sub>2</sub> to T<sub>2</sub> and E<sub>3</sub> onwards</li> </ul>	1
<b>Total</b>	<b>6</b>
Note: Deduct one mark for any missing/incorrect labels of T <sub>1</sub> , E <sub>1</sub> , axis labels etc. and for not maintaining a 1:1:2 ratio	

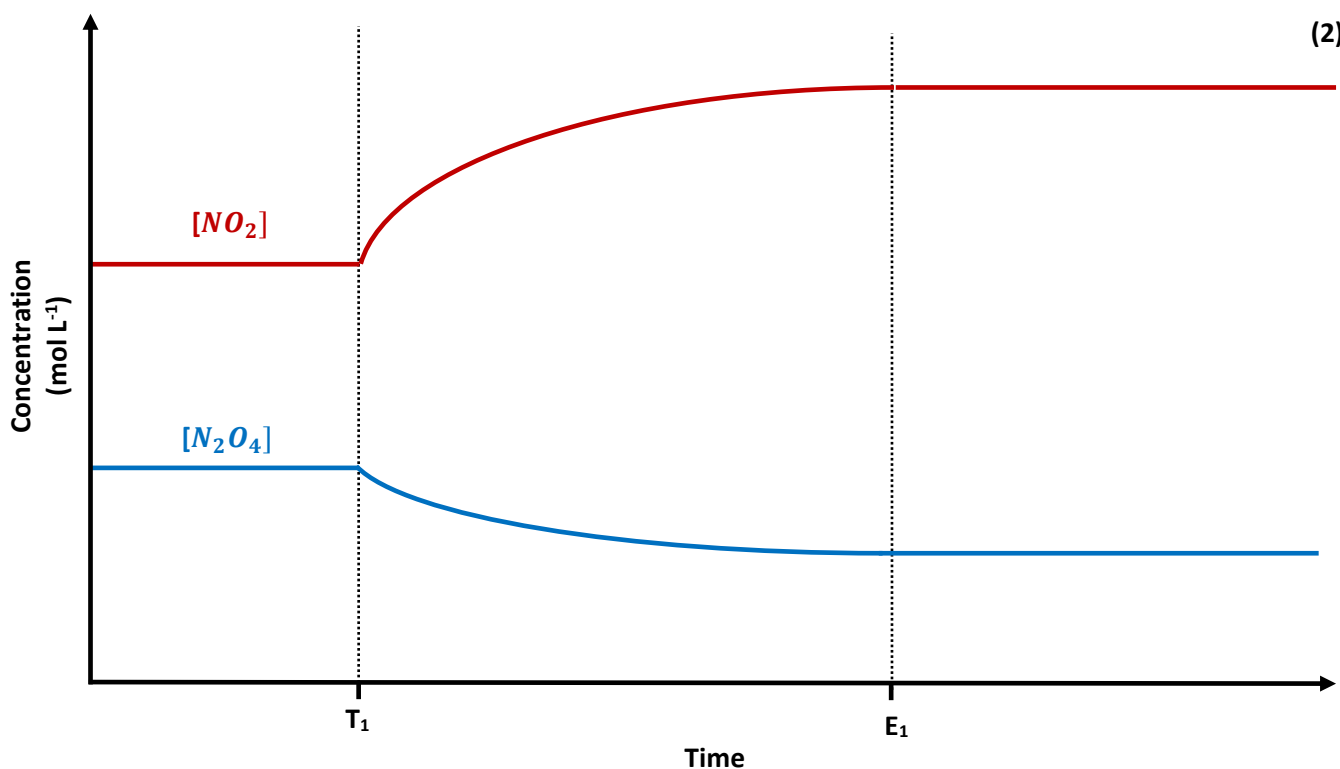


**Points to note:** For change  $T_1$ , when more of the same solution is added, the concentration of the ions will remain unchanged because the solution added has an identical concentration

Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Continuation of all equilibrium lines from <math>T_1</math> to <math>E_1</math></li> </ul>	1
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike in the <math>[H^+]</math> concentration curve at <math>T_2</math></li> <li>Correct curvature and orientation for all curves to reach equilibrium at <math>E_2</math></li> </ul>	1 – 2
<b>From <math>T_3</math> to <math>E_3</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in all concentration curves at <math>T_3</math>, proportional to 1:1:1 ratio</li> <li>Correct curvature and orientation for all curves to reach equilibrium at <math>E_3</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math> and <math>E_3</math> onwards</li> </ul>	1
<b>Total</b>	<b>6</b>
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	



Marking Criteria	Marks Allocated
<b>From <math>T_0</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>• Correct curvature and orientation of all curves, with <math>[CH_3OH]</math> starting from a zero concentration</li> <li>• All curves reach equilibrium at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_1</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>• Instantaneous drop in the <math>[CO]</math> concentration curve at <math>T_1</math></li> <li>• Correct curvature and orientation for all curves to reach equilibrium at <math>E_2</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>• Equilibrium lines from <math>E_1</math> to <math>T_1</math> and <math>E_2</math> onwards</li> </ul>	1
<b>Total</b>	<b>5</b>
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'	



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)**.

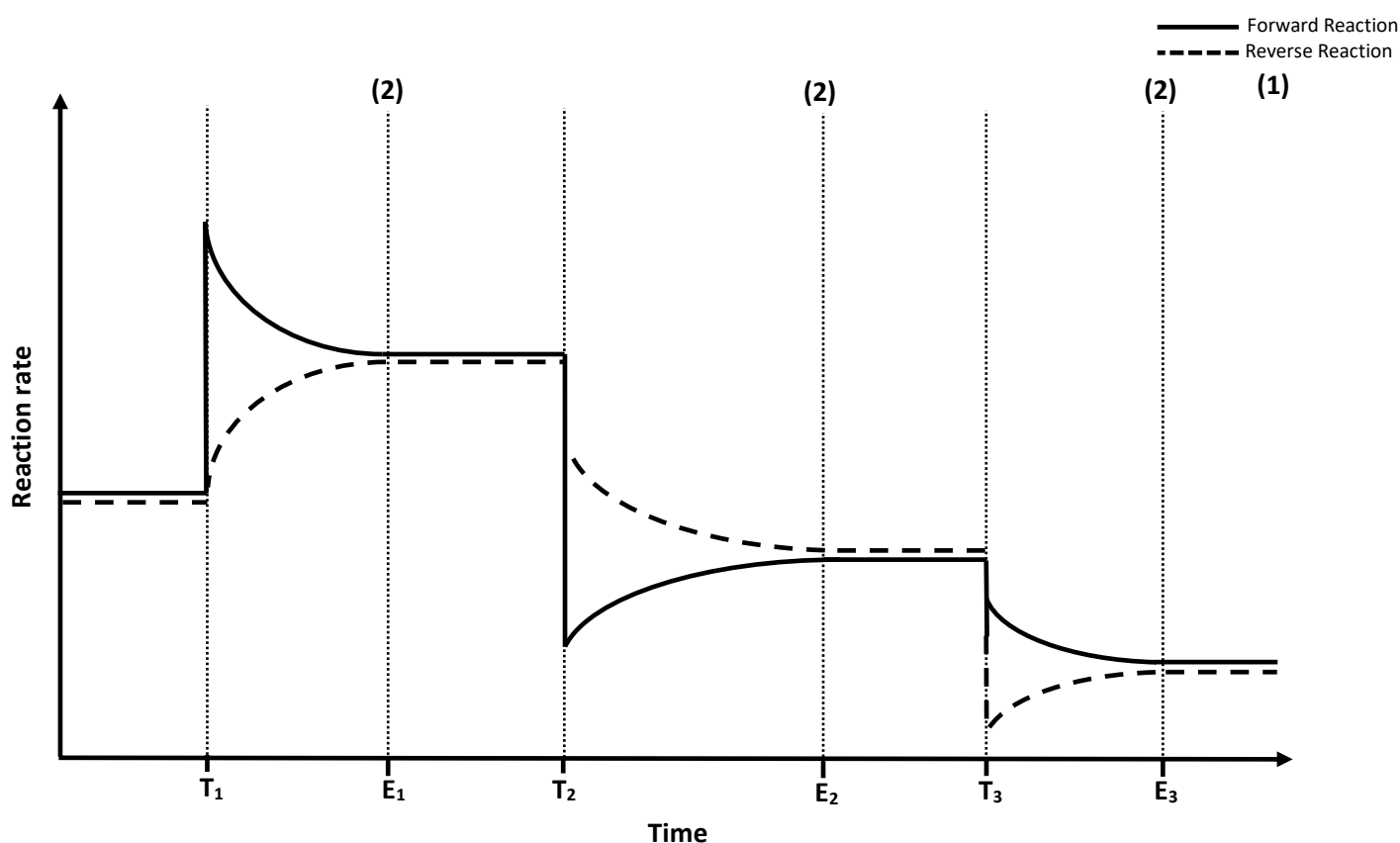
Marking Criteria	Marks Allocated
<b>Concentration curve</b> <ul style="list-style-type: none"> <li>• Correct curvature and orientation of curves from <math>T_1</math> to <math>E_1</math></li> <li>• Equilibrium from <math>T_0</math> to <math>T_1</math> and <math>E_1</math> onwards</li> </ul>	1 – 2
<b>Explanation:</b> <ul style="list-style-type: none"> <li>• Reference to the concentration graph, that <math>NO_2</math> increases and the <math>N_2O_4</math> decreases</li> <li>• Correct conclusion that the forward reaction is favoured</li> </ul>	1 – 2
<b>Total</b>	<b>4</b>

(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
<ul style="list-style-type: none"> <li>• 1 mark for each change stated correctly to <math>T_1</math>, <math>T_2</math> and <math>T_3</math></li> </ul>	1 – 3
<b>Total</b>	<b>3</b>



Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>• Instantaneous spike of forward reaction curve at <math>T_1</math></li> <li>• Correct curvature and orientation for all curves to re-join at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>• Instantaneous drop in both curves at <math>T_2</math>, however a greater drop in the forward reaction curve</li> <li>• Correct curvature and orientation for all curves to re-join at <math>E_2</math></li> </ul>	1 – 2
<b>From <math>T_3</math> to <math>E_3</math>:</b> <ul style="list-style-type: none"> <li>• Instantaneous drop in both curves at <math>T_3</math>, however a greater drop in the reverse reaction curve</li> <li>• Correct curvature and orientation for all curves to re-join at <math>E_3</math></li> </ul>	1 – 2

<b>Equilibrium lines</b>	1
<ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math>, <math>E_2</math> to <math>T_3</math> and <math>E_3</math> onwards</li> </ul>	
<b>Total</b>	<b>7</b>

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
<ul style="list-style-type: none"> <li>1 mark for each imposed change stated correctly</li> </ul>	1 – 3
<ul style="list-style-type: none"> <li>1 mark for each appropriate explanation given. Cannot simply re-state the changes shown on the graph</li> </ul>	1 – 3
<b>Total</b>	<b>6</b>

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
<ul style="list-style-type: none"> <li>Stating <math>T_3</math> is the time a catalyst was added to the system</li> </ul>	1
<b>Total</b>	<b>1</b>

(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
<ul style="list-style-type: none"> <li>The addition of a catalyst will create an equal instantaneous spike both reaction rates, which is shown at <math>T_3</math></li> </ul>	1 – 2

<ul style="list-style-type: none"> <li>The addition of a catalyst will also create no net forward or reverse reaction that follows from this instantaneous spike, which is shown at <math>T_3</math></li> </ul>	
<b>Total</b>	<b>2</b>

(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 six distinctive points and so on...

Marking Criteria	Marks Allocated
<b>At <math>T_1</math>:</b> <ul style="list-style-type: none"> <li>Temperature decrease</li> <li>Increase in the system volume</li> <li>Addition of an inert gas at constant pressure</li> </ul>	1 – 3
<b>At <math>T_2</math>:</b> <ul style="list-style-type: none"> <li>Addition of an inert gas at constant volume</li> </ul>	1
<b>At <math>T_4</math>:</b> <ul style="list-style-type: none"> <li>Removal of carbon dioxide gas</li> <li>Removal of hydrogen gas</li> </ul>	1 – 2
<b>Total</b>	<b>6</b>

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
<ul style="list-style-type: none"> <li>Stating <math>T_4</math> is the time a catalyst was added to the system</li> </ul>	1



<b>Total</b>	<b>1</b>
--------------	----------

(e) When a catalyst is added to the system, on a concentration graph this will be 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
<ul style="list-style-type: none"> <li>The addition of catalyst will have no effect on the concentration curves and will keep the system continuing in equilibrium, which is shown at <math>T_3</math></li> </ul>	1
<b>Total</b>	<b>1</b>

(f)

- At  $T_1$ : this represents an increase in the temperature **(1)**
- At  $T_2$ : this represents the doubling of the system's 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)**

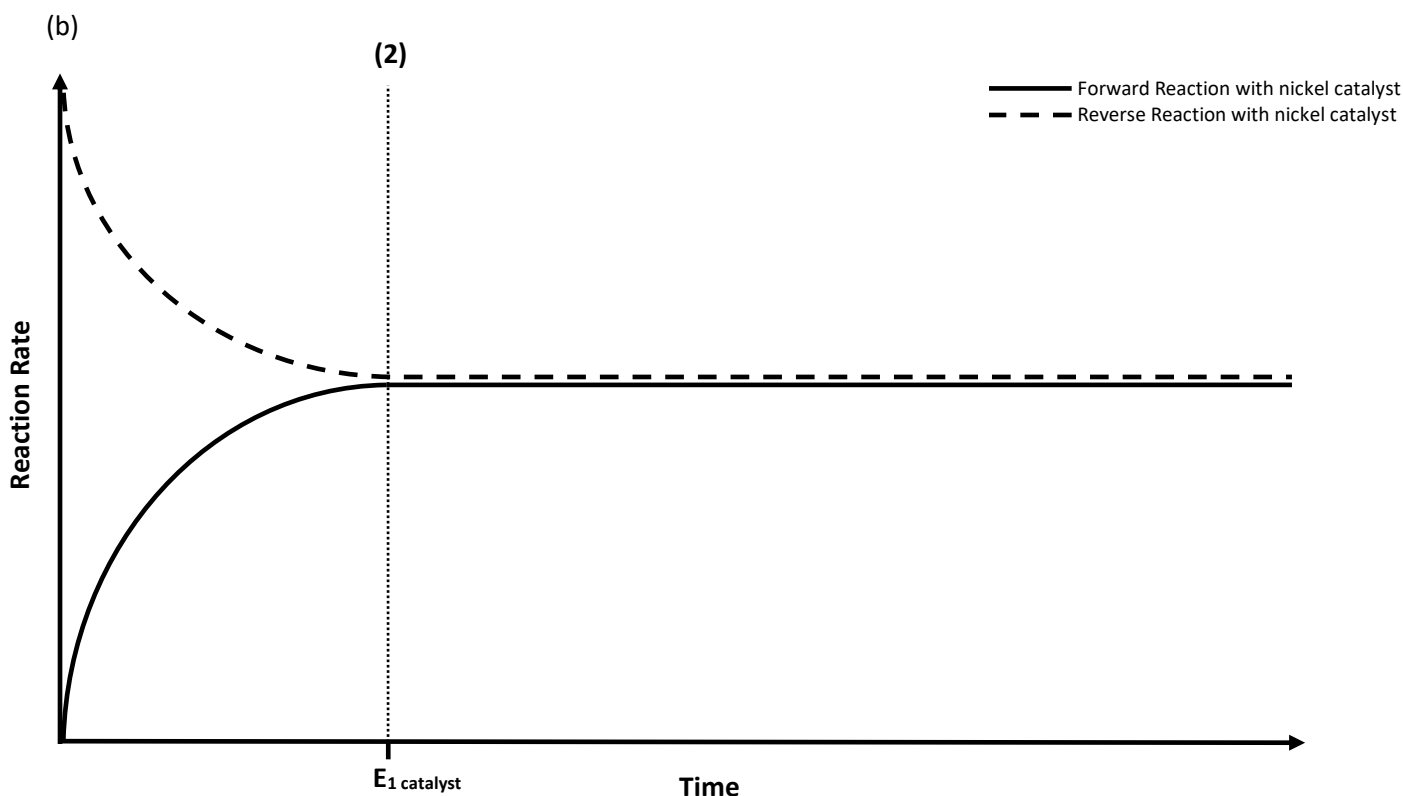
**Points to note:** again for ensuring you get full marks for this section, it is a good idea to use the process of . To explain each of the changes for any assistance:

- 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
<b>At <math>T_1</math>:</b> <ul style="list-style-type: none"> <li>Temperature increase</li> </ul>	1
<b>At <math>T_2</math>:</b> <ul style="list-style-type: none"> <li>Doubling the volume of the system</li> <li>Addition of an inert gas at constant pressure to double the system volume</li> </ul>	1 – 2
<b>At <math>T_4</math>:</b> <ul style="list-style-type: none"> <li>Addition of methane gas (<math>CH_4</math>)</li> </ul>	1
<b>Total</b>	<b>4</b>
Note: deduct one mark at $T_2$ if no mention has been made that both changes have doubled the volume of the system	

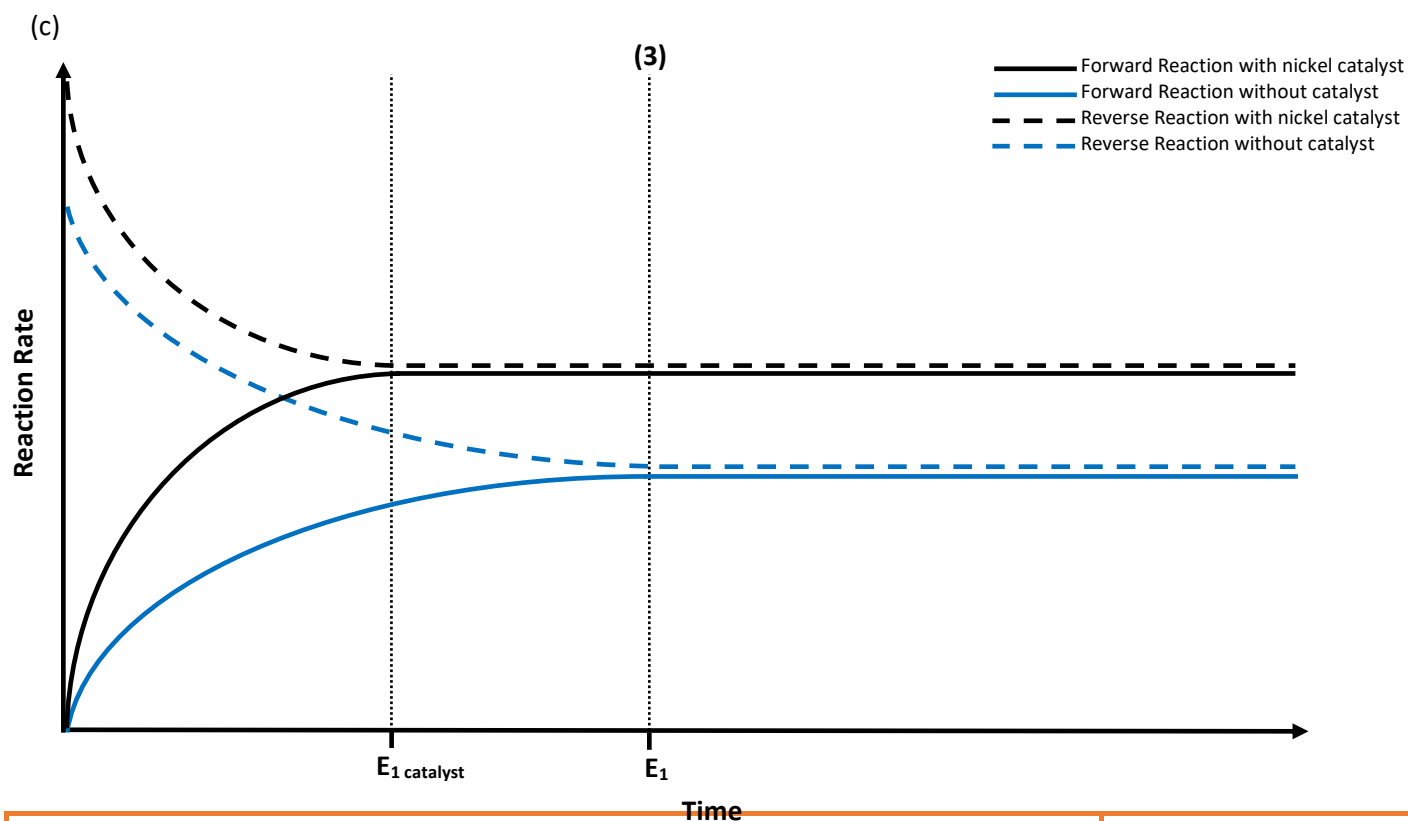
(a) 15,500kPa

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correct pressure of 15,500kPa stated</li> </ul>	1
<b>Total</b>	<b>1</b>



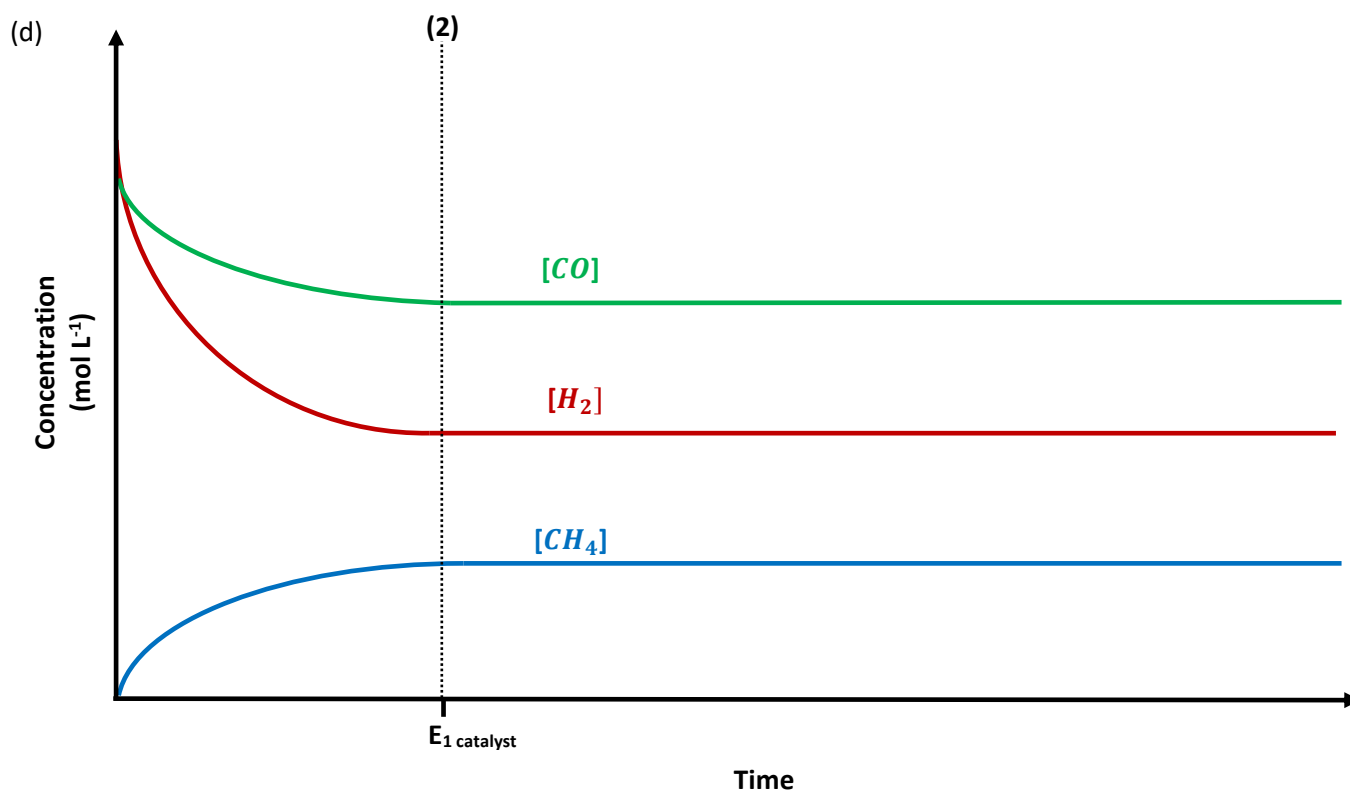
Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_{1 \text{ catalyst}}</math>:</b> <ul style="list-style-type: none"> <li>Forward reaction curve starting at a zero reaction rate</li> <li>Correct curvature and orientation for both curves to join at <math>E_{1 \text{ catalyst}}</math></li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

Note: Deduct one mark for any missing/incorrect labels of  $T_1$ ,  $E_{1 \text{ catalyst}}$ , axis labels etc.



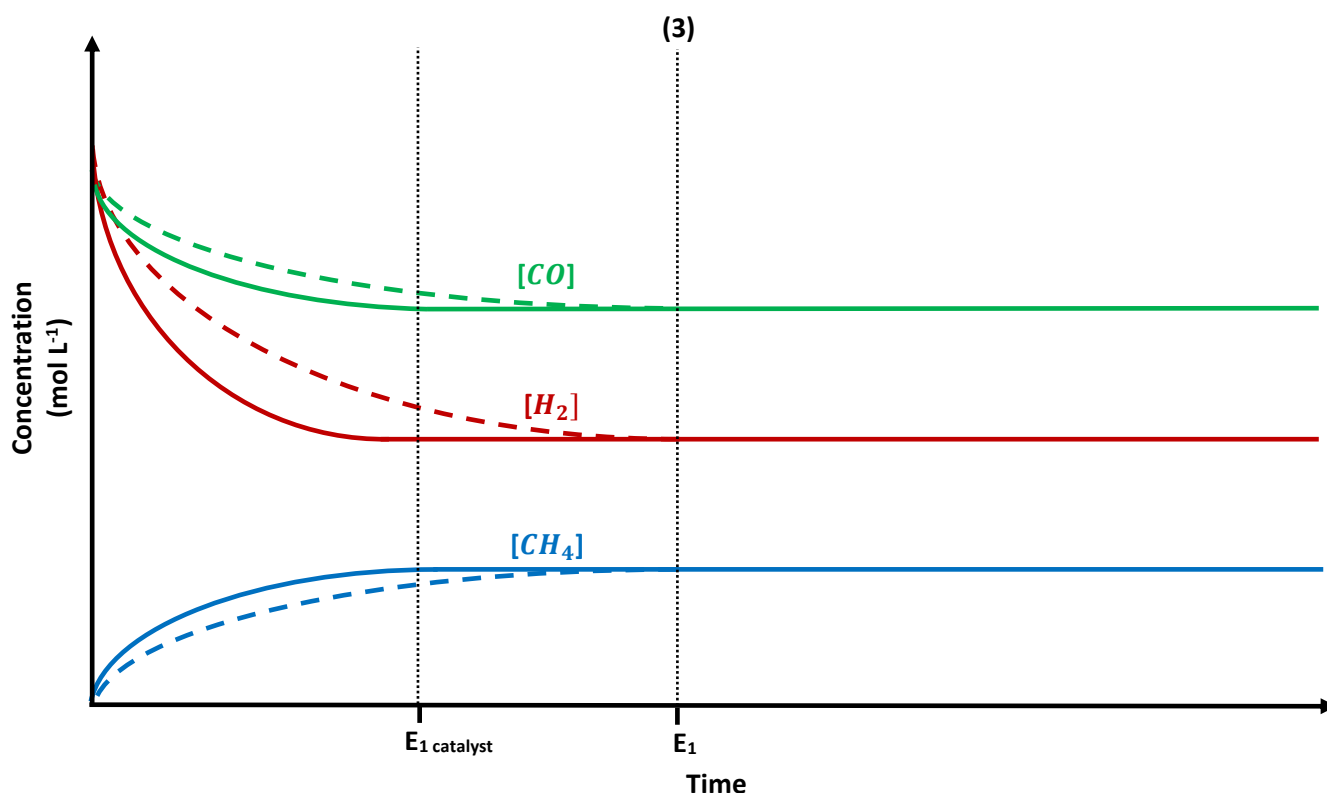
Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>• Equilibrium established at a later point than <math>E_{1 \text{ catalyst}}</math></li> <li>• Equilibrium reaction rate lower than that of the catalysed reaction rate</li> <li>• Correct curvature and orientation for all curves to join at <math>E_1</math></li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

Note: Deduct one mark for any missing/incorrect labels of  $T_1$ ,  $E_{1 \text{ catalyst}}$ , axis labels etc.



Marking Criteria	Marks Allocated
<b>From <math>T_0</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Correct curvature and orientation of all curves, with <math>[CH_4]</math> starting from a zero concentration</li> <li>All curves reach equilibrium at <math>E_{1 \text{ catalyst}}</math></li> </ul>	1 – 2
<b>Total</b>	<b>2</b>
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)



Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Equilibrium established at a later point than <math>E_{1 \text{ catalyst}}</math></li> <li>All concentration curves reach the same concentration as the catalysed concentration curves</li> <li>Correct curvature and orientation of all curves to establish equilibrium at <math>E_1</math></li> </ul>	1 – 3
<b>Total</b>	<b>3</b>
Note: Deduct one mark for any missing/incorrect labels of $T_1$ , $E_{1 \text{ catalyst}}$ , 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
<ul style="list-style-type: none"> <li>The addition of a catalyst will cause both rates to instantaneously increase equally with no net forward or reverse reaction created</li> <li>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</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(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
<ul style="list-style-type: none"> <li>The addition of a catalyst will have no effect on the concentration curves</li> <li>A temperature increase will cause the reacting species to increase/decrease as a result of a net endothermic reaction</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

1.8

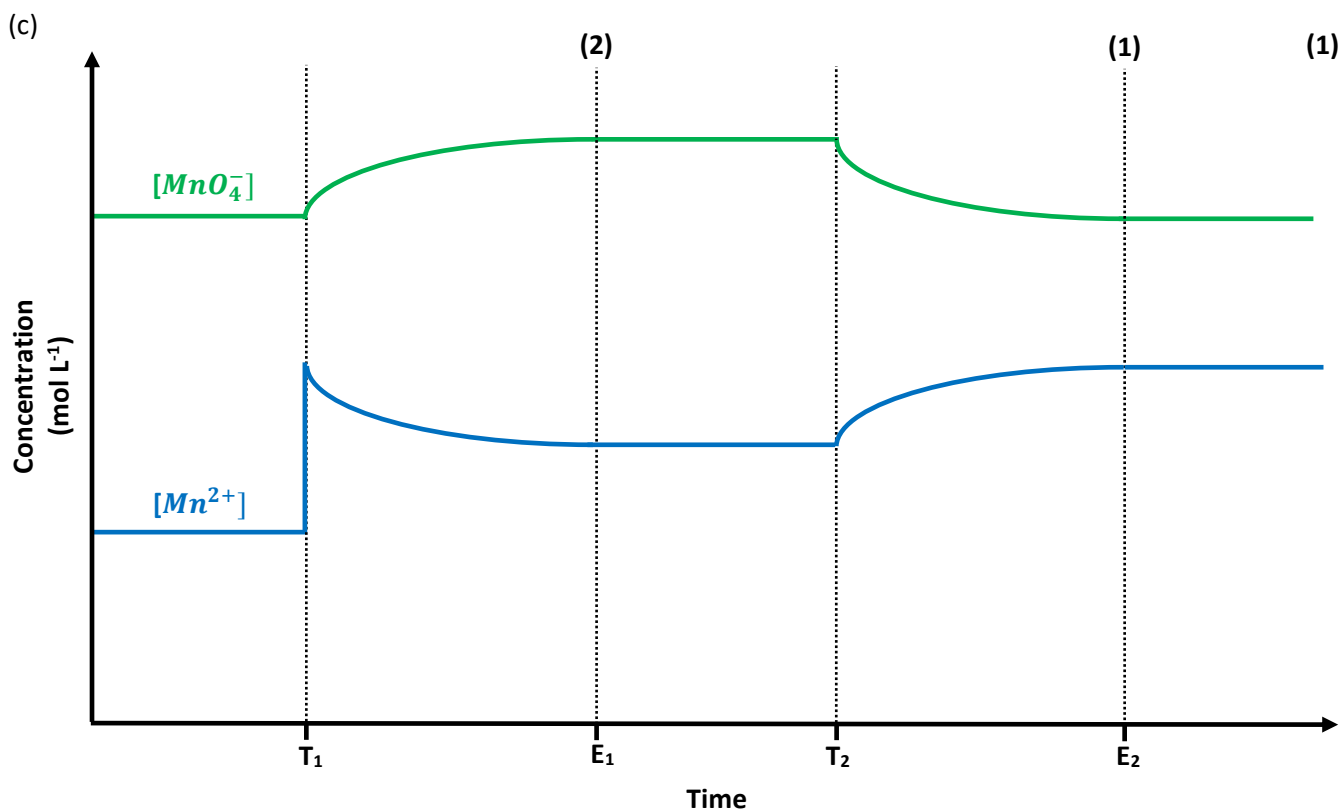
[11 marks]

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

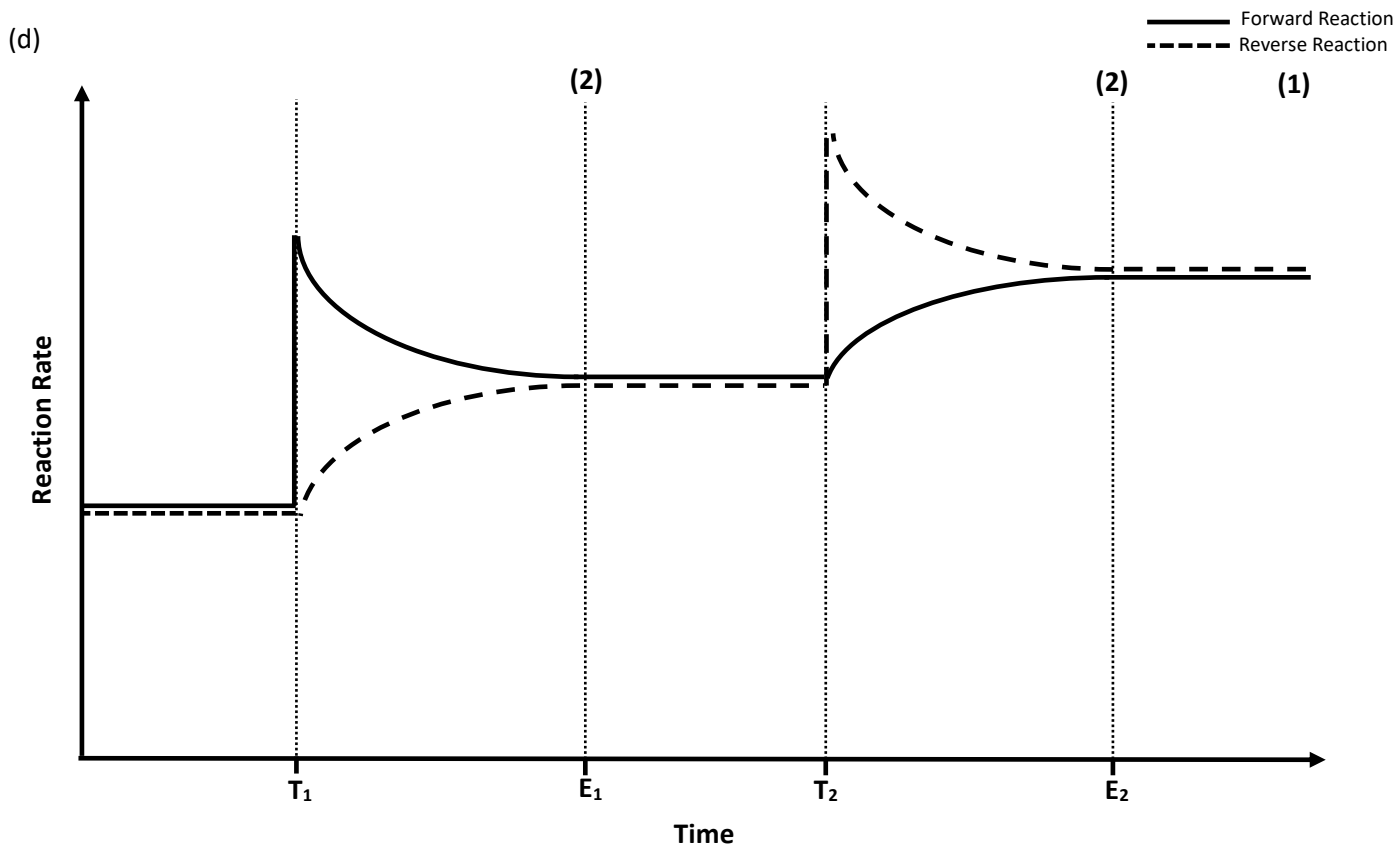
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correct statement that manganese ions are added or a solution containing manganese ions is added</li> </ul>	1
<b>Total</b>	<b>1</b>

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

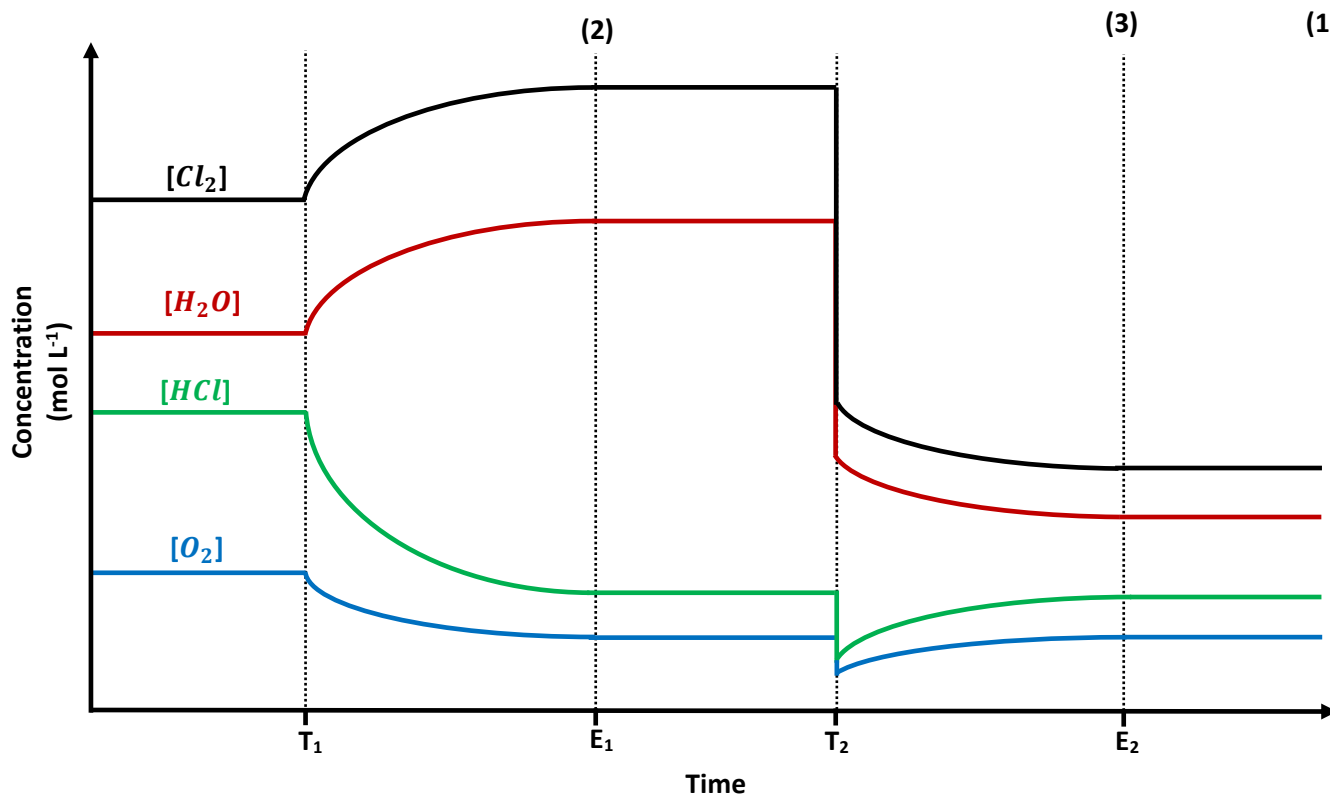
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correct statement that iron (II) ions are added or a solution containing iron (II) ions is added</li> </ul>	1
<b>Total</b>	<b>1</b>



Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike in the <math>[Mn^{2+}]</math> concentration curve at <math>T_1</math></li> <li>Correct curvature and orientation for both curves to reach equilibrium at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Correct curvature and orientation for all curves to reach equilibrium at <math>E_2</math></li> </ul>	1
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math> and <math>E_2</math> onwards</li> </ul>	1
<b>Total</b>	<b>4</b>
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.	



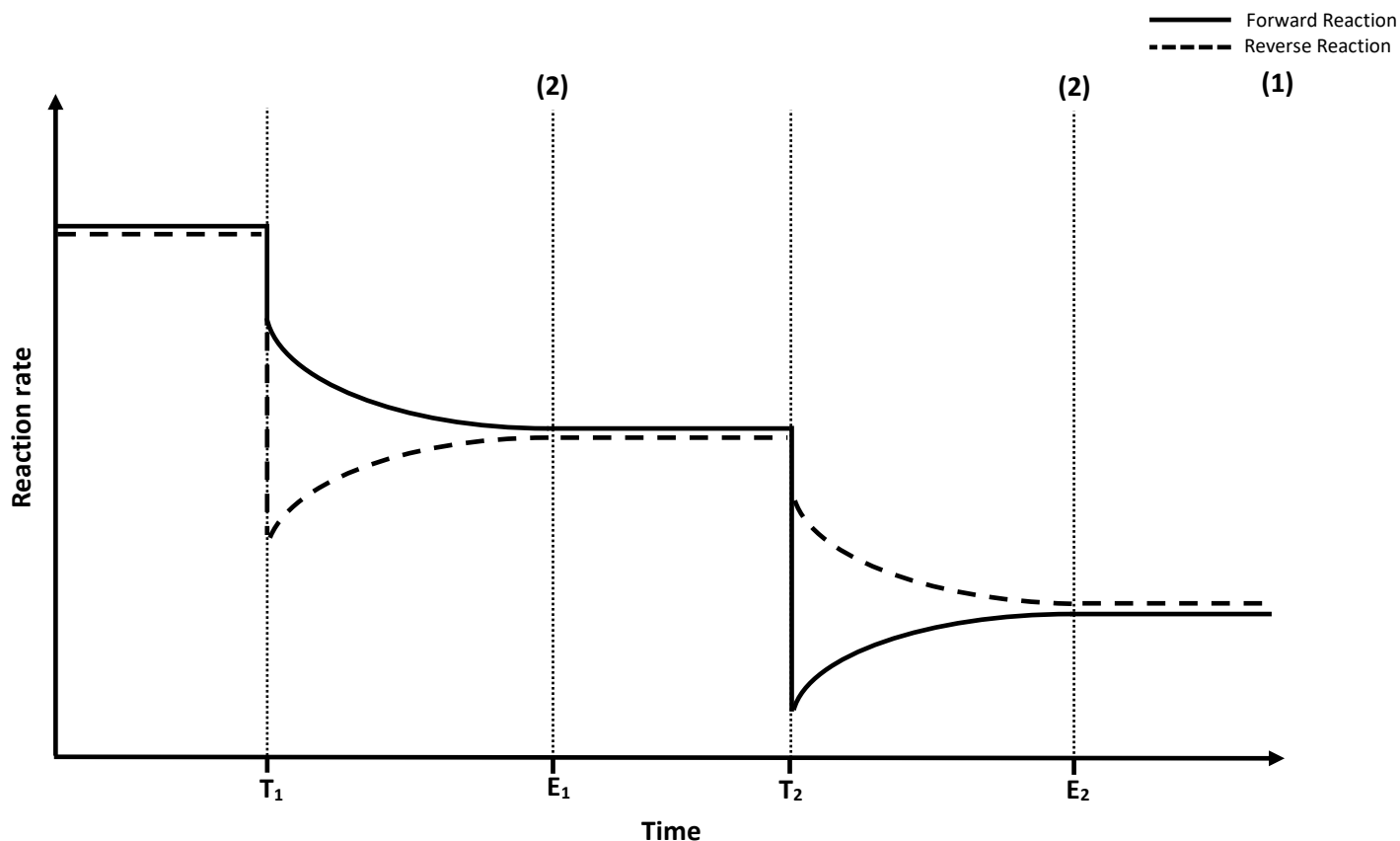
Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike of forward reaction curve at <math>T_1</math></li> <li>Correct curvature and orientation for all curves to re-join at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike of reverse reaction curve at <math>T_2</math></li> <li>Correct curvature and orientation for all curves to re-join at <math>E_2</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math> and <math>E_2</math> onwards</li> </ul>	1
<b>Total</b>	<b>5</b>
Note: Deduct one mark for any missing/incorrect labels of $T_1$ , $E_1$ , axis labels etc.	



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
<b>From T<sub>1</sub> to E<sub>1</sub>:</b> <ul style="list-style-type: none"> <li>Correct curvature and orientation for both curves to reach equilibrium at E<sub>1</sub></li> </ul>	1
<b>From T<sub>2</sub> to E<sub>2</sub>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in all curves at T<sub>2</sub></li> <li>The instantaneous drop for all curves is to half their concentrations</li> <li>Correct curvature and orientation for all curves to reach equilibrium at E<sub>2</sub></li> </ul>	1 – 3
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from T<sub>0</sub> to T<sub>1</sub>, E<sub>1</sub> to T<sub>2</sub> and E<sub>2</sub> onwards</li> </ul>	1
<b>Total</b>	<b>5</b>
Note: Deduct one mark for any missing/incorrect labels of T <sub>1</sub> , E <sub>1</sub> , axis labels etc. and for not maintaining a 4:1:2:2 ratio.	





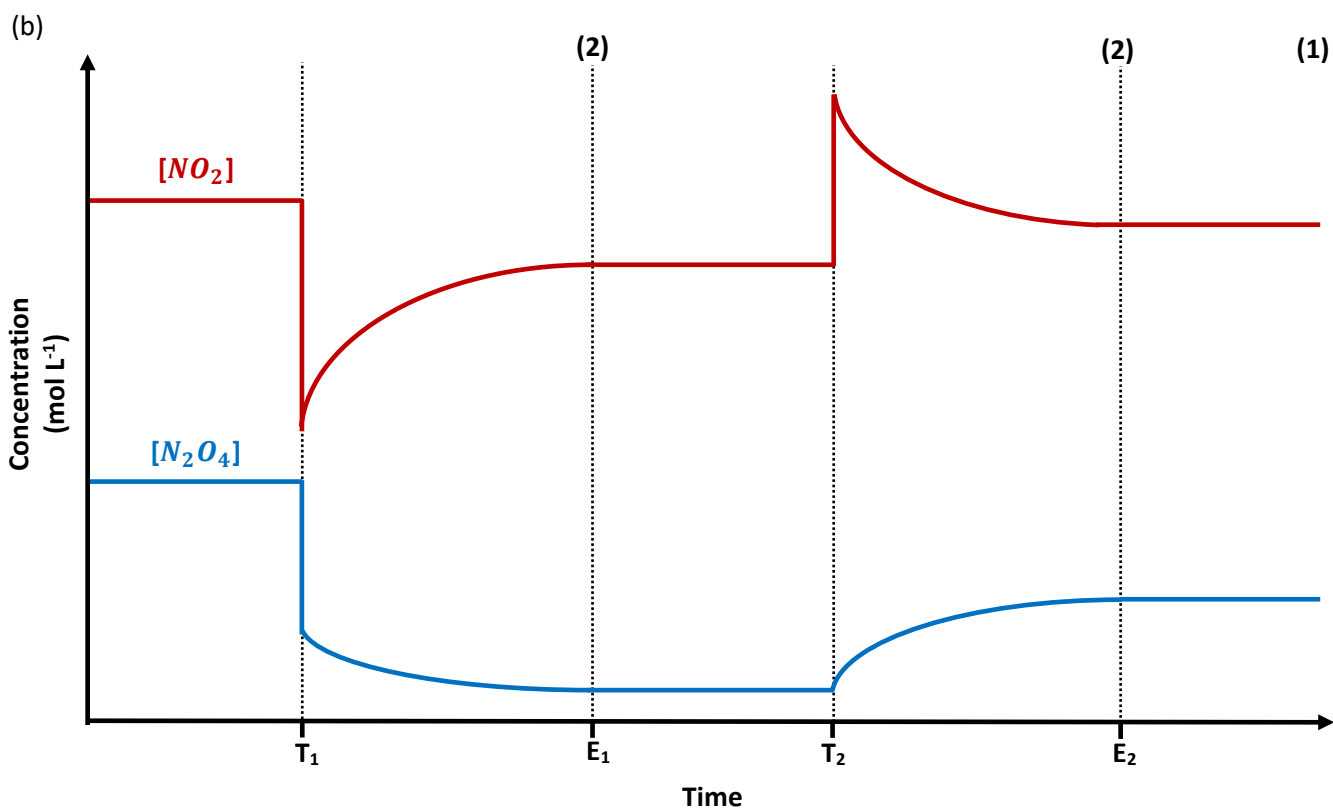
Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in both curves at <math>T_1</math>, however a greater drop in the reverse reaction curve</li> <li>Correct curvature and orientation for all curves to re-join at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in both curves at <math>T_2</math>, however a greater drop in the forward reaction curve</li> <li>Correct curvature and orientation for all curves to re-join at <math>E_2</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math> and <math>E_2</math> onwards</li> </ul>	1
<b>Total</b>	<b>5</b>

Note: Deduct one mark for any missing/incorrect labels of  $T_1$ ,  $E_1$ , axis labels etc.

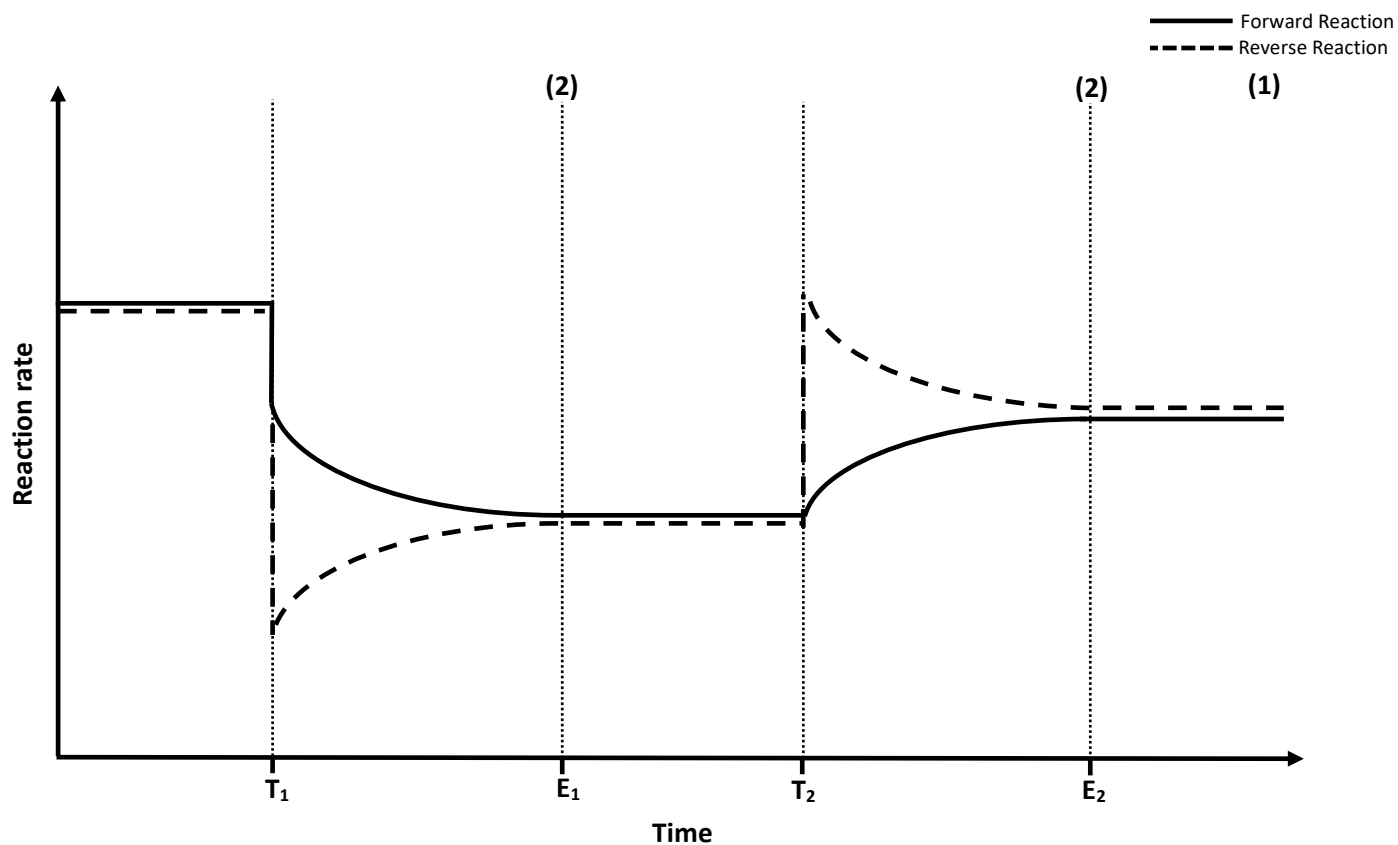
**1.91** **[12 marks]**

(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)**.

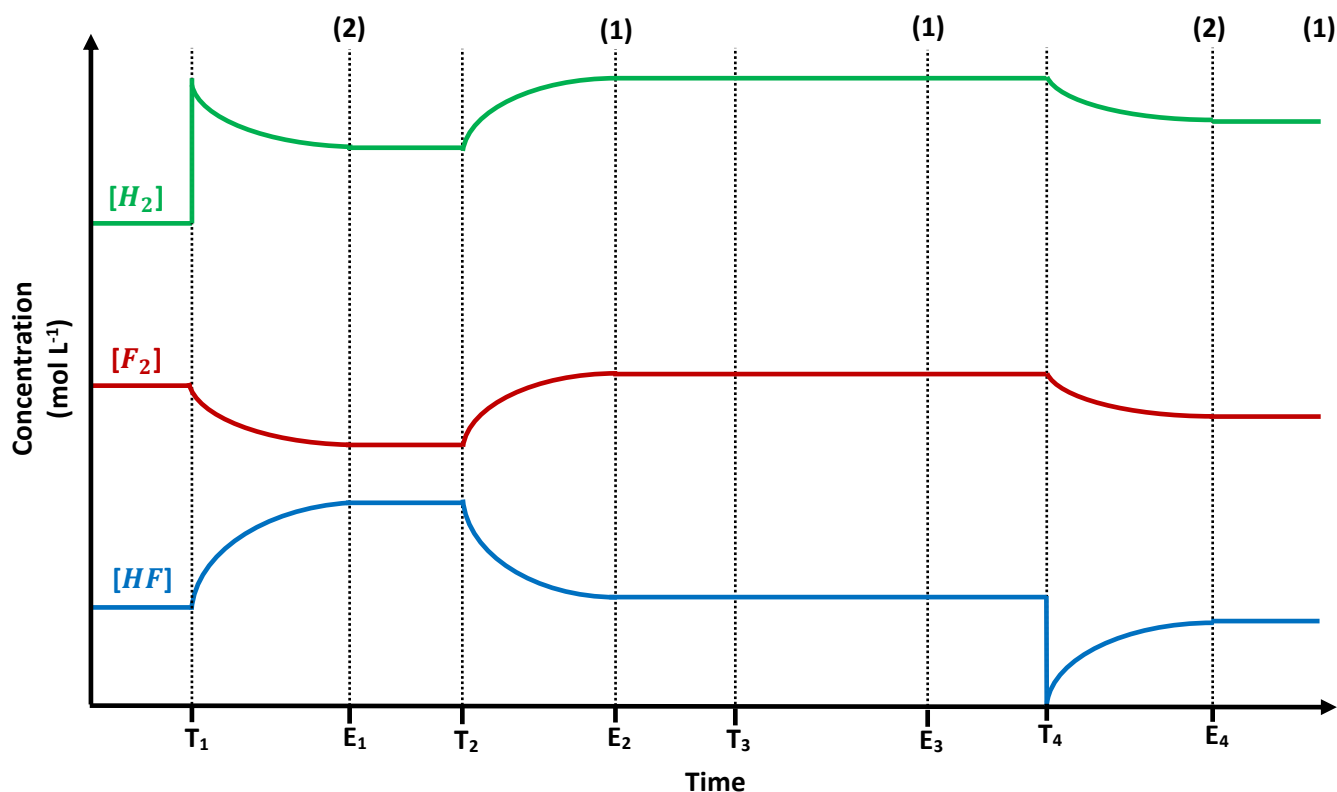
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Adding an inert gas at constant pressure, increases the system volume causing an instantaneous drop in all concentrations, making the system turn a lighter brown colour</li> <li>Over-time the system will become darker brown, however still remain a lighter brown than it was initially</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>



Marking Criteria	Marks Allocated
<b>From T<sub>1</sub> to E<sub>1</sub>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in both curves at T<sub>1</sub>, proportional to the 1:2 ratio</li> <li>Correct curvature and orientation for both curves to reach equilibrium at E<sub>1</sub></li> </ul>	1 – 2
<b>From T<sub>2</sub> to E<sub>2</sub>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike in [NO<sub>2</sub>] concentration curve</li> <li>Correct curvature and orientation for all curves to reach equilibrium at E<sub>2</sub></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from T<sub>0</sub> to T<sub>1</sub>, E<sub>1</sub> to T<sub>2</sub> and E<sub>2</sub> onwards</li> </ul>	1
<b>Total</b>	<b>5</b>
Note: Deduct one mark for any missing/incorrect labels of T <sub>1</sub> , E <sub>1</sub> , axis labels etc. and for not maintaining a 1:2 ratio.	

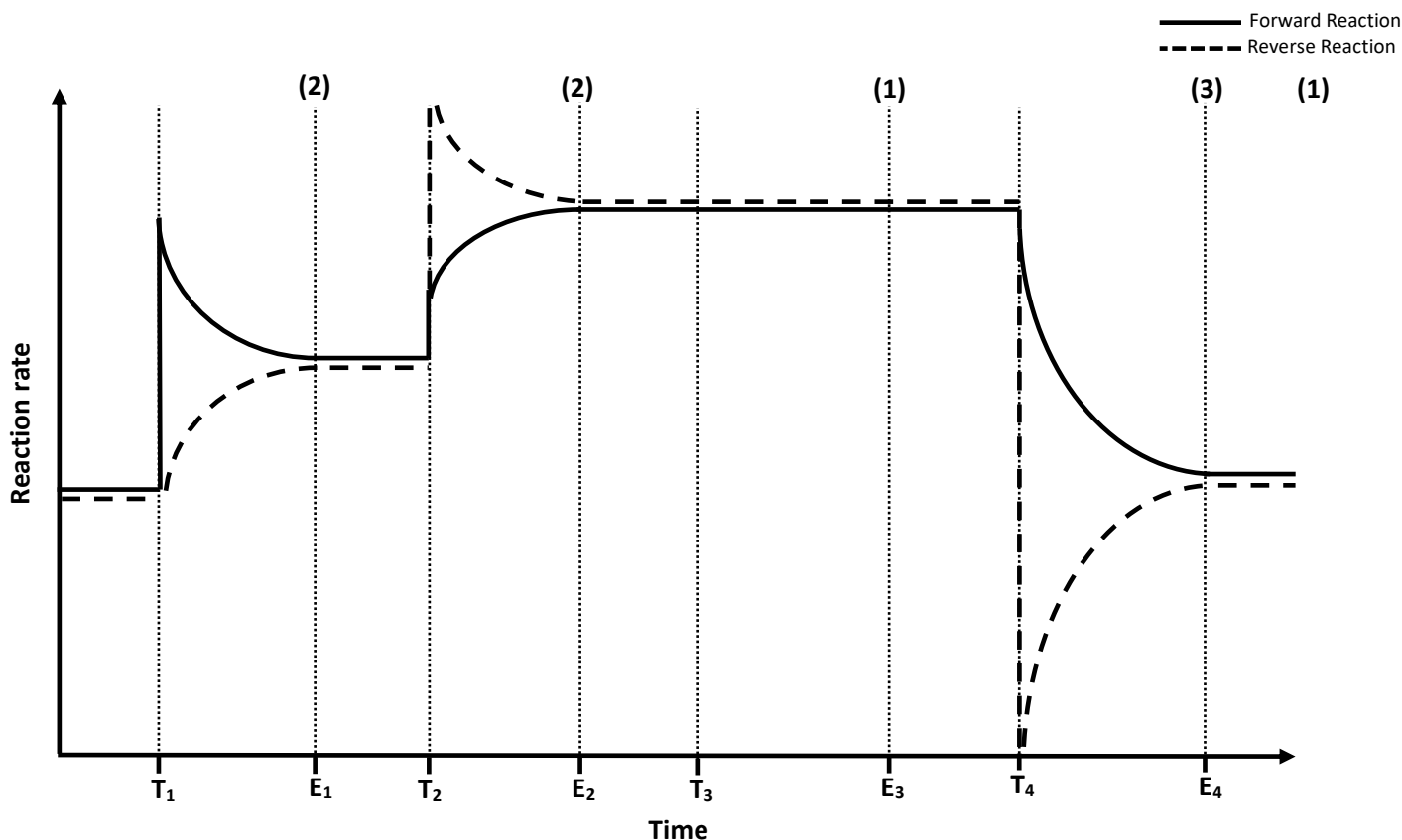


Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in both curves at <math>T_1</math>, however a greater drop in the reverse reaction curve</li> <li>Correct curvature and orientation for all curves to re-join at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike for reverse reaction curve at <math>T_2</math></li> <li>Correct curvature and orientation for all curves to re-join at <math>E_2</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math> and <math>E_2</math> onwards</li> </ul>	1
<b>Total</b>	<b>5</b>
Note: Deduct one mark for any missing/incorrect labels of $T_1$ , $E_1$ , axis labels etc.	

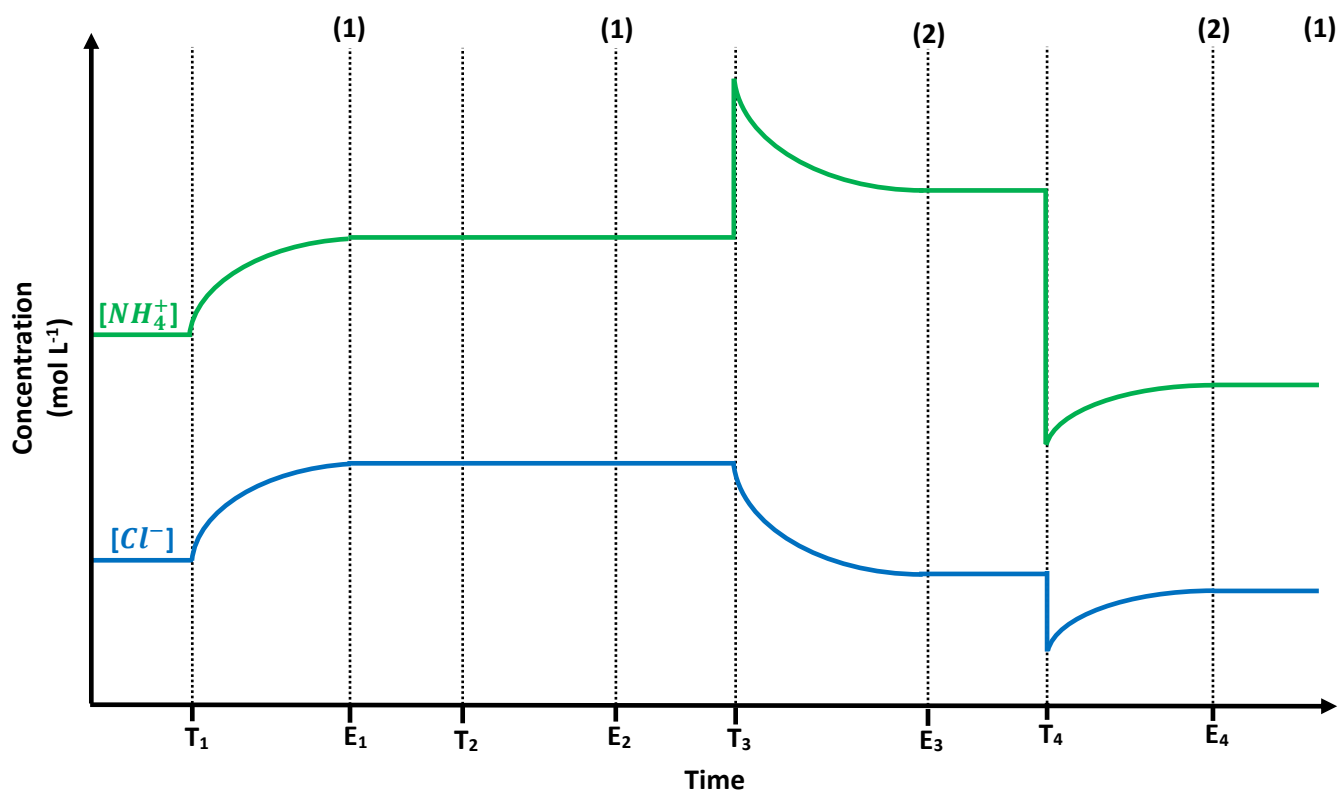


**Points to note:** It is unrealistic to expect to ever have to draw four different changes on a single concentration graph, however it is good practice none-the-less

Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike in the <math>[H_2]</math> concentration curve at <math>T_1</math></li> <li>Correct curvature and orientation for all curves to reach equilibrium at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Correct curvature and orientation for all curves to reach equilibrium at <math>E_2</math></li> </ul>	1
<b>From <math>T_3</math> to <math>E_3</math>:</b> <ul style="list-style-type: none"> <li>Continuation of all equilibrium lines from <math>T_3</math> to <math>E_3</math></li> </ul>	1
<b>From <math>T_4</math> to <math>E_4</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in the <math>[HF]</math> concentration to zero</li> <li>Correct curvature and orientation for all curves to reach equilibrium at <math>E_4</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math>, <math>E_2</math> to <math>T_3</math>, <math>E_3</math> to <math>T_4</math> and <math>E_4</math> onwards</li> </ul>	1
<b>Total</b>	<b>7</b>
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	

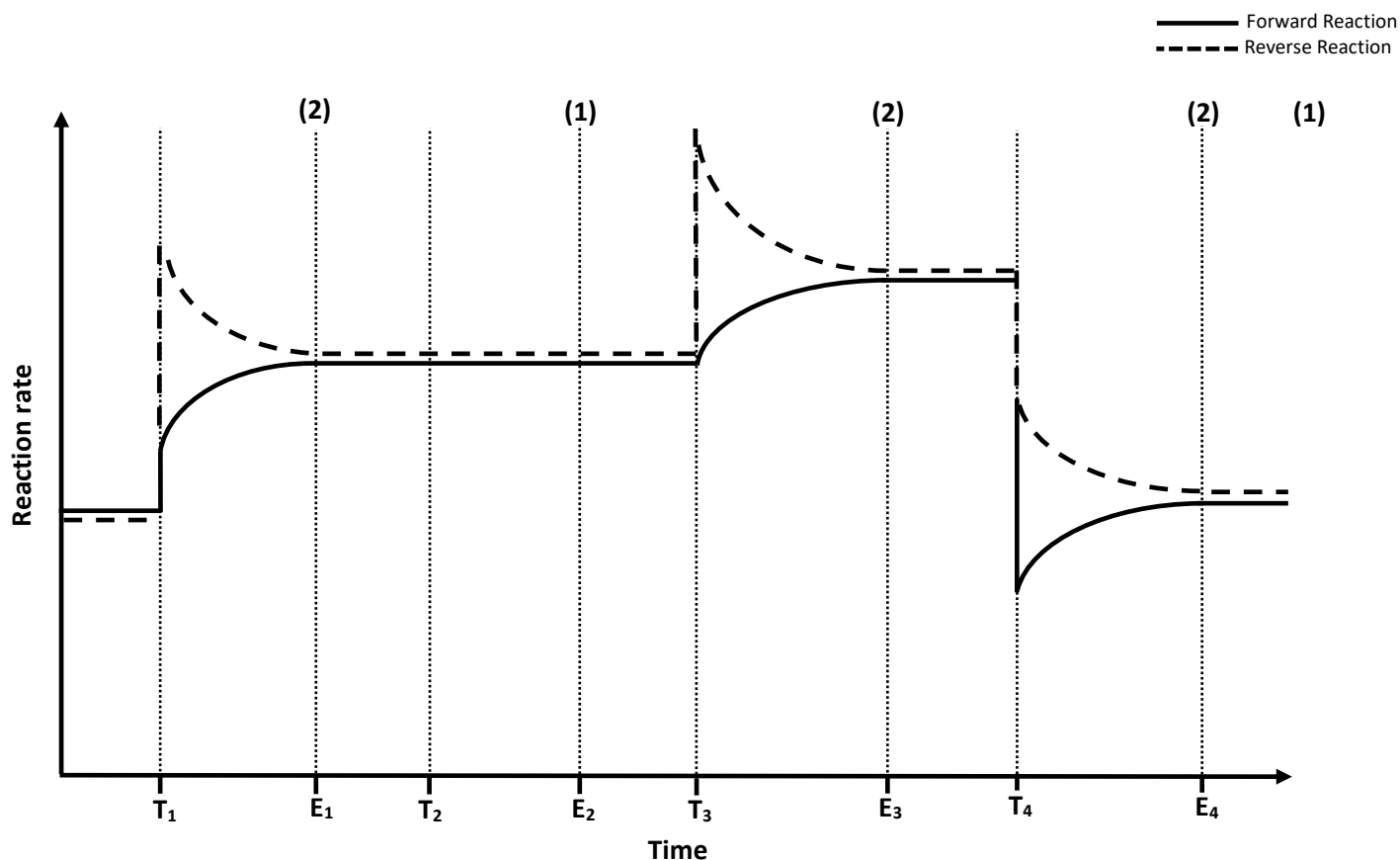


Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike of forward reaction curve at <math>T_1</math></li> <li>Correct curvature and orientation for all curves to re-join at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike in both curves at <math>T_2</math>, however a greater spike in the reverse reaction curve</li> <li>Correct curvature and orientation for all curves to re-join at <math>E_2</math></li> </ul>	1 – 2
<b>From <math>T_3</math> to <math>E_3</math>:</b> <ul style="list-style-type: none"> <li>Continuation of all equilibrium lines from <math>T_3</math> to <math>E_3</math></li> </ul>	1
<b>From <math>T_4</math> to <math>E_4</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop of the reverse reaction curve at <math>T_4</math></li> <li>Reverse reaction curve drops all the way to a zero reaction rate</li> <li>Correct curvature and orientation for all curves to re-join at <math>E_4</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math>, <math>E_2</math> to <math>T_3</math>, <math>E_3</math> to <math>T_4</math>, and <math>E_4</math> onwards</li> </ul>	1
<b>Total</b>	<b>8</b>
Note: Deduct one mark for any missing/incorrect labels of $T_1$ , $E_1$ , axis labels etc.	



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

Marking Criteria	Marks Allocated
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Correct curvature and orientation for all curves to reach equilibrium at <math>E_1</math></li> </ul>	1
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Continuation of all equilibrium lines from <math>T_2</math> to <math>E_2</math></li> </ul>	1
<b>From <math>T_3</math> to <math>E_3</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike in the <math>[NH_4^+]</math> concentration curve at <math>T_3</math></li> <li>Correct curvature and orientation for all curves to reach equilibrium at <math>E_3</math></li> </ul>	1 – 2
<b>From <math>T_4</math> to <math>E_4</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in all curves to half their concentrations</li> <li>Correct curvature and orientation for all curves to reach equilibrium at <math>E_4</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math>, <math>E_2</math> to <math>T_3</math>, <math>E_3</math> to <math>T_4</math> and <math>E_4</math> onwards</li> </ul>	1
<b>Total</b>	<b>7</b>
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
<b>From <math>T_1</math> to <math>E_1</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike of reverse reaction curve at <math>T_1</math></li> <li>Correct curvature and orientation for all curves to re-join at <math>E_1</math></li> </ul>	1 – 2
<b>From <math>T_2</math> to <math>E_2</math>:</b> <ul style="list-style-type: none"> <li>Continuation of all equilibrium lines from <math>T_2</math> to <math>E_2</math></li> </ul>	1
<b>From <math>T_3</math> to <math>E_3</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous spike of the reverse reaction curve at <math>T_3</math></li> <li>Correct curvature and orientation for all curves to re-join at <math>E_3</math></li> </ul>	1 – 2
<b>From <math>T_4</math> to <math>E_4</math>:</b> <ul style="list-style-type: none"> <li>Instantaneous drop in both curves at <math>T_4</math>, however a greater drop in the forward reaction curve</li> <li>Correct curvature and orientation for all curves to re-join at <math>E_4</math></li> </ul>	1 – 2
<b>Equilibrium lines</b> <ul style="list-style-type: none"> <li>Equilibrium lines from <math>T_0</math> to <math>T_1</math>, <math>E_1</math> to <math>T_2</math>, <math>E_2</math> to <math>T_3</math>, <math>E_3</math> to <math>T_4</math>, and <math>E_4</math> onwards</li> </ul>	1
<b>Total</b>	<b>8</b>
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
<ul style="list-style-type: none"> <li>• Decreasing the concentration of atmospheric carbon dioxide, will decrease the concentration of dissolved carbon dioxide (<math>CO_{2(g)} \rightleftharpoons CO_{2(aq)}</math> optional)</li> <li>• A decreased concentration of dissolved carbon dioxide will shift the equilibrium position for the production of carbonic acid to the left: <math>H_2O_{(l)} + CO_{2(aq)} \rightleftharpoons H_2CO_{3(aq)}</math> <b>(must use)</b></li> <li>• A decrease in carbonic acid will decrease the hydronium ion concentration and therefore the rate of ocean acidification</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(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
<ul style="list-style-type: none"> <li>• 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: <math>HCO_3^{-}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^{+}_{(aq)} + CO_3^{2-}_{(aq)}</math> producing more carbonate ions</li> <li>• An increased carbonate ion concentration, shifts the production of calcium carbonate to the right: <math>Ca^{2+}_{(aq)} + CO_3^{2-}_{(aq)} \rightleftharpoons CaCO_{3(s)}</math></li> <li>• This makes it easier for organisms to form their calcium carbonate shells because there is more calcium carbonate available</li> </ul>	1 – 3



**Total****3****2.11** **[15 marks]**

(a)

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

**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
<ul style="list-style-type: none"> <li>One mark for each correctly stated shift</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>

(b)

(i) Increase

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correctly stating 'Increase'</li> </ul>	1
<b>Total</b>	<b>1</b>

Note: No marks awarded for using any terms other than 'Increase'

(ii) Increase

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correctly stating 'Increase'</li> </ul>	1
<b>Total</b>	<b>1</b>

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
<ul style="list-style-type: none"> <li>Correctly stating 'No Change'</li> </ul>	1
<b>Total</b>	<b>1</b>

Note: No marks awarded for using any terms other than 'No Change'

(iv) Increase

**Points to note:** Whilst  $\text{HCO}_3^-$  ions are consumed in  $\text{HCO}_3^-_{(aq)} + \text{H}_2\text{O}_{(l)} \rightleftharpoons \text{H}_3\text{O}^+_{(aq)} + \text{CO}_3^{2-}_{(aq)}$ , this concentration increase is always only partially opposed. Thus there is a net increase in the hydrogen carbonate concentration.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>Correctly stating 'Increase'</li></ul>	1
<b>Total</b>	<b>1</b>
Note: No marks awarded for using any terms other than 'Increase'	

(v) Decrease

**Points to note:** Whilst carbonate ions are reproduced from  $\text{Ca}^{2+}_{(aq)} + \text{CO}_3^{2-}_{(aq)} \rightleftharpoons \text{CaCO}_{3(s)}$  this only partially opposes the concentration decrease from  $\text{HCO}_3^-_{(aq)} + \text{H}_2\text{O}_{(l)} \rightleftharpoons \text{H}_3\text{O}^+_{(aq)} + \text{CO}_3^{2-}_{(aq)}$ . Thus there is a net decrease in the carbonate ion concentration

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>Correctly stating 'Decrease'</li></ul>	1
<b>Total</b>	<b>1</b>
Note: No marks awarded for using any terms other than 'Decrease'	



---

# Chapter 2

---

# Stoichiometry Answers

Problem Set 4 Progressive Answers – Stoichiometry ..... 1

Problem Set 4 Repetitive Answers – Stoichiometry ..... 16

# Problem Set 4 – Stoichiometry

## Progressive Questions

### Concept 1

### The Mole - Progressive Questions Answers

---

#### Calculating Moles: Q1, Q2, Q3, Q4, Q5

1. [9 marks]

$$\begin{aligned} \text{(a)} \quad M(\text{H}_2) &= 2 \times 1.008 \\ &= \mathbf{2.016 \text{ g mol}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(b)} \quad M(\text{CO}_2) &= 12.01 + 2 \times 16 \\ &= \mathbf{44.01 \text{ g mol}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(c)} \quad M(\text{H}_2\text{O}) &= 2 \times 1.008 + 16 \\ &= \mathbf{18.016 \text{ g mol}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(d)} \quad M(\text{SO}_3) &= 32.07 + 3 \times 16 \\ &= \mathbf{80.07 \text{ g mol}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(e)} \quad M(\text{H}_3\text{PO}_4) &= 3 \times 1.008 + 30.97 + 4 \times 16 & \text{(f)} \quad M(\text{CO}(\text{NH}_2)_2) &= 12.01 + 16 + 14.01 \times 2 + 1.008 \times 4 \\ &= \mathbf{97.994 \text{ g mol}^{-1}} \quad (1) & &= \mathbf{60.062 \text{ g mol}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(g)} \quad M(\text{CaCO}_3 \cdot 2\text{H}_2\text{O}) &= 40.08 + 12.01 + 16 \times 3 + 1.008 \times 4 + 16 \times 2 \\ &= \mathbf{136.122 \text{ g mol}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(h)} \quad M(\text{Mg}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}) &= 24.31 \times 3 + 30.97 \times 2 + 16 \times 8 + 1.008 \times 16 + 16 \times 8 \\ &= \mathbf{406.998 \text{ g mol}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(i)} \quad M(\text{NaAl}_3(\text{PO}_4)_2(\text{OH})_4) &= 22.99 + 26.98 \times 3 + 30.97 \times 2 + 16 \times 8 + 16 \times 4 + 1.008 \times 4 \\ &= \mathbf{361.902 \text{ g mol}^{-1}} \quad (1) \end{aligned}$$

2. [5 marks]

$$\begin{aligned} \text{(a)} \quad n(\text{CO}_2) &= \frac{m}{M} \\ &= \frac{15}{12.01 + 2 \times 16} \\ &= \mathbf{0.341 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(b)} \quad n(\text{H}_2\text{O}) &= \frac{m}{M} \\ &= \frac{1.05 \times 10^3}{2 \times 1.008 + 16} \\ &= \mathbf{58.28 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(c)} \quad n(\text{Mg}^{2+}) &= \frac{m}{M} \\ &= \frac{1.5 \times 10^6}{24.31} \\ &= \mathbf{6.17 \times 10^4 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(d)} \quad n(\text{NaAl}_3(\text{PO}_4)_2(\text{OH})_4) &= \frac{m}{M} \\ &= \frac{5 \times 10^6}{361.902} \\ &= \mathbf{1.382 \times 10^4 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned}
 \text{(e)} \quad m(\text{CaCO}_3) &= 2.5 \times 10^6 \times 0.37 \\
 &= \mathbf{9.25 \times 10^5 \text{ g}} \\
 M(\text{CaCO}_3) &= 40.08 + 12.01 + 16 \times 3 \\
 &= \mathbf{100.09 \text{ g mol}^{-1}} \\
 n(\text{CaCO}_3) &= \frac{m}{M} \\
 &= \frac{9.25 \times 10^5}{100.09} \\
 &= \mathbf{9.242 \times 10^3 \text{ mol}}
 \end{aligned}$$

$$\begin{aligned}
 m(\text{Mg}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}) &= 2.5 \times 10^6 \times 0.63 \\
 &= \mathbf{15.75 \times 10^5 \text{ g}} \\
 n(\text{Mg}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}) &= \frac{m}{M} \\
 &= \frac{15.75 \times 10^5}{406.998} \\
 &= \mathbf{3.87 \times 10^3 \text{ mol}}
 \end{aligned}$$

(1)

3.

[8 marks]

$$\begin{aligned}
 \text{(a)} \quad n(\text{Cl}_2) &= \frac{PV}{RT} & (1) \\
 &= \frac{101 \times 2.5}{8.314 \times 300} \\
 &= \mathbf{0.1012 \text{ mol}} & (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{(b)} \quad n(\text{CO}_2) &= \frac{m}{M} \\
 &= \frac{800}{12.01 + 2 \times 16} \\
 &= \mathbf{18.18 \text{ mol}} & (1)
 \end{aligned}$$

$$\begin{aligned}
 P(\text{CO}_2) &= \frac{nRT}{V} \\
 &= \frac{18.18 \times 8.314 \times (30 + 273.15)}{100} \\
 &= \mathbf{458 \text{ kPa}} & (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{(c)} \quad T &= \frac{PV}{Rn} & (1) \\
 &= \frac{3 \times 101 \times 50}{8.314 \times 5} \\
 &= \mathbf{364 \text{ K} \text{ or } 91.3^\circ\text{C}} & (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{(d)} \quad n(\text{H}_2\text{O}) &= \frac{PV}{RT} \\
 &= \frac{205 \times 1 \times 10^3}{8.314 \times 373.15} \\
 &= \mathbf{66.079 \text{ mol}} & (1)
 \end{aligned}$$

$$\begin{aligned}
 m(\text{H}_2\text{O}) &= n \times M \\
 &= 66.079 \times 18.016 \\
 &= \mathbf{1.191 \times 10^3 \text{ g}} & (1)
 \end{aligned}$$

4.

[4 marks]

- (a) The system must be at standard temperature and pressure (STP), which are:  $0.0^\circ\text{C}$  ( $273.15\text{K}$ ) (1) and  $100.0\text{kPa}$  (1)

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>One mark for each correct condition</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(b)

$$\begin{aligned}
 \text{(i)} \quad n(\text{SO}_2) &= \frac{V}{22.71} \\
 &= \frac{2}{22.71} \\
 &= \mathbf{0.0881 \text{ mol}} & (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{(ii)} \quad V(\text{I}_2) &= n \times 22.71 \\
 &= 2 \times 22.71 \\
 &= \mathbf{45.4 \text{ L}} & (1)
 \end{aligned}$$

**Point to note:** All halogens (group 17 elements) are diatomic in their gaseous form (e.g.  $\text{F}_2(\text{g})$ ,  $\text{Cl}_2(\text{g})$ ,  $\text{Br}_2(\text{g})$ ,  $\text{I}_2(\text{g})$  etc.)

5.

[9 marks]

$$(a) m(\text{Na}_8[\text{Al}_6\text{Si}_6\text{O}_{24}][(\text{OH})_2]) = 100 \times 1 \times 10^3 \\ = 1 \times 10^5 \text{ g}$$

$$M(\text{Na}_8[\text{Al}_6\text{Si}_6\text{O}_{24}][(\text{OH})_2]) = 22.99 \times 8 + 26.98 \times 6 + 28.09 \times 6 + 16 \times 24 + 16 \times 2 + 1.008 \times 2 \\ = 932.356 \quad (1)$$

$$n(\text{Na}_8[\text{Al}_6\text{Si}_6\text{O}_{24}][(\text{OH})_2]) = \frac{m}{M} \\ = \frac{1 \times 10^5 \text{ g}}{932.356} \\ = 107.255 \text{ mol} \quad (1)$$

$$(b) n(\text{HCl}) = cV \\ = 0.323 \times 10 \\ = 3.23 \text{ mol} \quad (1)$$

$$(c) V(\text{H}_2\text{O}) = \frac{893}{1 \times 10^3} \\ = 0.893 \text{ L} \\ n(\text{H}_2\text{O}) = cV \\ = 1 \times 0.893 \\ = 0.893 \text{ mol} \quad (1)$$

## Concept 2

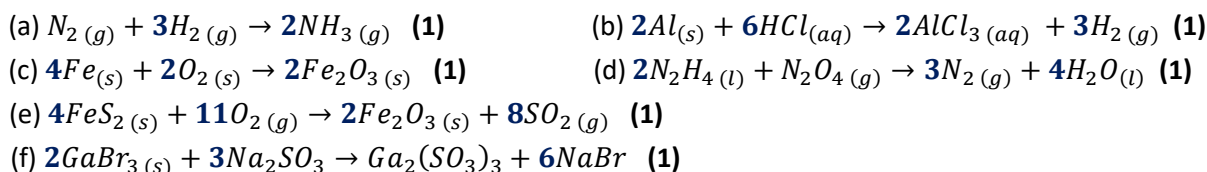
### Reaction Equations and the Molar Ratio - Progressive Questions

#### Answers

#### Balancing Single Equations: Q1, Q2

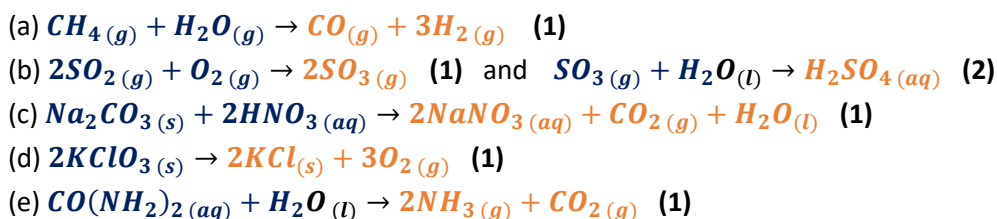
1.

[6 marks]



2.

[6 marks]

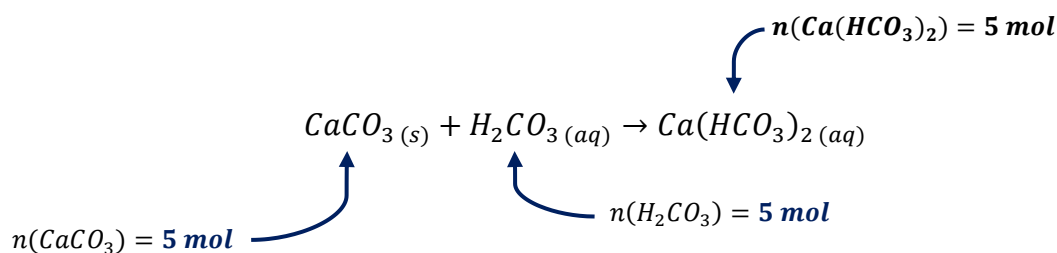


#### Molar Ratios: Q3

3.

[8 marks]

(a)





### Concept 3

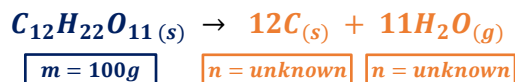
## Real World Stoichiometry - Progressive Questions Answers

### Fundamental Stoichiometry: Q1, Q2, Q3

1.

[5 marks]

(a)



$$\begin{aligned} n(\text{C}_{12}\text{H}_{22}\text{O}_{11}) &= \frac{m}{M} \\ &= \frac{100}{12 \times 12.01 + 22 \times 1.008 + 11 \times 16} \\ &= \mathbf{0.2921 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{C}) &= n(\text{C}_{12}\text{H}_{22}\text{O}_{11}) \times 12 \\ &= 0.2921 \times 12 \\ &= \mathbf{3.506 \text{ mol}} \quad (1) \end{aligned}$$

(b)

$$\begin{aligned} n(\text{H}_2\text{O}) &= n(\text{C}_{12}\text{H}_{22}\text{O}_{11}) \times 11 \\ &= 0.2921 \times 11 \\ &= \mathbf{3.213 \text{ mol}} \quad (1) \end{aligned}$$

(c)

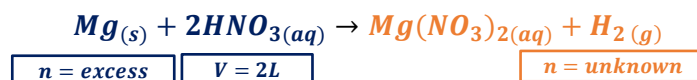
$$\begin{aligned} m(\text{C}) &= nM \\ &= 3.506 \times 12.01 \\ &= \mathbf{42.11 \text{ g}} \quad (1) \end{aligned}$$

$$\begin{aligned} \therefore \text{Tower Height} &= \frac{m(\text{C})}{2} \\ &= \frac{42.11}{2} \\ &\approx \mathbf{21.1 \text{ cm}} \quad (1) \end{aligned}$$

2.

[12 marks]

a)



$$\begin{aligned} T &= 30 + 273.15 \\ &= \mathbf{303.15 \text{ K}} \end{aligned}$$

$$\begin{aligned} n(\text{H}_2 \text{ to burst container}) &= \frac{PV}{RT} \\ &= \frac{200 \times 5}{8.314 \times 303.15} \\ &= \mathbf{0.397 \text{ mol}} \quad (1) \end{aligned}$$



$$\begin{aligned}
 n(\text{HNO}_3) &= cV \\
 &= 0.1 \times 2 \\
 &= \mathbf{0.2 \text{ mol (1)}} \\
 n(\text{H}_2) &= \frac{1}{2} \times n(\text{HNO}_3) \\
 &= \mathbf{0.1 \text{ mol (1)}}
 \end{aligned}$$

∴ the container would not burst, as the moles of hydrogen gas produced is less than the moles that would burst the container. (1)

Either Option

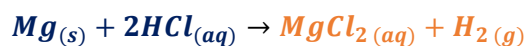
$$\begin{aligned}
 n(\text{HNO}_3) &= cV \\
 &= 0.1 \times 2 \\
 &= \mathbf{0.2 \text{ mol (1)}}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{H}_2) &= \frac{1}{2} \times n(\text{HNO}_3) \\
 &= \mathbf{0.1 \text{ mol (1)}}
 \end{aligned}$$

$$\begin{aligned}
 V(\text{H}_2) &= \frac{nRT}{P} \\
 &= \frac{0.1 \times 8.314 \times 303.15}{200} \\
 &= \mathbf{1.26 \text{ L (1)}}
 \end{aligned}$$

∴ the container would not burst, as the volume of gas produced does not exceed the container's volume. (1)

b)



$n = \text{excess}$

$V = 500\text{ml}$

$n = \text{unknown}$

$$\begin{aligned}
 T &= 30 + 273.15 \\
 &= \mathbf{303.15 \text{ K}}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{H}_2 \text{ to burst container}) &= \frac{PV}{RT} \\
 &= \frac{200 \times 5}{8.314 \times 303.15} \\
 &= \mathbf{0.397 \text{ mol (1)}}
 \end{aligned}$$

$$\begin{aligned}
 V(\text{HCl}) &= \frac{500}{1 \times 10^3} \\
 &= \mathbf{0.5 \text{ L}} \\
 n(\text{HCl}) &= cV \\
 &= 2 \times 0.5 \\
 &= \mathbf{1 \text{ mol (1)}} \\
 n(\text{H}_2) &= \frac{1}{2} \times n(\text{HCl}) \\
 &= \mathbf{0.5 \text{ mol (1)}}
 \end{aligned}$$

∴ the container would burst, as the moles of hydrogen gas produced exceeds the moles that will burst the container. (1)

Either Option

$$\begin{aligned}
 V(\text{HCl}) &= \frac{500}{1 \times 10^3} \\
 &= \mathbf{0.5 \text{ L}}
 \end{aligned}$$

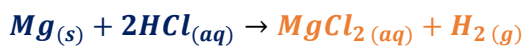
$$\begin{aligned}
 n(\text{HCl}) &= cV \\
 &= 2 \times 0.5 \\
 &= \mathbf{1 \text{ mol (1)}}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{H}_2) &= \frac{1}{2} \times n(\text{HCl}) \\
 &= \mathbf{0.5 \text{ mol (1)}}
 \end{aligned}$$

$$\begin{aligned}
 V(\text{H}_2) &= \frac{nRT}{P} \\
 &= \frac{0.5 \times 8.314 \times 303.15}{200} \\
 &= \mathbf{6.3 \text{ L (1)}}
 \end{aligned}$$

∴ the container would burst, as the volume of gas produced exceeds the container's volume. (1)

c)



$$\boxed{n = \text{excess}} \quad \boxed{V = \text{unknown}}$$

$$\boxed{n = \text{unknown}}$$

$$\begin{aligned} T &= 30 + 273.15 \\ &= \mathbf{303.15 \text{ K}} \\ n(\text{H}_2 \text{ required}) &= \frac{PV}{RT} \\ &= \frac{200 \times 5}{8.314 \times 303.15} \\ &= \mathbf{0.397 \text{ mol (1)}} \end{aligned}$$

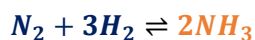
$$\begin{aligned} n(\text{HCl}) &= 2 \times n(\text{H}_2 \text{ required}) \\ &= 2 \times 0.397 \\ &= \mathbf{0.794 \text{ mol (1)}} \\ V(\text{HCl}) &= \frac{n}{c} \\ &= \frac{0.794}{2} \\ &= \mathbf{0.397 \text{ L (1)}} \end{aligned}$$

$\therefore$  Neil would need to add 0.397L of hydrochloric acid. (1)

3.

[6 marks]

a)



$$\boxed{n = \text{excess}} \quad \boxed{V = 1\text{L}} \quad \boxed{m = \text{unknown}}$$

$$\begin{aligned} T &= 100 + 273.15 \\ &= \mathbf{373.15 \text{ K}} \\ n(\text{H}_2) &= \frac{PV}{RT} \\ &= \frac{175 \times 1}{8.314 \times 373.15} \\ &= \mathbf{0.056 \text{ mol (1)}} \end{aligned}$$

$$\begin{aligned} n(\text{NH}_3) &= \frac{2}{3} n(\text{H}_2) \\ &= \frac{2}{3} \times 0.056 \\ &= \mathbf{0.038 \text{ mol (1)}} \\ M(\text{NH}_3) &= 14.01 + 1.008 \times 3 \\ &= \mathbf{17.034 \text{ (1)}} \\ m(\text{NH}_3) &= 0.038 \times 17.034 \\ &= \mathbf{0.64 \text{ kg (1)}} \end{aligned}$$

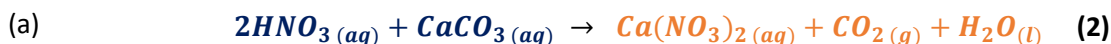
b)

$$\begin{aligned} \% \text{yield}(\text{NH}_3) &= \frac{\text{actual yield}(\text{NH}_3)}{\text{theoretical yield}(\text{NH}_3)} \times 100 \\ \text{actual yield}(\text{NH}_3) &= 0.64 \times 100 \\ &= 640\text{g} \\ \% \text{yield}(\text{NH}_3) &= \frac{200}{640} \times 100 \text{ (1)} \\ &= \mathbf{31.25 \% (1)} \end{aligned}$$

## Limiting Reagents: Q4, Q5, Q6, Q7

4.

[9 marks]



$$\boxed{c = 0.500 \text{ mol L}^{-1}}$$

$$\boxed{V = 400\text{mL}}$$

$$\boxed{m = 50\text{g}}$$

$$\boxed{V = \text{unknown}}$$

(b)  $n(\text{HNO}_3) = cV$   
 $= 0.500 \times 0.4$   
 $= \mathbf{0.2 \text{ mol}}$  (1)

$$n(\text{CaCO}_3) = \frac{m}{M}$$

$$= \frac{50}{40.08 + 12.01 + 3 \times 16}$$

$$= \mathbf{0.4996 \text{ mol}}$$
 (1)

$$n(\text{HNO}_3)_{\text{required}} = n(\text{CaCO}_3) \times \frac{1}{2}$$

$$= 0.4996 \times \frac{1}{2}$$

$$= \mathbf{0.2498 \text{ mol}}$$
 (1)

$$n(\text{HNO}_3) < n(\text{HNO}_3)_{\text{required}}$$

$$\therefore \mathbf{HNO}_3 \text{ is limiting reagent}$$
 (1)

$$n(\text{CaCO}_3)_{\text{required}} = n(\text{HNO}_3) \times 2$$

$$= 0.2 \times 2$$

$$= \mathbf{0.4 \text{ mol}}$$
 (1)

$$n(\text{CaCO}_3) > n(\text{CaCO}_3)_{\text{required}}$$

$$\therefore \mathbf{HNO}_3 \text{ is limiting reagent}$$
 (1)

Either  
Option

(c)

$$n(\text{CO}_2) = n(\text{HNO}_3) \times \frac{1}{2}$$

$$= 0.2 \times \frac{1}{2}$$

$$= \mathbf{0.1 \text{ mol}}$$
 (1)

$$V(\text{CO}_2) = n \times 22.71$$

$$= 0.1 \times 22.71$$

$$= \mathbf{2.27\text{L}}$$
 (1)

5.

[8 marks]



$$\boxed{m = 0.52\text{kg}}$$

$$\boxed{n = 10 \text{ mol}}$$

$$\boxed{m = \text{unknown}}$$

$$n(\text{Al}_2\text{S}_3) = \frac{m}{M}$$

$$= \frac{0.52 \times 10^3}{2 \times 26.96 + 3 \times 32.07}$$

$$= \mathbf{3.464 \text{ mol}}$$
 (1)

$$n(\text{Al}_2\text{S}_3)_{\text{required}} = n(\text{H}_2\text{O}) \times \frac{1}{6}$$

$$= 10 \times \frac{1}{6}$$

$$= \mathbf{1.667 \text{ mol}}$$
 (1)

$$n(\text{Al}_2\text{S}_3) > n(\text{Al}_2\text{S}_3)_{\text{required}}$$

$$\therefore \mathbf{H}_2\text{O} \text{ is limiting reagent}$$
 (1)

$$n(\text{H}_2\text{O})_{\text{required}} = n(\text{Al}_2\text{S}_3) \times 6$$

$$= 3.464 \times 6$$

$$= \mathbf{20.78 \text{ mol}}$$
 (1)

$$n(\text{H}_2\text{O}) < n(\text{H}_2\text{O})_{\text{required}}$$

$$\therefore \mathbf{H}_2\text{O} \text{ is limiting reagent}$$
 (1)

Either  
Option

$\therefore$  Dylan is correct (1)

Point to note: One kilogram is 1000g or  $1 \times 10^3\text{g}$ . In stoichiometry it is always crucial to remember  $1\text{kg} = 1 \times 10^3\text{g}$ .

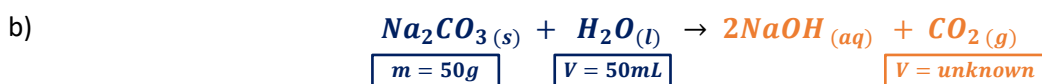
(b)

$$\begin{aligned}n(\text{Al}(\text{OH})_3) &= n(\text{H}_2\text{O}) \times \frac{2}{6} \times \text{Efficiency} \\&= 10 \times \frac{1}{3} \times 0.92 \\&= \mathbf{3.067 \text{ mol}} \quad (1)\end{aligned}$$

$$\begin{aligned}m(\text{Al}(\text{OH})_3) &= nM \\&= 3.067 \times (26.98 + 3 \times 16 + 3 \times 1.008) \\&= \mathbf{239 \text{ g}} \quad (1)\end{aligned}$$

6.

[12 marks]



$$\begin{aligned}n(\text{Na}_2\text{CO}_3) &= \frac{m}{M} & n(\text{H}_2\text{O}) &= \frac{m}{M} \\&= \frac{50}{22.99 \times 2 + 12.01 + 16 \times 3} & &= \frac{50 \times 10^{-3}}{1.008 \times 2 + 16} \\&= \mathbf{0.472 \text{ mol}} \quad (1) & &= \mathbf{2.78 \times 10^{-3} \text{ mol}} \quad (1)\end{aligned}$$

$$\begin{aligned}n(\text{Na}_2\text{CO}_3)_{\text{required}} &= n(\text{H}_2\text{O}) \\&= \mathbf{2.78 \times 10^{-3} \text{ mol}}\end{aligned}$$

$$\begin{aligned}n(\text{Na}_2\text{CO}_3) &> n(\text{Na}_2\text{CO}_3)_{\text{required}} \\&\therefore \mathbf{H_2O \text{ is the limiting reagent}} \quad (1)\end{aligned}$$

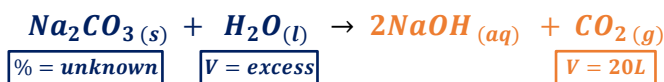
Either Option

$$\begin{aligned}n(\text{H}_2\text{O})_{\text{required}} &= n(\text{Na}_2\text{CO}_3) \\&= \mathbf{0.472 \text{ mol}} \\n(\text{H}_2\text{O}) &< n(\text{H}_2\text{O})_{\text{required}} \\&\therefore \mathbf{H_2O \text{ is the limiting reagent}} \quad (1)\end{aligned}$$

$$\begin{aligned}n(\text{CO}_2) &= n(\text{H}_2\text{O}) \\&= \mathbf{2.78 \times 10^{-3} \text{ mol}} \quad (1)\end{aligned}$$

$$\begin{aligned}V(\text{CO}_2) &= \frac{nRT}{P} \\&= \frac{2.78 \times 10^{-3} \times 8.314 \times (25 + 273.15)}{101} \\&= \mathbf{0.068 \text{ L}} \quad (1)\end{aligned}$$

c)



$$\begin{aligned}n(\text{CO}_2) &= \frac{V}{22.71} \\&= \frac{2}{22.71} \\&= \mathbf{0.088 \text{ mol}} \quad (1)\end{aligned}$$

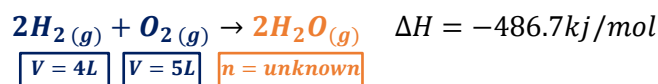
$$\begin{aligned}n(\text{Na}_2\text{CO}_3) &= n(\text{CO}_2) \\&= \mathbf{0.088 \text{ mol}} \quad (1)\end{aligned}$$

$$\begin{aligned}m(\text{Na}_2\text{CO}_3) &= n \times M \\&= 0.088 \times (22.99 \times 2 + 12.01 + 16 \times 3) \\&= \mathbf{9.33\text{g}} \quad (1)\end{aligned}$$

$$\begin{aligned}\%(\text{Na}_2\text{CO}_3) &= \frac{\text{actual } m(\text{Na}_2\text{CO}_3)}{\text{theoretical } m(\text{Na}_2\text{CO}_3)} \times 100 \\&= \frac{9.33}{10} \times 100 \quad (1) \\&= \mathbf{93.34\%} \quad (1)\end{aligned}$$

$\therefore$  Sarah and Janet are incorrect (1)

7.



[6 marks]

$$\boxed{V = 4\text{L}} \quad \boxed{V = 5\text{L}} \quad \boxed{n = \text{unknown}}$$

$$T = 30 + 273.15 \\ = 303.15 \text{ K}$$

$$n(\text{H}_2) = \frac{PV}{RT} \\ = \frac{143 \times 4}{8.314 \times 303.15} \\ = 0.227 \text{ mol} \quad (1)$$

$$n(\text{O}_2) = \frac{PV}{RT} \\ = \frac{101 \times 5}{8.314 \times 303.15} \\ = 0.2 \text{ mol} \quad (1)$$

$$n(\text{O}_2)_{\text{required}} = n(\text{H}_2) \times \frac{1}{2} \\ = 0.1335 \text{ mol}$$

$$n(\text{O}_2) > n(\text{O}_2)_{\text{required}} \\ \therefore \text{H}_2 \text{ is limiting reagent}$$

$$n(\text{H}_2)_{\text{required}} = n(\text{O}_2) \times 2 \\ = 0.4 \text{ mol}$$

$$n(\text{H}_2) < n(\text{H}_2)_{\text{required}} \\ \therefore \text{H}_2 \text{ is limiting reagent}$$

(1)

$$n(\text{H}_2\text{O}) = n(\text{O}_2) \\ = 0.2 \text{ mol} \quad (1)$$

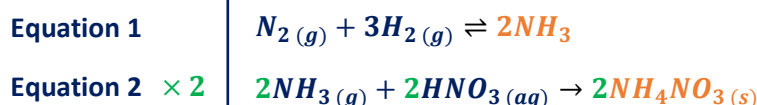
$$H = n(\text{H}_2\text{O}) \times |\Delta H| \quad (1)$$

$$= 0.2 \times 486.7 \\ = 97.518 \text{ kJ} \quad (1)$$

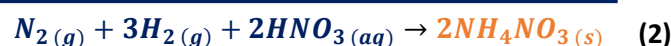
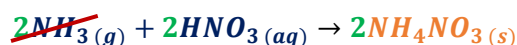
**Point to note:** We use the absolute value of  $H$  here as we are calculating the total energy released, which will be a positive number – not the change in energy, which can be positive or negative.

### Multi-Reaction Stoichiometry: Q8, Q9, Q10

8.



[6 marks]



$$n(\text{NH}_4\text{NO}_3) = \frac{m}{M} \\ = \frac{5 \times 10^6}{2 \times 14.01 + 4 \times 1.008 + 3 \times 16} \\ = 62459.4 \text{ mol} \quad (1)$$

$$n(\text{N}_2) = n(\text{NH}_4\text{NO}_3) \times \frac{1}{2} \\ = 62459.4 \times \frac{1}{2} \\ = 31229.7 \text{ mol} \quad (1)$$

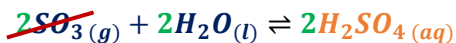
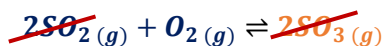
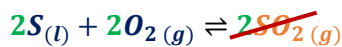
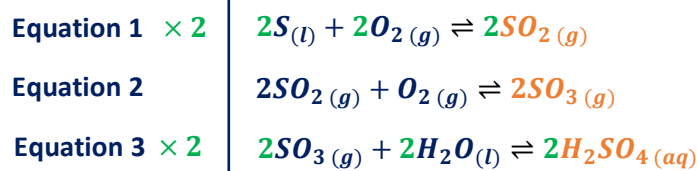
$$V(\text{N}_2) = \frac{nRT}{P} \\ = \frac{31229.7 \times 8.314 \times 400}{10 \times 101} \\ = 100 \text{ kL} \quad (2)$$

**Point to note:** One Tonne is 1000 kg or  $1 \times 10^3 \text{ kg}$  which in grams is:  $1 \times 10^3 \times 1 \times 10^3 = 1 \times 10^6 \text{ g}$ . In stoichiometry it is always crucial to remember **1 Tonne =  $1 \times 10^6 \text{ g}$** . Also remember that this answer is to one significant figure, because that is the lowest significant figure provided in the question

9.

[8 marks]

(a)



(b)

$$n(S) = \frac{m}{M}$$

$$= \frac{1 \times 10^3}{32.07}$$

$$= 31.18 \text{ mol} \quad (1)$$

$$n(O_2) = \frac{PV}{RT}$$

$$= \frac{200 \times 800}{8.314 \times (450 + 273.15)}$$

$$= 26.61 \text{ mol} \quad (1)$$

$$n(S)_{\text{required}} = n(O_2) \times \frac{2}{3}$$

$$= 26.61 \times \frac{2}{3}$$

$$= 17.74 \text{ mol} \quad (1)$$

$$n(S) > n(S)_{\text{required}}$$

$$\therefore O_2 \text{ is limiting reagent} \quad (1)$$

$$n(O_2)_{\text{required}} = n(S) \times \frac{3}{2}$$

$$= 31.18 \times \frac{3}{2}$$

$$= 46.77 \text{ mol} \quad (1)$$

$$n(O_2) < n(O_2)_{\text{required}}$$

$$\therefore O_2 \text{ is limiting reagent} \quad (1)$$

Either  
Option

$$n(H_2SO_4) = n(O_2) \times \frac{2}{3} \times \text{Efficiency}$$

$$= 26.61 \times \frac{2}{3} \times 0.98$$

$$= 17.39 \text{ mol} \quad (1)$$

$$m(H_2SO_4) = nM$$

$$= 17.39 \times (2 \times 1.008 + 32.07 + 4 \times 16)$$

$$= 1.71 \text{ kg} \quad (1)$$

(c)

$$n(S) = \frac{m}{M}$$

$$= \frac{33 \times 10^3}{32.07}$$

$$= 1029 \text{ mol} \quad (1)$$

$$n(H_2SO_4) = n(S)$$

$$= 1029 \text{ mol} \quad (1)$$

$$m(H_2SO_4) = nM$$

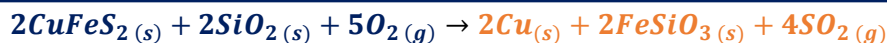
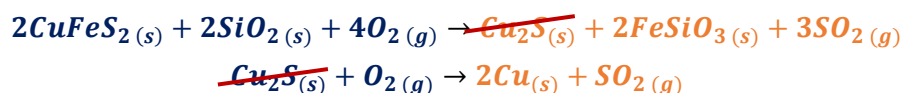
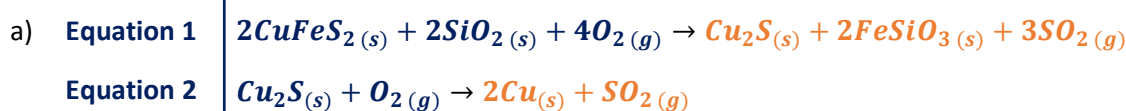
$$= 1029 \times (2 \times 1.008 + 32.07 + 4 \times 16)$$

$$= 100.9 \text{ kg} \quad (1)$$

$\therefore$  Rupert will invest to build Tom's sulfuric acid factory (1)

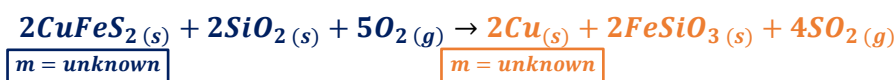
10.

[7 marks]



(2)

b)



$$m(\text{CuFeS}_2) = m(\text{rock}) \times 0.05$$

$$= 100 \times 0.05$$

$$= 5 \text{ tonnes}$$

$$= 5 \times 10^6 \text{ g} \quad (1)$$

$$n(\text{CuFeS}_2) = \frac{m}{M}$$

$$= \frac{5 \times 10^6}{63.55 + 55.85 + 32.06 \times 2}$$

$$= 2.725 \times 10^4 \text{ mol} \quad (1)$$

$$n(\text{Cu}) = n(\text{CuFeS}_2) \times 0.6 \quad (1)$$

$$= 1.635 \times 10^4 \text{ mol} \quad (1)$$

$$m(\text{Cu}) = n \times M$$

$$= 1.635 \times 10^4 \times 63.55$$

$$= 1.039 \times 10^6 \text{ g}$$

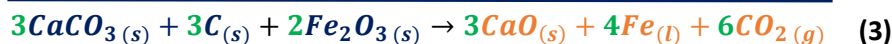
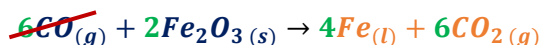
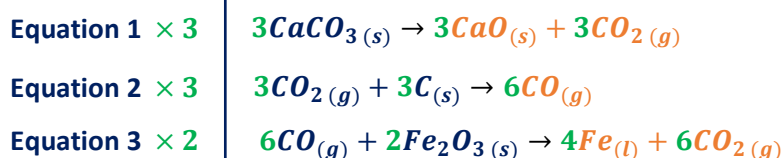
$$= 1.039 \text{ tonnes} \quad (1)$$

## Exam-Style Stoichiometry: Q11, Q12, Q13, Q14

11.

[7 marks]

a)

 $m = \text{unknown}$  $V = 500\text{L}$ 

$$n(\text{CO}_2) = \frac{V}{22.71}$$

$$= \frac{500}{22.71}$$

$$= 22.017 \text{ mol} \quad (1)$$

$$n(\text{CaCO}_3) = \frac{\frac{3}{6} \times n(\text{CO}_2)}{0.92}$$

$$= 11.966 \text{ mol} \quad (2)$$

$$m(\text{CaCO}_3) = n \times M$$

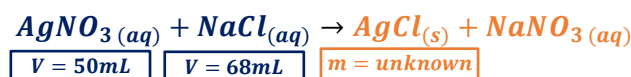
$$= 11.966 \times (40.08 + 12.01 + 16 \times 3)$$

$$= 1198 \text{ g} \quad (1)$$

12.

[7 marks]

a)



$$\begin{aligned} m(\text{AgNO}_3) &= 60 \times 0.05 & n(\text{NaCl}) &= cV \\ &= \mathbf{3\text{g}} \quad (1) & &= 0.5 \times 0.068 \\ n(\text{AgNO}_3) &= \frac{m}{M} & &= \mathbf{3.4 \times 10^{-2} \text{ mol}} \quad (1) \\ &= \frac{3}{107.9+14.01+16 \times 3} \\ &= \mathbf{1.766 \times 10^{-2} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{NaCl}) &> n(\text{AgNO}_3) \\ \therefore \text{AgNO}_3 &\text{ is limiting reagent} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{AgCl}) &= n(\text{AgNO}_3) \times 0.9 \\ &= 1.766 \times 10^{-2} \times 0.9 \\ &= \mathbf{1.589 \times 10^{-2} \text{ mol}} \quad (1) \end{aligned}$$

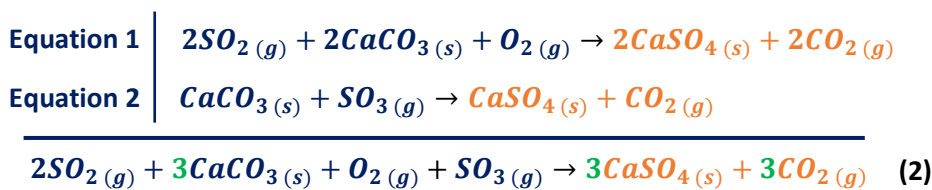
$$\begin{aligned} m(\text{AgCl}) &= n \times M \\ &= 1.589 \times 10^{-2} \times (107.9 + 35.45) \\ &= \mathbf{2.278\text{g}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{Number of reactions required} &= \frac{1000}{2.278} \\ &= \mathbf{439 \text{ reactions}} \quad (1) \end{aligned}$$

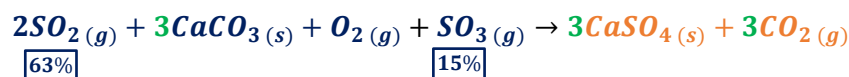
13.

[8 marks]

a)



b)



$$\begin{aligned} V(\text{SO}_2)_{\text{per day}} &= 500 \times 0.63 \times 24 \\ &= \mathbf{7560\text{L}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{SO}_2)_{\text{per day}} &= \frac{PV}{RT} \\ &= \frac{20 \times 101 \times 7560}{8.314 \times 473.15} \\ &= \mathbf{3882 \text{ mol}} \end{aligned}$$

$$\begin{aligned} n(\text{CaCO}_3) &= \frac{2}{2} \times n(\text{SO}_2) \\ &= \frac{2}{2} \times 3882 \\ &= \mathbf{3882 \text{ mol}} \end{aligned}$$

$$\begin{aligned} m(\text{CaCO}_3) &= n \times M \\ &= 3882 \times (40.08 + 12.01 + 16 \times 3) \\ &= 3.885 \times 10^6 \text{ g} \\ &= \mathbf{3.9 \text{ tonnes}} \quad (1) \end{aligned}$$

$$\begin{aligned} V(\text{SO}_3)_{\text{per day}} &= 500 \times 0.15 \times 24 \\ &= \mathbf{1800\text{L}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{SO}_3)_{\text{per day}} &= \frac{PV}{RT} \\ &= \frac{20 \times 101 \times 1800}{8.314 \times 473.15} \\ &= \mathbf{924.3 \text{ mol}} \end{aligned}$$

$$\begin{aligned} n(\text{CaCO}_3) &= \frac{1}{1} \times n(\text{SO}_3) \\ &= \frac{1}{1} \times 924.3 \\ &= \mathbf{924.3 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} m(\text{CaCO}_3) &= n \times M \\ &= 924.3 \times (40.08 + 12.01 + 16 \times 3) \\ &= 92513 \text{ g} \\ &= \mathbf{0.93 \text{ tonnes}} \quad (1) \end{aligned}$$

$$\begin{aligned} m(\text{CaCO}_3)_{\text{total}} &= 3.9 + 0.93 \\ &= \mathbf{4.83 \text{ tonne}} \quad (1) \end{aligned}$$

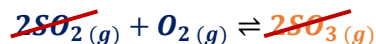
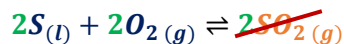
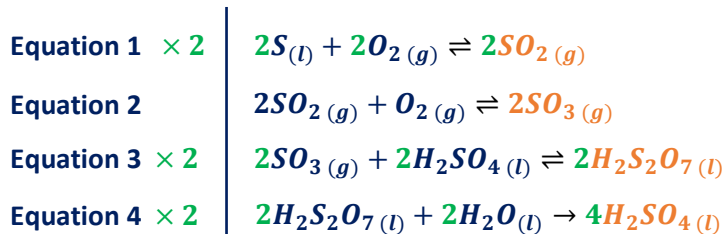
**Points to note:** This question can be quite confusing, and you need to read the question carefully. Whilst you determined the net ionic equation, you should not actually use this equation when determining  $n(\text{CaCO}_3)$  because those aren't the ratios in which  $\text{SO}_2$  and  $\text{SO}_3$  react individually. That is why you should use the molar ratios from the individual equations.



14.

[19 marks]

(a)



(b)

$$\begin{aligned}
 n(H_2SO_4) &= cV \\
 &= 0.1 \times 5000 \\
 &= \mathbf{500 \text{ mol}} \quad (1)
 \end{aligned}$$

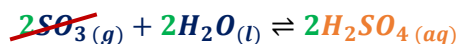
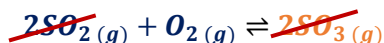
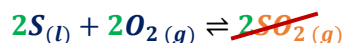
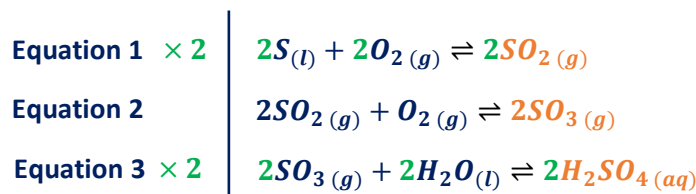
$$\begin{aligned}
 n(S) &= \frac{n(H_2SO_4)}{\% \text{ Efficiency}} \times \frac{2}{2} \\
 &= \frac{500}{0.90} \\
 &= \mathbf{555.6 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(S) &= nM \\
 &= 555.6 \times 32.07 \\
 &= \mathbf{17.82 \text{ kg}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(S)_{\text{impure}} &= \frac{m(S)}{\% \text{ Purity}} \\
 &= \frac{17.8}{0.60} \\
 &= \mathbf{29.7 \text{ kg}} \quad (1)
 \end{aligned}$$

**Point to note:** The reason that we are dividing by efficiency and purity is because we are working backwards. Usually we would multiply the efficiency to determine the products, but we want to know the amount of reactants, and usually we would multiply by the purity because we want to determine the pure products, but in this question we want to know the amount of impure reactant.

(c)



$$\begin{aligned}
 n(S) &= \frac{m}{M} \\
 &= \frac{50 \times 10^6}{32.07} \\
 &= \mathbf{1559089.5 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(O_2) &= \frac{PV}{RT} \\
 &= \frac{2 \times 10^6 \times 8000}{8.314 \times 1000} \\
 &= \mathbf{1924465 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(S)_{\text{required}} &= n(O_2) \times \frac{2}{3} \\
 &= 1924465 \times \frac{2}{3} \\
 &= \mathbf{1282976.7 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(S) &> n(S)_{\text{required}} \\
 \therefore O_2 &\text{ is limiting reagent} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(O_2)_{\text{required}} &= n(S) \times \frac{3}{2} \\
 &= 1559089.5 \times \frac{3}{2} \\
 &= \mathbf{2338634 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(O_2) &< n(O_2)_{\text{required}} \\
 \therefore O_2 &\text{ is limiting reagent} \quad (1)
 \end{aligned}$$

Either  
Option

$$\begin{aligned}
 n(H_2SO_4) &= n(O_2) \times \frac{2}{3} \times \text{Efficiency} \\
 &= 1924465 \times \frac{2}{3} \times 0.60 \\
 &= \mathbf{769786 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(H_2SO_4) &= nM \\
 &= 769786 \times (2 \times 1.008 + 32.07 + 4 \times 16) \\
 &= 75505229.6g \\
 &\approx \mathbf{75.5 \text{ Tonne}} \quad (1)
 \end{aligned}$$

- (d) The **total energy** is going to equal the  $n(H_2SO_4)$  multiplied by the change in **enthalpy ( $\Delta H$ )**:

$$\begin{aligned}
 \text{Total energy} &= n(H_2SO_4) \times \Delta H \\
 &= 769786 \times 230 \\
 &= 177050780 \text{ kJ} \\
 &\approx \mathbf{177 \text{ MJ}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{Maximum Energy} &= 170 \text{ MJ} + 5 \text{ MJ} \\
 &= \mathbf{175 \text{ MJ}} \quad (1)
 \end{aligned}$$

$\therefore$  As the **energy produced exceeds the maximum cooling capacity**, the **factory will burn down** (1)

**Point to note:** Questions involving calculating energy are not typically asked in Chemistry exams, but this is still a good conceptual question to test your ability to deal with new question types.

# Problem Set 4 – Stoichiometry

## Repetitive Questions

### Concept 1

### The Mole – Repetitive Questions Answers

#### Calculating Moles: 1.5 & 1.51

1.5

[6 marks]

$$\begin{aligned} \text{(a)} \quad n(\text{H}_2\text{O}) &= \frac{m}{M} \\ &= \frac{100}{16+1.008 \times 2} \\ &= \mathbf{5.551 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(b)} \quad n(\text{Na}_8\text{Be}_6\text{Si}_6\text{O}_{24}\text{Cl}_2) &= \frac{m}{M} \times 0.62 \\ &= \frac{1.232 \times 10^6}{22.99 \times 8 + 9.012 \times 6 + 28.09 \times 6 + 16 \times 24 + 35.45 \times 2} \\ &= \mathbf{1430.177 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(c)} \quad n(\text{NH}_3) &= \frac{V}{22.71} \\ &= \frac{22 \times 10^3}{22.71} \\ &= \mathbf{968.736 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(d)} \quad n(\text{H}_2\text{O}) &= \frac{PV}{RT} \\ &= \frac{(101 \times 3) \times 1}{8.314 \times (600 + 273.15)} \\ &= \mathbf{4.174 \times 10^{-2} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(e)} \quad n(\text{NaOH}) &= cV \\ &= 1 \times \left(\frac{50}{1000}\right) \\ &= \mathbf{0.05 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(f)} \quad n(\text{He}) &= \frac{V}{22.71} \\ &= \frac{300}{22.71} \\ &= \mathbf{13.21 \text{ mol}} \quad (1) \end{aligned}$$

1.51

[6 marks]

$$\begin{aligned} \text{(a) (i)} \quad n(\text{NH}_3) &= \frac{PV}{RT} \\ &= \frac{343 \times 10}{8.314 \times (72 + 273.15)} \\ &= \mathbf{1.195 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(ii)} \quad n(\text{NH}_3) &= \frac{V}{22.71} \\ &= \frac{10}{22.71} \\ &= \mathbf{0.44 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(b) (i)} \quad n(\text{H}_2\text{SO}_4) &= cV \\ &= 1 \times \left(\frac{50}{1000}\right) \\ &= \mathbf{0.05 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(ii)} \quad n(\text{H}_2\text{SO}_4) &= \frac{m}{M} \\ &= \frac{(1 \times 1000)}{1.008 \times 2 + 32.06 + 16 \times 4} \\ &= \mathbf{10.196 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(c) (i)} \quad n(\text{Cl}_2) &= \frac{m}{M} \\ &= \frac{(63 \times 1000)}{35.45 \times 2} \\ &= \mathbf{888.575 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(ii)} \quad n(\text{Cl}_2) &= \frac{PV}{RT} \\ &= \frac{400 \times 63}{8.314 \times (300 + 273.15)} \\ &= \mathbf{5.288 \text{ mol}} \quad (1) \end{aligned}$$

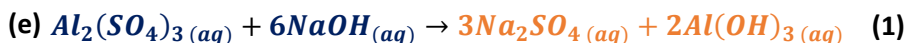
## Concept 2

# Reaction Equations and the Molar Ratio – Repetitive Questions Answers

### Balancing Single Equations: 2.2

2.2

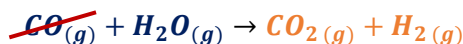
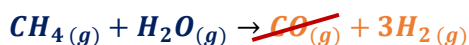
[10 marks]



### Multi-Stage Reactions: 2.3 & 2.4

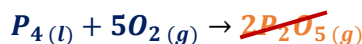
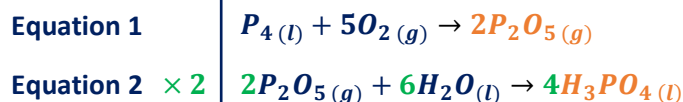
2.3

[3 marks]



2.4

[3 marks]



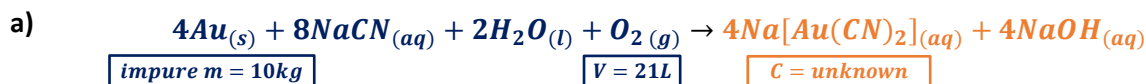
## Concept 3

# Real World Stoichiometry – Repetitive Questions Answers

### Limiting Reagents: 3.5, 3.6 & 3.7

3.5

[8 marks]



$$n(Au) = \frac{m \times 0.42}{M} \quad (1)$$

$$= \frac{(10 \times 10^3) \times 0.42}{197} \quad (1)$$

$$= 21.32\ mol \quad (1)$$

$$n(O_2) = \frac{PV}{RT}$$

$$= \frac{178 \times 21}{8.314 \times (100 + 273.15)}$$

$$= 1.205\ mol \quad (1)$$

$$n(O_2)_{required} = \frac{1}{4} \times n(Au)$$

$$= 5.33\ mol$$

$$n(O_2) < n(O_2)_{required}$$

$$\therefore O_2\ is\ limiting\ reagent \quad (1)$$

$$n(Au)_{required} = 4 \times n(O_2)$$

$$= 4.82\ mol$$

$$n(Au) > n(Au)_{required}$$

$$\therefore O_2\ is\ limiting\ reagent \quad (1)$$

$$\begin{aligned}
 n(4\text{Na}[\text{Au}(\text{CN})_2]) &= \frac{4}{1} \times n(\text{O}_2) \\
 &= 4 \times 1.205 \\
 &= \mathbf{4.82 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 C(4\text{Na}[\text{Au}(\text{CN})_2]) &= \frac{n}{V} \\
 &= \frac{4.82}{2} \\
 &= \mathbf{2.41 \text{ molL}^{-1}} \quad (1)
 \end{aligned}$$

b)

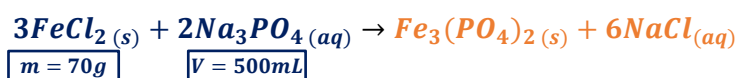
$$\begin{aligned}
 V(\text{H}_2\text{O})_{\text{total}} &= \frac{n(4\text{Na}[\text{Au}(\text{CN})_2])}{c} \\
 &= \frac{4.82}{1.2} \\
 &= \mathbf{4.016 \text{ L}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 V(\text{H}_2\text{O})_{\text{added}} &= V(\text{H}_2\text{O})_{\text{total}} - V(\text{H}_2\text{O}) \\
 &= 4.016 - 2 \\
 &= \mathbf{2.02 \text{ L}} \quad (1)
 \end{aligned}$$

3.6

[8 marks]

a)



$$\begin{aligned}
 n(\text{FeCl}_2) &= \frac{m}{M} \\
 &= \frac{70}{55.85 + 35.45 \times 2} \\
 &= \mathbf{0.552 \text{ mol}}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{Na}_3\text{PO}_4) &= cV \\
 &= 0.5 \times \left(\frac{500}{1000}\right) \\
 &= \mathbf{0.25 \text{ mol}}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{FeCl}_2)_{\text{required}} &= \frac{3}{2} \times n(\text{Na}_3\text{PO}_4) \\
 &= \mathbf{0.375 \text{ mol}}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{Na}_3\text{PO}_4)_{\text{required}} &= \frac{2}{3} \times n(\text{FeCl}_2) \\
 &= \mathbf{0.368 \text{ mol}}
 \end{aligned}$$

$$n(\text{FeCl}_2) > n(\text{FeCl}_2)_{\text{required}}$$

$\therefore \text{Na}_3\text{PO}_4$  is limiting reagent (1)

Either  
Option

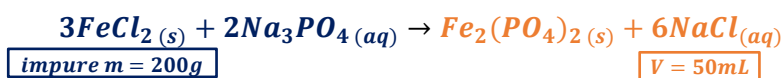
$$n(\text{Na}_3\text{PO}_4) < n(\text{Na}_3\text{PO}_4)_{\text{required}}$$

$\therefore \text{Na}_3\text{PO}_4$  is limiting reagent (1)

$$\begin{aligned}
 n(\text{Fe}_2(\text{PO}_4)_2) &= \frac{1}{2} \times n(\text{Na}_3\text{PO}_4) \\
 &= \frac{1}{2} \times 0.25 \\
 &= \mathbf{0.125 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(\text{Fe}_2(\text{PO}_4)_2) &= n \times M \\
 &= 0.125 \times (55.85 \times 2 + 30.97 \times 2 + 16 \times 8) \\
 &= \mathbf{37.705 \text{ g}} \quad (1)
 \end{aligned}$$

b)



$$\begin{aligned}
 n(\text{NaCl}) &= cV \\
 &= 0.8 \times \frac{750}{1000} \\
 &= \mathbf{0.6 \text{ mol}} \quad (1)
 \end{aligned}$$

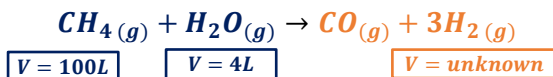
$$\begin{aligned}
 n(\text{FeCl}_2) &= \frac{3}{6} \times n(\text{NaCl}) \\
 &= \frac{3}{6} \times 0.6 \\
 &= \mathbf{0.3 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(\text{FeCl}_2) &= n \times M \\
 &= 0.3 \times (55.85 + 35.45 \times 2) \\
 &= \mathbf{38.025 \text{ g}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \%(\text{FeCl}_2) &= \frac{m_{\text{actual}}}{m_{\text{theoretical}}} \times 100 \\
 &= \frac{38.025}{200} \times 100 \\
 &= \mathbf{19.013\%} \quad (1)
 \end{aligned}$$

3.7

[9 marks]



a)

$$\begin{aligned} n(\text{CH}_4) &= \frac{m}{M} \times 0.87 \\ &= \frac{0.657 \times 100 \times 1000}{12.01 + 1.008 \times 4} \times 0.87 \\ &= \mathbf{3563 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{H}_2\text{O}) &= \frac{PV}{RT} \\ &= \frac{110 \times 4}{8.314 \times (300 + 273.15)} \\ &= \mathbf{9.234 \times 10^{-2} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{CH}_4)_{\text{required}} &= \frac{1}{2} \times n(\text{H}_2\text{O}) \\ &= \mathbf{4.617 \times 10^{-2} \text{ mol}} \end{aligned}$$

$$\begin{aligned} n(\text{CH}_4) &> n(\text{CH}_4)_{\text{required}} \\ \therefore \mathbf{H_2O \text{ is limiting reagent}} \quad (1) \end{aligned}$$

Either  
Option

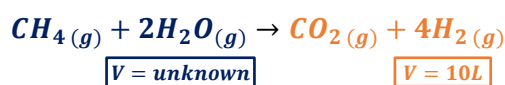
$$\begin{aligned} n(\text{H}_2\text{O})_{\text{required}} &= \frac{2}{1} \times n(\text{CH}_4) \\ &= \mathbf{7126 \text{ mol}} \end{aligned}$$

$$\begin{aligned} n(\text{H}_2\text{O}) &< n(\text{H}_2\text{O})_{\text{required}} \\ \therefore \mathbf{H_2O \text{ is limiting reagent}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{H}_2) &= \frac{3}{1} \times n(\text{H}_2\text{O}) \\ &= \frac{3}{1} \times 9.234 \times 10^{-2} \\ &= \mathbf{0.277 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} V(\text{H}_2) &= \frac{nRT}{P} \\ &= \frac{0.277 \times 8.314 \times (300 + 273.15)}{110} \\ &= \mathbf{12 \text{ L}} \quad (1) \end{aligned}$$

b)



$$\begin{aligned} n(\text{H}_2) &= \frac{PV}{RT} \\ &= \frac{110 \times 10}{8.314 \times (200 + 273.15)} \\ &= \mathbf{0.28 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{H}_2\text{O}) &= \frac{\frac{2}{4} \times n(\text{H}_2)}{0.92} \\ &= \frac{\frac{2}{4} \times 0.28}{0.92} \\ &= \mathbf{0.152 \text{ mol}} \quad (1) \end{aligned}$$

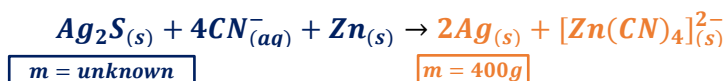
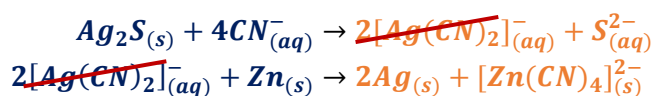
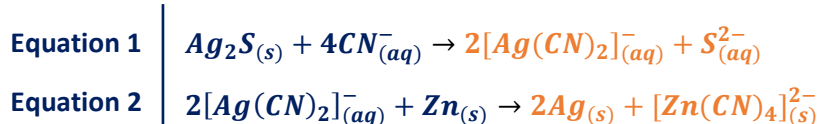
$$\begin{aligned} V(\text{H}_2\text{O}) &= \frac{nRT}{P} \\ &= \frac{0.152 \times 8.314 \times (200 + 273.15)}{110} \\ &= \mathbf{5.435 \text{ L}} \quad (1) \end{aligned}$$

## Multi-Reaction Stoichiometry: 3.9 & 3.101

3.9

[10 marks]

a)



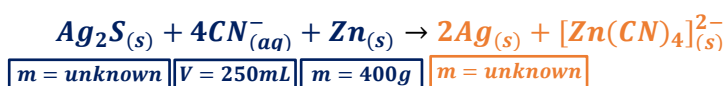
$$\begin{aligned} n(\text{Ag}) &= \frac{m}{M} \\ &= \frac{400}{107.9} \\ &= 3.707 \text{ mol} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{Ag}_2\text{S}) &= \frac{1}{2} \times n(\text{Ag}) \\ &= \frac{1}{2} \times 3.707 \\ &= 1.854 \text{ mol} \quad (1) \end{aligned}$$

$$\begin{aligned} m(\text{Ag}_2\text{S}) &= n \times M \\ &= 1.854 \times (107.9 \times 2 + 32.07) \\ &= 459.6 \text{ g} \quad (1) \end{aligned}$$

$$\begin{aligned} \%( \text{Ag}_2\text{S} ) &= \frac{m_{\text{actual}}}{m_{\text{theoretical}}} \times 100 \\ &= \frac{459.6}{2 \times 1000} \times 100 \\ &\approx 23\% \quad (1) \end{aligned}$$

b)



$$\begin{aligned} n(\text{Ag}_2\text{S}) &= \frac{m}{M} \times 0.24 \\ &= \frac{1.87 \times 1000}{(107.9 \times 2 + 32.07)} \times 0.24 \\ &= 1.811 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{CN}^-) &= cV \\ &= 1 \times 16 \\ &= 16 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{Zn}) &= \frac{m}{M} \\ &= \frac{400}{65.38} \\ &= 6.118 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{Ag}_2\text{S})_{\text{required}} &= \frac{1}{4} \times n(\text{CN}^-) \\ &= 4 \text{ mol} \\ n(\text{Ag}_2\text{S}) &< n(\text{Ag}_2\text{S})_{\text{required}} \\ \therefore \text{Ag}_2\text{S} &\text{ is limiting reagent} \end{aligned} \quad (1)$$

$$\begin{aligned} n(\text{Ag}_2\text{S})_{\text{required}} &= n(\text{Zn}) \\ &= 6.118 \text{ mol} \\ n(\text{Ag}_2\text{S}) &< n(\text{Ag}_2\text{S})_{\text{required}} \\ \therefore \text{Ag}_2\text{S} &\text{ is limiting reagent} \end{aligned} \quad (1)$$

Check  
Both

$$\begin{aligned} n(\text{Ag}) &= 2 \times n(\text{Ag}_2\text{S}) \\ &= 2 \times 1.811 \\ &= 3.622 \text{ mol} \quad (1) \end{aligned}$$

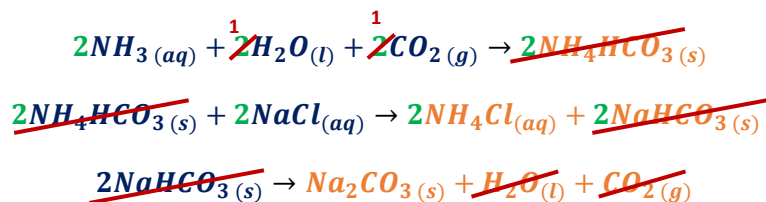
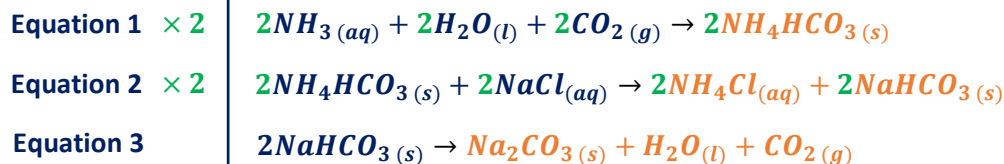
$$\begin{aligned} m(\text{Ag}) &= n \times M \\ &= 3.622 \times 107.9 \\ &= 391 \text{ g} \quad (1) \end{aligned}$$

**Point to note:** There are 3 interacting reagents here, of which one will be limiting. We can guess that  $\text{Ag}_2\text{S}$  will be the limiting reagent there is only a very small amount available, but still need to check this against the other reactants.

3.101

[10 marks]

a)



$$\begin{aligned} n(\text{NH}_3) &= \frac{m}{M} \times 0.98 \\ &= \frac{(50 \times 1000)}{(14.01 + 1.008 \times 3)} \times 0.98 \\ &= 2.876 \times 10^3 \text{ mol} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{NaCl}) &= cV \\ &= 12.5 \times 250 \\ &= 3.125 \times 10^3 \text{ mol} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{NH}_3)_{\text{required}} &= \frac{2}{2} \times n(\text{NaCl}) \\ &= 3.125 \times 10^3 \text{ mol} \\ n(\text{NH}_3) &< n(\text{NH}_3)_{\text{required}} \\ \therefore \text{NH}_3 &\text{ is limiting reagent} \quad (1) \end{aligned}$$

Either  
Option

$$\begin{aligned} n(\text{NaCl})_{\text{required}} &= \frac{2}{2} \times n(\text{NH}_3) \\ &= 2.876 \times 10^3 \text{ mol} \\ n(\text{NaCl}) &> n(\text{NaCl})_{\text{required}} \\ \therefore \text{NH}_3 &\text{ is limiting reagent} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{Na}_2\text{CO}_3) &= \frac{1}{2} \times n(\text{NH}_3) \times 0.85 \\ &= \frac{1}{2} \times 2.876 \times 10^3 \times 0.85 \\ &= 1.223 \times 10^3 \text{ mol} \quad (1) \end{aligned}$$

$$\begin{aligned} m(\text{Na}_2\text{CO}_3) &= n \times M \\ &= 1.223 \times 10^3 \times (22.99 \times 2 + 12.01 + 16 \times 3) \\ &= 12.958 \times 10^4 \text{ g} \\ &= 129.58 \text{ kg} \quad (1) \end{aligned}$$

b)

$$\begin{aligned} V(\text{H}_2\text{O})_{\text{total}} &= \frac{n(\text{Na}_2\text{CO}_3)}{c} \\ &= \frac{1.223 \times 10^3}{1} \\ &= 1.223 \times 10^3 \text{ L} \quad (1) \\ V(\text{H}_2\text{O})_{\text{added}} &= V(\text{H}_2\text{O})_{\text{total}} - V(\text{H}_2\text{O}) \quad (1) \\ &= 1.223 \times 10^3 - 500 \\ &= 722.6 \text{ L} \quad (1) \end{aligned}$$

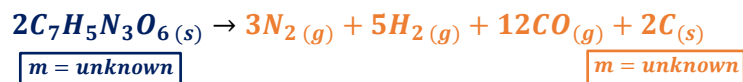


## Exam-Style Stoichiometry: 3.111, 3.121, 3.131 & 3.141

3.111

[10 marks]

a)



$m = \text{unknown}$

$m = \text{unknown}$

$$m(C)_{total} = \frac{m(C)_{recovered} \times 0.3}{0.25} \quad (1)$$

$$= 1800 \text{ g} \quad (1)$$

$$n(C) = \frac{m}{M}$$

$$= \frac{1800}{12.01}$$

$$= 149.9 \text{ mol} \quad (1)$$

$$n(C_7H_5N_3O_6) = \frac{2}{2} \times n(C)$$

$$= \frac{2}{2} \times 149.9$$

$$= 149.9 \text{ mol} \quad (1)$$

$$m(C_7H_5N_3O_6) = n \times M$$

$$= 149.9 \times (12.01 \times 7 + 1.008 \times 5 + 14.01 \times 3 + 16 \times 6)$$

$$= 34 \text{ kg} \quad (1)$$

b)



$m = 5 \text{ kg}$

$H = \text{unknown}$

$$n(C_7H_5N_3O_6) = \frac{m}{M}$$

$$= \frac{5 \times 1000}{(12.01 \times 7 + 1.008 \times 5 + 14.01 \times 3 + 16 \times 6)}$$

$$= 22.01 \text{ mol} \quad (1)$$

$$H = |\Delta H| \times n(C_7H_5N_3O_6) \quad (1)$$

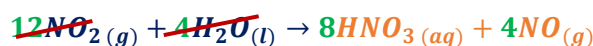
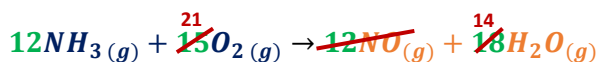
$$= 54.4 \times 22.01$$

$$= 1.2 \times 10^3 \text{ kJ} \quad (1)$$

3.121

[10 marks]

a)



$$n(HNO_3) = cV$$

$$= 1 \times 15$$

$$= 15 \text{ mol} \quad (1)$$

$$n(NH_3) = \frac{12}{8} \times n(HNO_3)$$

$$= \frac{12}{8} \times 15$$

$$= 22.5 \text{ mol} \quad (1)$$

$$V(NH_3) = \frac{nRT}{P}$$

$$= \frac{22.5 \times 8.314 \times (80 + 273.15)}{150}$$

$$= 440.413 \text{ L} \quad (1)$$

b)

$$V(\text{H}_2\text{O})_{\text{total}} = \frac{n(\text{HNO}_3)}{c}$$

$$= \frac{15}{0.777}$$

$$= 19.305 \text{ L} \quad (1)$$

$$V(\text{H}_2\text{O})_{\text{added}} = V(\text{H}_2\text{O})_{\text{total}} - V(\text{H}_2\text{O}) \quad (1)$$

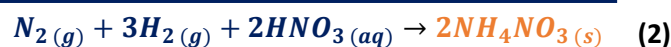
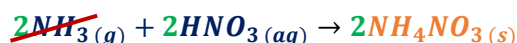
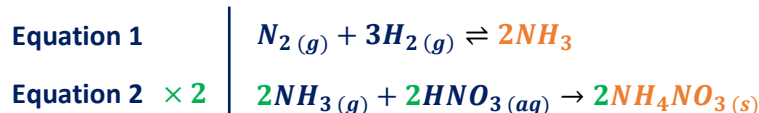
$$= 19.305 - 15$$

$$= 4.305 \text{ L} \quad (1)$$

3.131

[11 marks]

a)



$$n(N_2) = \frac{PV}{RT}$$

$$= \frac{189 \times 10}{8.314 \times (90 + 273.15)}$$

$$= 0.626 \text{ mol}$$

$$n(H_2) = \frac{V}{22.71}$$

$$= \frac{20}{22.71}$$

$$= 0.881 \text{ mol}$$

$$n(HNO_3) = \frac{m}{M}$$

$$= \frac{(89.2 \times 200)}{(1.008 + 14.01 + 16 \times 3)}$$

$$= 70.773 \text{ mol}$$

(1)

$$n(H_2)_{\text{required}} = \frac{3}{1} \times n(N_2)$$

$$= 1.878 \text{ mol}$$

$$n(H_2) < n(H_2)_{\text{required}}$$

$$\therefore H_2 \text{ is limiting reagent}$$

(1)

Check  
Both

$$n(H_2)_{\text{required}} = \frac{3}{2} \times n(HNO_3)$$

$$= 106.16 \text{ mol}$$

$$n(H_2) < n(H_2)_{\text{required}}$$

$$\therefore H_2 \text{ is limiting reagent} \quad (1)$$

$$n(NH_4NO_3)_{\text{theoretical}} = \frac{2}{3} \times n(H_2)$$

$$= \frac{2}{3} \times 0.881$$

$$= 0.587 \text{ mol} \quad (1)$$

$$m(NH_4NO_3)_{\text{theoretical}} = n \times M$$

$$= 0.587 \times (14.01 \times 2 + 1.008 \times 4 + 16 \times 3)$$

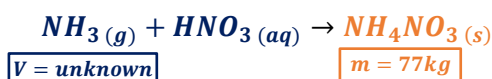
$$= 47 \text{ g} \quad (1)$$

$$\text{Efficiency} = \frac{m(NH_4NO_3)_{\text{actual}}}{m(NH_4NO_3)_{\text{theoretical}}} \times 100$$

$$= \frac{10}{47} \times 100$$

$$= 21.3\% \quad (1)$$

b)



$$n(NH_4NO_3) = \frac{m}{M}$$

$$= \frac{(77 \times 1000)}{(14.01 \times 2 + 1.008 \times 4 + 16 \times 3)} \quad (1)$$

$$= 961.9 \text{ mol}$$

$$n(NH_3) = \frac{n(NH_4NO_3)}{0.78}$$

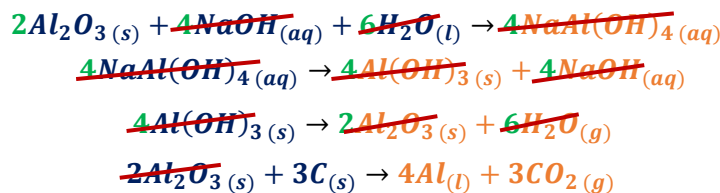
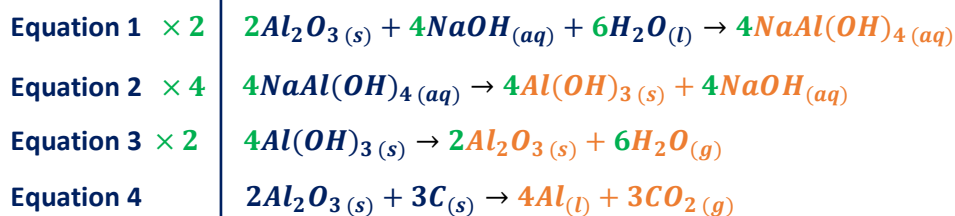
$$= 1233 \text{ mol} \quad (1)$$

$$V(NH_3) = n \times 22.71$$

$$= 1233 \times 22.71$$

$$\stackrel{23}{=} 28 \text{ kL} \quad (1)$$

a)



$$\begin{aligned} n(\text{Al}_2\text{O}_3) &= \frac{m}{M} \\ &= \frac{(10 \times 1000)}{(26.98 \times 2 + 16 \times 3)} \\ &= \mathbf{98.078 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{Al})_{\text{theoretical}} &= \frac{4}{2} \times n(\text{Al}_2\text{O}_3) \\ &= \frac{4}{2} \times 98.078 \\ &= \mathbf{196.155 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} m(\text{Al})_{\text{theoretical}} &= n \times M \\ &= 196.155 \times 26.98 \\ &= 5.292 \times 10^3 \text{ g} \\ &= \mathbf{5.292 \text{ kg}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{Efficiency} &= \frac{m(\text{Al})_{\text{actual}}}{m(\text{Al})_{\text{theoretical}}} \times 100 \\ &= \frac{3}{5.292} \times 100 \\ &= \mathbf{56.7\%} \quad (1) \end{aligned}$$

b)

$$\begin{aligned} n(\text{Al}_2\text{O}_3) &= \frac{m}{M} \times 0.86 \\ &= \frac{(250 \times 1000)}{26.98 \times 2 + 16 \times 3} \times 0.86 \\ &= \mathbf{2.452 \times 10^3 \text{ mol}} \end{aligned}$$

$$\begin{aligned} n(\text{NaOH}) &= cV \\ &= 0.8 \times 200 \\ &= \mathbf{160 \text{ mol}} \end{aligned}$$

$$\begin{aligned} n(\text{H}_2\text{O}) &= \frac{m}{M} \\ &= \frac{(140 \times 1000)}{1.008 \times 2 + 16} \\ &= \mathbf{7.771 \times 10^3 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{NaOH})_{\text{required}} &= \frac{2}{1} \times n(\text{Al}_2\text{O}_3) \\ &= \mathbf{4.904 \times 10^3 \text{ mol}} \\ n(\text{NaOH}) &< n(\text{NaOH})_{\text{required}} \\ \therefore \text{NaOH is limiting reagent} \end{aligned}$$

Check  
Both

$$\begin{aligned} n(\text{NaOH})_{\text{required}} &= \frac{2}{3} \times n(\text{H}_2\text{O}) \\ &= \mathbf{5.181 \times 10^3 \text{ mol}} \\ n(\text{NaOH}) &< n(\text{NaOH})_{\text{required}} \\ \therefore \text{NaOH is limiting reagent} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{Al}) &= \frac{4}{4} \times n(\text{NaOH}) \\ &= \mathbf{160 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} m(\text{Al}) &= n \times M \\ &= 160 \times 26.98 \\ &= 4.317 \times 10^3 \text{ g} \\ &= \mathbf{4.317 \text{ kg}} \quad (1) \end{aligned}$$

$\therefore$  Neil will not have enough aluminium for the order (1)

**Point to note:** While NaOH is not included in the overall reaction, it still plays a part in the reaction process. We can see from steps 1 and 4 of the reaction that 4 moles of NaOH are required to produce 4 moles of aluminium, giving us our molar ratio.

c)

$$\begin{aligned}
 n(\text{Al}) &= \frac{m}{M} \\
 &= \frac{300}{26.98} \\
 &= \mathbf{11.119 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(\text{Al}_2\text{O}_3)_{\text{actual}} &= \frac{2}{4} \times n(\text{Al}) \\
 &= \frac{2}{4} \times 11.119 \\
 &= \mathbf{5.56 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(\text{Al}_2\text{O}_3)_{\text{actual}} &= n \times M \\
 &= 5.56 \times (26.98 \times 2 + 16 \times 3) \\
 &= \mathbf{566.864 \text{ g}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \%(\text{Al}_2\text{O}_3) &= \frac{m(\text{Al}_2\text{O}_3)_{\text{actual}}}{m(\text{Al}_2\text{O}_3)_{\text{theoretical}}} \times 100 \\
 &= \frac{566.864}{(6 \times 1000)} \times 100 \\
 &= \mathbf{9.45\%} \quad (1)
 \end{aligned}$$

### Extra Dilution Questions: Q1, Q2, Q3

1.

[8 marks]

(a)

$$\begin{aligned}
 c_1V_1 &= c_2V_2 \\
 V_2 &= \frac{c_1V_1}{c_2} \\
 &= \frac{2 \times 0.05}{0.4} \\
 &= \mathbf{0.25 \text{ L}} \quad (1) \\
 \Delta V &= V_2 - V_1 \\
 &= \mathbf{0.2 \text{ L}} \quad (1)
 \end{aligned}$$

(b)

$$\begin{aligned}
 c_1V_1 &= c_2V_2 \\
 c_1 &= \frac{c_2V_2}{V_1} \quad (1) \\
 &= \frac{1 \times 0.1}{0.02} \\
 &= \mathbf{5 \text{ mol L}^{-1}} \quad (1)
 \end{aligned}$$

**Point to note:** In this question we can deduce the original volume was 20mL because 80mL was added to get  $V_2$  to 100mL

(c)

$$\begin{aligned}
 c_1V_1 &= c_2V_2 \\
 c_2 &= \frac{c_1V_1}{V_2} \quad (1) \\
 &= \frac{0.3 \times 1}{3} \\
 &= \mathbf{0.1 \text{ mol L}^{-1}}
 \end{aligned}$$

**Point to note:** In this question we can use any numbers as long as the ratio of  $\frac{V_1}{V_2} = \frac{1}{3}$ , which is easiest if you just use the numbers of 1L and 3L.

(d)

$$\begin{aligned}
 c_1V_1 &= c_2V_2 \\
 c_2 &= \frac{c_1V_1}{V_2} \quad (1) \\
 &= \frac{0.4 \times 0.2}{1} \\
 &= \mathbf{0.08 \text{ mol L}^{-1}}
 \end{aligned}$$

2.

[3 marks]

You need to think through this question as follows:

“You have two solutions that you can combine together to get an overall concentration of  $0.5 \text{ mol L}^{-1}$ . Therefore you need to figure out the ratio of  $0.6 \text{ mol L}^{-1}$  solution to  $0.2 \text{ mol L}^{-1}$  solution.”



To do this you can do this via trial and error. Let's start with 'one part'  $0.6 \text{ mol L}^{-1}$  solution and 'one part'  $0.2 \text{ mol L}^{-1}$  solution. The overall concentration is:

$$\frac{0.6 + 0.2}{2} = 0.4 \text{ mol L}^{-1}$$

To get it closer to  $0.5 \text{ mol L}^{-1}$ , we need to increase the number of parts of  $0.6 \text{ mol L}^{-1}$  solution. So now let's try with 'two parts'  $0.6 \text{ mol L}^{-1}$  solution and 'one part'  $0.2 \text{ mol L}^{-1}$  solution. The overall concentration is:

$$\frac{0.6 \times 2 + 0.2}{3} = 0.467 \text{ mol L}^{-1}$$

It's getting closer, so now let's try with 'three parts'  $0.6 \text{ mol L}^{-1}$  solution and 'one part'  $0.2 \text{ mol L}^{-1}$  solution. The overall concentration is:

$$\frac{0.6 \times 3 + 0.2}{4} = 0.5 \text{ mol L}^{-1} \quad (3)$$

**Point to note:** This question requires a high level of thought. It's less about the maths and more just about thinking it through logically. It is also important to note that it is unlikely that

3.

[3 marks]

$$V_2 = V_1 + 0.2 \quad (1)$$

$$c_1 V_1 = c_2 (V_1 + 0.2)$$

$$\frac{V_1 + 0.2}{V_1} = \frac{c_1}{c_2}$$

$$1 + \frac{0.2}{V_1} = \frac{1.6 \times 10^{-2}}{5 \times 10^{-3}}$$

$$\frac{0.2}{V_1} = 2.2 \quad (1)$$

$$V_1 = 0.909 \text{ L}$$

$$= 90.9 \text{ mL}$$

---

# Chapter 3

---

## Acids and Bases Answers

<b>Problem Set 5 Progressive Answers – Acids and Bases BTG .....</b>	<b>1</b>
<b>Problem Set 5 Repetitive Answers – Acids and Bases BTG .....</b>	<b>5</b>
<b>Problem Set 6 Progressive Answers – Acids and Bases .....</b>	<b>8</b>
<b>Problem Set 6 Repetitive Answers – Acids and Bases .....</b>	<b>26</b>



# Problem Set 5 – Acids and Bases BTG

## Progressive Questions

### Concept 1

## Bridging the Gap - Progressive Questions Answers

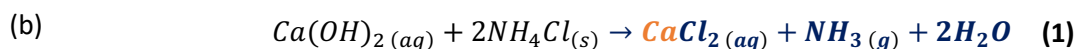
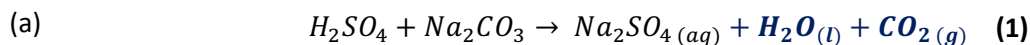
### Balanced Equations and Net Ionic Equations: Q1, Q2, Q3, Q4, Q5

1. [3 marks]

- (i) Equal      (ii) **Salt and by-products**      (iii) **Negative**      (iv) **Positive**  
 (v) **H, O, C, N and S**      (vi) **H<sub>2</sub>, H<sub>2</sub>O, CO<sub>2</sub>, NO<sub>2</sub> and SO<sub>2</sub>**

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Half a mark for each correct option</li> </ul>	0.5 – 3
<b>Total</b>	<b>3</b>

2. [3 marks]

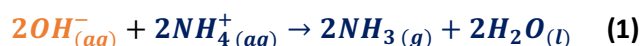


3. [3 marks]

(a) By definition, a net ionic equation is an equation that does not include spectator ions (1), so that they are only showing the species that are actually reacting. Balanced equations show all of the species of the reaction (1).



2. Remove all ions that remain aqueous throughout the reaction



4.

[6 marks]

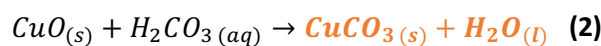
## Correct Reaction 1



## Correct Reaction 2



## Correct Reaction 3



5.

[16 marks]

- (i)  $\text{Mg}_{(s)} + 2\text{HCl}_{(aq)} \rightarrow \text{MgCl}_2(aq) + \text{H}_2(g) \quad (2)$
- (ii)  $\text{CH}_3\text{COOH}_{(aq)} + \text{NaOH}_{(aq)} \rightarrow \text{NaCH}_3\text{COO}_{(aq)} + \text{H}_2\text{O}_{(l)} \quad (2)$
- (iii)  $\text{CO}_2(g) + \text{Ca}(\text{OH})_2(aq) \rightarrow \text{CaCO}_3(s) + \text{H}_2\text{O}_{(l)} \quad (2)$
- (iv)  $\text{Na}_2\text{CO}_3(s) + \text{HNO}_3(aq) \rightarrow \text{NaNO}_3(aq) + \text{H}_2\text{O}_{(l)} + \text{CO}_2(g) \quad (2)$
- (v)  $2\text{NaHCO}_3(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + 2\text{H}_2\text{O}_{(l)} + 2\text{CO}_2(g) \quad (2)$
- (vi)  $\text{Na}_2\text{O}_{(s)} + 2\text{HCl}_{(aq)} \rightarrow 2\text{NaCl}_{(aq)} + \text{H}_2(g) \quad (2)$
- (vii)  $2\text{NH}_4\text{Cl}_{(s)} + \text{Ca}(\text{OH})_2(aq) \rightarrow \text{CaCl}_2(aq) + 2\text{H}_2\text{O}_{(l)} + 2\text{NH}_3(g) \quad (2)$
- (viii)  $\text{H}_2\text{SO}_4(aq) + \text{CaSO}_3(s) \rightarrow \text{CaSO}_4(aq) + \text{SO}_2(g) + \text{H}_2\text{O}_{(l)} \quad (2)$

6.

[8 marks]

- (i)  $\text{Mg}_{(s)} + 2\text{H}^+_{(aq)} \rightarrow \text{Mg}^{2+}_{(aq)} + \text{H}_2(g) \quad (1)$
- (ii)  $\text{H}^+_{(aq)} + \text{OH}^-_{(aq)} \rightarrow \text{H}_2\text{O}_{(l)} \quad (1)$
- (iii)  $\text{CO}_2(g) + \text{Ca}(\text{OH})_2(aq) \rightarrow \text{CaCO}_3(s) + \text{H}_2\text{O}_{(l)} \quad (1)$

**Point to note:** All species undergo a change, so all remain included in the net ionic equation.

- (iv)  $\text{Na}_2\text{CO}_3(s) + 2\text{H}^+_{(aq)} \rightarrow 2\text{Na}^+_{(aq)} + \text{H}_2\text{O}_{(l)} + \text{CO}_2(g) \quad (1)$
- (v)  $2\text{NaHCO}_3(s) + 2\text{H}^+_{(aq)} \rightarrow 2\text{Na}^+_{(aq)} + 2\text{H}_2\text{O}_{(l)} + 2\text{CO}_2(g) \quad (1)$
- (vi)  $\text{Na}_2\text{O}_{(s)} + 2\text{H}^+_{(aq)} \rightarrow 2\text{Na}^+_{(aq)} + \text{H}_2(g) \quad (1)$
- (vii)  $2\text{NH}_4\text{Cl}_{(s)} + 2\text{OH}^-_{(aq)} \rightarrow 2\text{Cl}^-_{(aq)} + 2\text{H}_2\text{O}_{(l)} + 2\text{NH}_3(g) \quad (1)$
- (viii)  $2\text{H}^+_{(aq)} + \text{CaSO}_3(s) \rightarrow \text{Ca}^{2+}_{(aq)} + \text{SO}_2(g) + \text{H}_2\text{O}_{(l)} \quad (1)$



## Observations of Reactions: Q7, Q8, Q9, Q10

7.

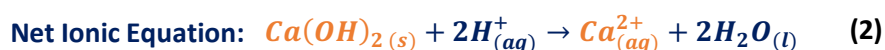
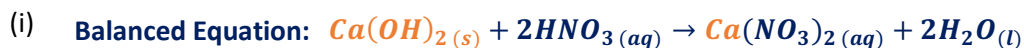
[6 marks]

The observations for each reaction are as follows:

- Reaction 1: A black powder is added to a colourless solution (1), to produce a blue solution (1).
- Reaction 2: A black powder is added to a colourless solution (1), to produce a blue precipitate and a colourless solution (1).
- Reaction 3: A white powder is added to a colourless solution (1), to produce a green precipitate and a colourless solution (1).

8.

[32 marks]



**Observations:** A white powder is added to a colourless solution (1), to produce a colourless solution (1).

**Point to note:** No marks are awarded for the balanced equation, but it can be a helpful intermediate step for ensuring your net ionic equation is balanced and correct!



**Observations:** A salmon pink metal is added to a colourless solution (1), to produce a blue solution and a colourless, odourless gas (1).

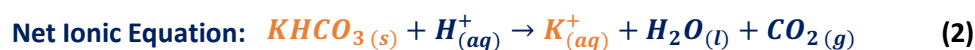


**Observations:** A white powder is added to a colourless solution (1), to produce a colourless solution and a white precipitate (1).

**Point to note:**  $\text{PbCl}_2$  is only 'slightly soluble', so it is recognised in the equation as a solid not aqueous. A precipitate will also be observed, because some  $\text{PbCl}_2$  will be soluble and some will be insoluble.



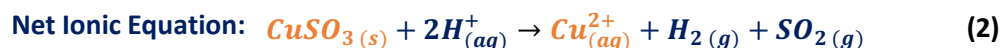
**Observations:** A white powder is added to a colourless solution (1), to produce a colourless solution and a colourless, pungent gas (1).



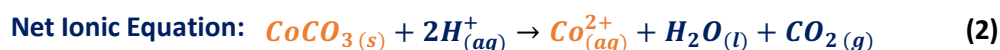
**Observations:** A white powder is added to a colourless solution (1), to produce a colourless solution and a colourless, odourless gas (1).



**Observations:** A colourless, odourless gas is bubbled through a colourless solution (1), to produce a colourless solution and a white precipitate (1).



**Observations:** A colourless, odourless gas is bubbled through a colourless solution (1), to produce a colourless solution and a white precipitate (1).



**Observations:** A pink solid is added to a colourless solution (1), to produce a pink solution and a colourless, odourless gas (1).

9.

[8 marks]

Statements	Correct	Incorrect
A white powder is added to a colourless solution, to produce a colourless solution and a colourless gas with a pungent odour.		✓ (1)
<b>Corrected Observation (if you ticked 'Incorrect'):</b> The products of this reaction are solid ammonium hydroxide, barium bromide and water, not any kind of colourless, pungent gas (1). Therefore Jamie's observation is incorrect.		
A deep green powder is dissolved in a colourless solution to produce a colourless solution.		✓ (1)
<b>Corrected Observation (if you ticked 'Incorrect'):</b> Whilst the reactant observations are correct, the products of the reaction should be a chromium ethanoate solution, carbon dioxide and water. Therefore the observations are incorrect, as it should be observed that a deep green solution and a colourless, odourless gas are produced (1).		
A white powder is dissolved in a colourless solution to produce a blue solution and a colourless, odourless gas.		✓ (1)
<b>Corrected Observation (if you ticked 'Incorrect'):</b> Copper sulphate is blue (1), so a blue powder is added to a colourless solution to produce a blue solution and a colourless, odourless gas.		
A white solid is added to a colourless solution to produce a colourless solution		✓ (1)
<b>Corrected Observation (if you ticked 'Incorrect'):</b> Nickel carbonate is a green solid not a white solid, and an insoluble green solid should be produced along with a colourless, odourless gas (1).		

**Point to note:** This question is a good test of your ability to visualise an equation in your head, and be able to determine the observations without having to actually write the equation down.

# Problem Set 5 – Acids and Bases BTG

## Repetitive Questions

### Concept 1

### Bridging the Gap – Repetitive Questions Answers

#### Writing Balanced Equations and Net Ionic Equations: Qs 1.51, 1.61, 1.62

1.51 [16 marks]

- (i)  $Ag_2O_{(s)} + 2HBr_{(aq)} \rightarrow 2AgBr_{(aq)} + H_2O_{(l)}$  (2)
- (ii)  $Sr_{(s)} + H_2SO_{4(aq)} \rightarrow SrSO_{4(s)} + H_2(g)$  (2)
- (iii)  $ZnCO_{3(s)} + 2HNO_{3(aq)} \rightarrow Zn(NO_3)_2_{(aq)} + H_2O_{(l)} + CO_2(g)$  (2)
- (iv)  $KOH_{(aq)} + NH_4Br_{(aq)} \rightarrow KBr_{(aq)} + NH_3(g) + H_2O_{(l)}$  (2)
- (v)  $MgSO_3_{(s)} + H_2SO_{4(aq)} \rightarrow MgSO_4_{(aq)} + SO_2(g) + H_2O_{(l)}$  (2)
- (vi)  $CH_3COOH_{(aq)} + KHCO_3_{(aq)} \rightarrow KCH_3COO_{(aq)} + H_2O_{(l)} + CO_2(g)$  (2)
- (vii)  $2HCl_{(aq)} + LiOH_{(aq)} \rightarrow LiCl_{(aq)} + H_2O_{(l)}$  (2)
- (viii)  $3Ba(OH)_2_{(aq)} + 2H_3PO_4_{(aq)} \rightarrow Ba_3(PO_4)_2_{(s)} + 6H_2O_{(l)}$  (2)

1.61 [16 marks]

- (i)  $Ag_2O_{(s)} + 2H^+_{(aq)} \rightarrow 2Ag^+_{(aq)} + H_2O_{(l)}$  (2)
- (ii)  $Sr_{(s)} + H_2SO_{4(aq)} \rightarrow SrSO_{4(s)} + H_2(g)$  (2)

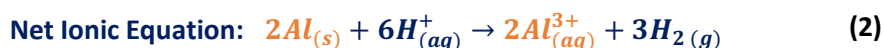
**Point to note:** Strontium is not removed from the equation because: (1) it is not a spectator ion; and (2) it transforms from a metal to a precipitate, meaning it is taking part in the reaction.

- (iii)  $ZnCO_3_{(s)} + 2H^+_{(aq)} \rightarrow Zn^{2+}_{(aq)} + H_2O_{(l)} + CO_2(g)$  (2)
- (iv)  $OH^-_{(aq)} + NH_4^+_{(aq)} \rightarrow NH_3(g) + H_2O_{(l)}$  (2)
- (v)  $MgSO_3_{(s)} + 2H^+_{(aq)} \rightarrow Mg^{2+}_{(aq)} + SO_2(g) + H_2O_{(l)}$  (2)
- (vi)  $H^+_{(aq)} + KHCO_3_{(aq)} \rightarrow K^+_{(aq)} + H_2O_{(l)} + CO_2(g)$  (2)
- (vii)  $2H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)}$  (2)
- (viii)  $3Ba(OH)_2_{(aq)} + 2H_3PO_4_{(aq)} \rightarrow Ba_3(PO_4)_2_{(s)} + 6H_2O_{(l)}$  (2)

## Observation Writing: Qs 1.81, 1.91, 1.92

1.81

[32 marks]



**Observations:** A silver solid is added to a colourless solution (1), to produce a colourless solution and a colourless, odourless gas (1).



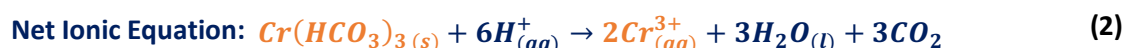
**Observations:** A white solid is added to a colourless solution (1), to produce a colourless solution (1).



**Observations:** A pale brown solid is added to a colourless solution (1), to produce a pale brown solution(1).



**Observations:** A green solid is added to a colourless solution (1), to produce a blue solution and a colourless, odourless gas (1).



**Observations:** A deep green solid is added to a colourless solution (1), to produce a deep green solution and a colourless, odourless gas (1).

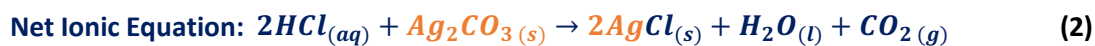
(vi)



**Observations:** A white solid is added to a colourless solution (1), to produce a colourless solution, a yellow precipitate and a colourless, pungent gas (1).



**Observations:** A green solid is added to a colourless solution (1), to produce a green solution and a colourless, pungent gas (1).



**Observations:** A white solid is added to a colourless solution (1), to produce a colourless solution, a white precipitate, and a colourless, odourless gas (1).

1.91 [4 marks]



**Point to note:** In this reaction, the air is being blown through the straw, this causes  $CO_2$  to pass through the limewater. This  $CO_2$  dissolves in the calcium hydroxide to produce insoluble calcium carbonate.

(b) When the bubbles are blown through the straw, it will be observed that the initially colourless solution (1) will turn a milky-white colour due to the formation of a white precipitate (1).

# Problem Set 6 – Acids and Bases

## Progressive Questions

### Concept 1

## Acid-Base History - Progressive Questions Answers

### Davy's Theory: Q1

1. [10 marks]
- (a) Davy's theory would correctly classify **nitric acid** as an **acid**, because it contains a replaceable hydrogen (1). An example would be reacting it with magnesium, where the  $H^+$  ion is replaced by the magnesium:  $2HNO_{3(aq)} + Mg_{(s)} \rightarrow Mg(NO_3)_{2(aq)} + H_{2(g)}$  (1).
- (b) Davy's theory would incorrectly classify **ammonia** as an **acid**, because it contains replaceable hydrogen (1). If ammonia were to react with a metal, the hydrogen would not be replaced because it is actually a **base** (1).
- (c) Davy's theory would correctly classify **potassium hydroxide** as a **base**, because it reacts with an acid to form a salt and water (1). An example is it reacting with hydrochloric acid:  $NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$  (1).
- (d) Davy's theory would correctly classify **sulfuric acid** as an **acid**, because it contains replaceable hydrogen (1). An example would be if it reacted with lithium:  $H_2SO_{4(aq)} + Li_{(s)} \rightarrow Li_2SO_{4(aq)} + H_{2(g)}$
- (e) Davy's theory would incorrectly classify **ethane** as an **acid**, because it contains replaceable hydrogen (1). However, as it is actually **neutral**, if it were to be reacted with a metal, nothing would happen (1).

Marking Criteria	Marks Allocated
• Correctly states how Davy's theory would classify the substance	1 – 5
• Provides an accurate example	1 – 5
<b>Total</b>	<b>10</b>

2. [4 marks]
- (a)  $Mg(OH)_2$  would be classified as an **Arrhenius base** because it **contains  $OH^-$  ions** (1). However, it will not be able to dissolve the floor because  $Mg(OH)_2$  is **insoluble**, so it will **not dissolve in water** and produce the  $OH^-$  ions needed to escape (1).

Marking Criteria	Marks Allocated
• Explains that $Mg(OH)_2$ is an Arrhenius base	1 – 2
• Explains that it is insoluble so it will not dissolve and produce $OH^-$ ions	
<b>Total</b>	<b>2</b>

- (b)  $NH_3$  is not classified as an **Arrhenius base** because it **does not** contain  **$OH^-$  ions** (1).

3. [10 marks]
- (a)  $HCl$  is an **Arrhenius acid**:  $HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$  (1)
- (b)  $NaOH$  is an **Arrhenius base**:  $NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$  (1)
- (c)  $NH_3$  is **neither** an Arrhenius acid nor Arrhenius base (1)
- (d)  $H_2CO_3$  is an **Arrhenius acid**:  $H_2CO_{3(aq)} \rightarrow 2H^+_{(aq)} + CO_3^{2-}_{(aq)}$  (1)
- (e)  $Ba(OH)_2$  is an **Arrhenius base**:  $Ba(OH)_{2(aq)} \rightarrow Ba^{2+}_{(aq)} + 2OH^-_{(aq)}$  (1)



## Concept 2

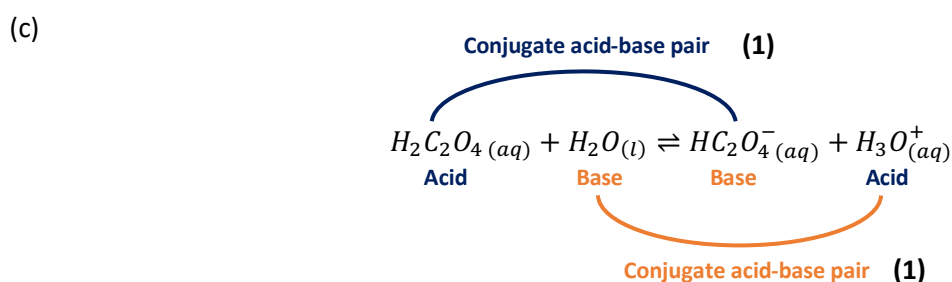
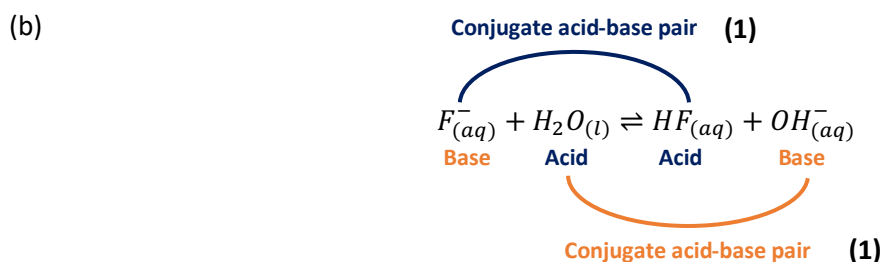
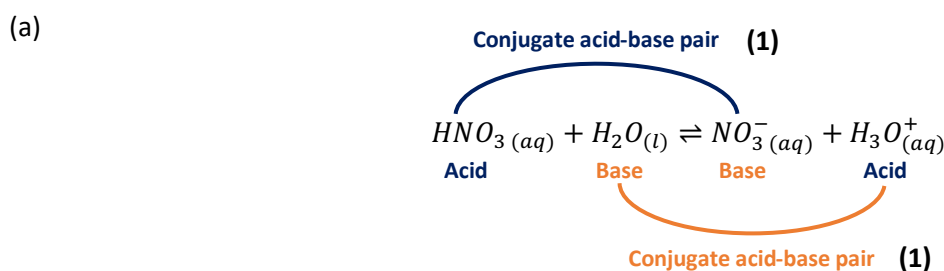
# Conjugate Acid-Base Pairs & Amphiprotic Substances - Progressive Questions Answers

### Identifying Conjugate Acid-Base Pairs: Q1, Q2, Q3,

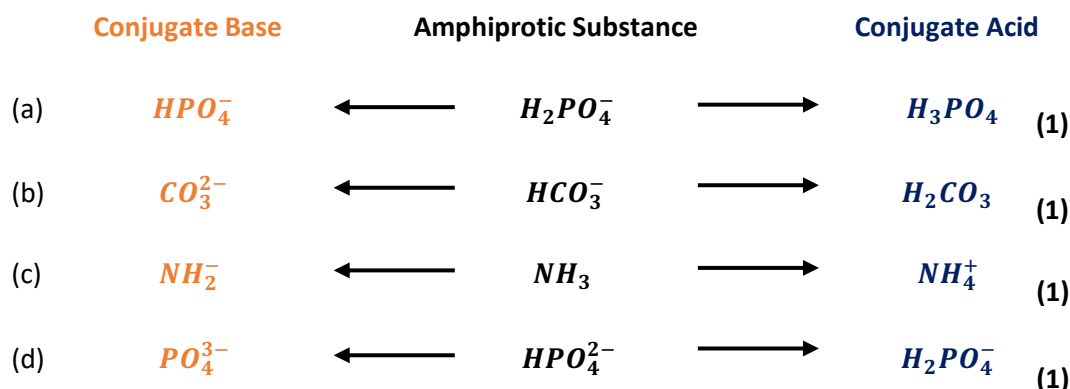
1. [6 marks]

$NH_4^+$	$NO_3^-$	$H_2O$ (in acidic solution)	$SO_4^{2-}$	$OH^-$	$H_2PO_4^{2-}$ (acidic nature)
$NH_3$ (1)	$HNO_3$ (1)	$H_3O^+$ (1)	$HSO_4^-$ (1)	$H_2O$ (1)	$HPO_4^{2-}$ (1)

2. [6 marks]



3. [4 marks]





### Concept 3

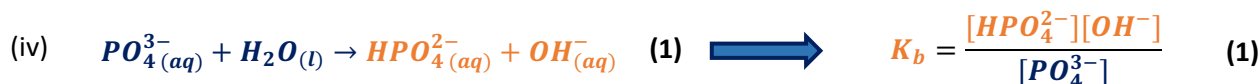
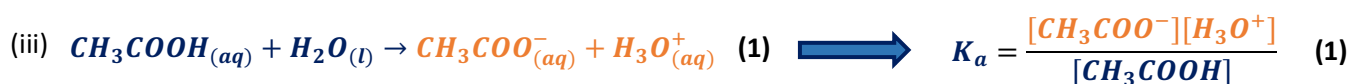
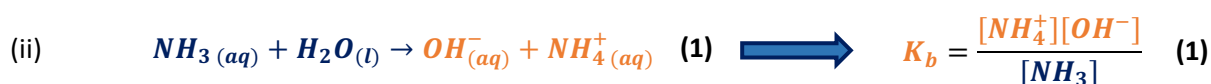
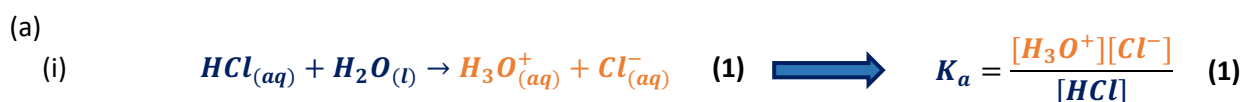
## Acid-Base Strength – Progressive Questions Answers

### Constructing $K_a$ and $K_b$ : Q1, Q2

1. [3 marks]  
 (a) The **acid constant**  $K_a$  and **base constant**  $K_b$  are a **measure** of the **extent** to which an **acidic** or **basic reaction occurs** (1). It has the same definition as the **equilibrium constant**,  $K_c$ , because it is the **same thing** (1). As seen below they have the same formulas:

$$K_a \text{ or } K_b = \frac{[C]^c [D]^d}{[A]^a [B]^b} = K_c \quad (1)$$

2. [12 marks]



(b)

$$\begin{array}{lll} \text{Reaction (ii): } K_b = \frac{[NH_4^+][OH^-]}{[NH_3]} & \text{Reaction (iii): } K_a = \frac{[CH_3COO^-][H_3O^+]}{[CH_3COOH]} & \text{Reaction (iv): } K_b = \frac{[HPO_4^{2-}][OH^-]}{[PO_4^{3-}]} \\ = \frac{[0.023]^2}{[0.312]} & = \frac{[0.00118]^2}{[0.023]} & = \frac{[3.09 \times 10^{-5}]^2}{[0.048]} \\ = 1.7 \times 10^{-3} \quad (1) & = 6.1 \times 10^{-5} \quad (1) & = 1.99 \times 10^{-8} \quad (1) \end{array}$$

$\therefore$  Jamie and Dylan are incorrect, but Alex is correct (1)

3. [8 marks]  
 (a) Strength and concentration are two different scales of measurement. **Strength** is a **measure** of the **reaction extent** (1), whereas **concentration** is a measure of the **number of moles** in a **given volume** (1).

This means you can have a **strong acid/base** reacting to a full extent, but it can **still be in a low concentration** if only a **small amount** of was added, or there can be a **weak acid/base** reacting to a partial extent, but still be in a **high concentration** because a **large amount** was added (1).

Marking Criteria	Marks Allocated
• Defines acid-base strength and concentration	1 – 3

<ul style="list-style-type: none"> <li>Explains they are different measurements</li> <li>Provides an example of when the terms are different</li> </ul>	
<b>Total</b>	<b>3</b>

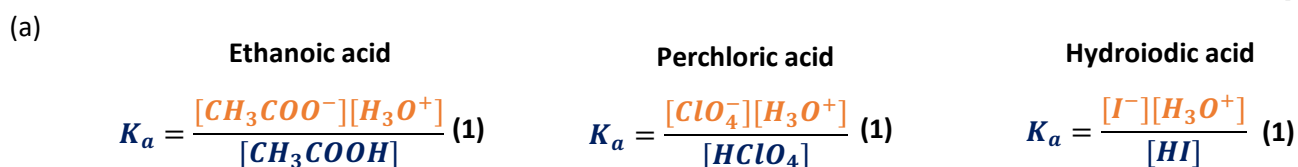
(b) The pH formula:  $pH = -\log [H_3O^+]$  is a result of the **concentration** of the  $H_3O^+$  ions (1). The concentration of the  $H_3O^+$  ions is a **result** of both the **concentration** of the acid/base initially added, and the extent to which the reaction occurs (i.e. **acid-base strength**) (1). However, the pH **cannot be directly used** to measure the strength or concentration of an acid or base (1), because it only informs us about the  $H_3O^+$  ions. In general, pH can be used as a general indicator of acid-base strength and concentration.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains what the pH formula represents in terms of <math>H_3O^+</math> ions</li> <li>Explains that the <math>H_3O^+</math> concentration is a result of both the acid's/base's strength and concentration.</li> <li>Explains that pH cannot be directly used to measure either terms</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(c) Whilst **ethanoic acid** is a weak acid, if it is in a **high concentration** then its  $H_3O^+$  concentration will be high, allowing it to have a low pH like 2.3 (1). As **hydrochloric acid** is a strong acid, if it is in a **low concentration** then its  $H_3O^+$  concentration will be lower, allowing it to have a pH like (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>States that ethanoic acid must be in a high/very high concentration</li> <li>States that hydrochloric acid must be in a low concentration</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

4. [8 marks]



(b) The **acid constant**  $K_a$  is a **measure** of the **extent** to which the acidic reaction occurs, and therefore the amount of  $H_3O^+$  ions produced. This will determine the pH of the solutions and how **acidic/dangerous** they are (1). Perchloric acid has the largest acidity constant of  $K_a = 2.12 \times 10^{10}$  which is quickly followed by hydroiodic acid with  $K_a = 8.2 \times 10^9$ , which indicates both fully ionise and are therefore both dangerous, with perchloric acid the most dangerous (2). Ethanoic acid has a much smaller acidity constant of  $K_a = 1.8 \times 10^{-5}$ , which indicates partial ionisation and is therefore less dangerous (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains how the acid-strength indicates how 'dangerous' an acid is</li> <li>States that perchloric acid is the most dangerous (linking to its acidity constant)</li> <li>States that hydroiodic acid is the second most dangerous (linking to its acidity constant)</li> <li>States that ethanoic acid is the least dangerous (linking to its acidity constant)</li> </ul>	1 – 4
<b>Total</b>	<b>3</b>

5.

[8 marks]

- (a) The strength of an acid is a measure of the extent to which the reaction occurs (1). As a strong acid,  $HCl$  will **always ionise to its full extent**, irrespective of its concentration. Therefore Jamie is incorrect (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains/defines acid-base strength</li> <li>States Jamie is incorrect and explains why</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

- (b) **Acid-base strength** is a measure of the **extent** to which the reaction occurs (1), whereas **concentration** is a measure of the **number of moles** of substance in a **given volume** (1). When Nick is adding more  $HCl$  to the beaker, the **strength** of the  $HCl$  is **remaining the same** whilst its' **concentration** is **increasing** (1). Therefore Jamie and Dylan are correct in saying the  $HCl$  strength has remained the same, and the concentration is now high, but they are incorrect in saying that the  $HCl$  strength is still low (1).  $HCl$  is a strong acid, not a weak acid.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Defines acid-base strength</li> <li>Defines concentration</li> <li>Explains what is happening when the additional <math>HCl</math> is added in terms of strength and concentration</li> <li>Explains why Dylan and Alex's statement is partially correct and incorrect</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

- (c) Alex and Dylan should explain that as the ammonia is in a high concentration, then its concentration is high, however this does not affect the strength of ammonia (1). As ammonia is a weak base, it will always remain a weak base, irrespective of the concentration (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains that concentration does not affect the strength of ammonia</li> <li>States that ammonia is a weak base</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

## Concept 4

### Monoprotic & Polyprotic Acids – Progressive Questions Answers

(i)

[8 marks]

- (a) The key difference between monoprotic and polyprotic acids are the number of protons they can donate (1). **Monoprotic acids** are those acids that are only capable of donating **one proton** per molecule, such as  $HCl$ ,  $HNO_3$ ,  $CH_3COOH$ ,  $NH_4^+$ ,  $HF$  (1). Whereas **polyprotic acids** are those acids that are capable of donating **two or more protons** per molecule, such as  $H_2SO_4$ ,  $H_2CO_3$ ,  $H_3PO_4$  (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains the key difference between monoprotic and polyprotic acids</li> <li>Defines monoprotic acids and gives an example</li> <li>Defines polyprotic acids and gives an example</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(b)

Acid	Tyler	Rupert	Answer
$HCl$	Neither	Neither	<b>Monoprotic (1)</b>
$HNO_3$	Triprotic	Monoprotic	<b>Monoprotic (1)</b>
$H_2CO_3$	Diprotic	Diprotic	<b>Diprotic (1)</b>
$H_2SO_4$	Neither	Diprotic	<b>Diprotic (1)</b>

Winner: **Rupert (1)**

(ii)

[3 marks]

Rupert and Tyler are both correct in saying that  $H_3PO_4$  is a **polyprotic acid** because it is capable of donating two or more protons per molecule (1). Tyler is also correct in saying that  $H_3PO_4$  is a **triprotic acid**, because it specifically capable of donating three protons per molecule (1). Therefore, Tyler is more correct and therefore wins the round (1).

(iii)

[8 marks]

(a) pH is a measure of the  $H_3O^+$  concentration:  $pH = -\log [H_3O^+]$ . When carbonic acid ionises, it will ionise to form  $H_3O^+$  ions:  $H_2CO_3(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)$  (1), therefore increasing the  $H_3O^+$  concentration and **decreasing the pH** from 7 to 5.62 (1). Whereas, when  $HPO_4^{2-}$  ionises in solution, it **prefers to act as a base** and will form  $OH^-$  ions:  $HPO_4^{2-} + H_2O(l) \rightleftharpoons H_2PO_4^-(aq) + OH^-(aq)$  (1). This will therefore decrease the  $H_3O^+$  concentration and **increase the pH** from 7 to 7.23 (1).

**Point to note:** The second equation for the ionisation carbonic acid is not included, because  $HCO_3^-$  actually prefers to **act as a base**, and the second equation for  $H_2PO_4^-$  is not included because it **prefers to act as an acid**. Additionally, note that for sodium hydrogen-phosphate ( $Na_2HPO_4$ ) you can just ignore the **sodium ions** as these are just spectator ions.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>Explains <math>H_2CO_3</math> acts as an acid and correctly states its first ionisation equation</li><li>Explains the increase in the <math>H_3O^+</math> concentration decreases the pH of the <math>H_2CO_3</math> solution</li><li>Explains <math>HPO_4^{2-}</math> acts as an base and correctly states its first ionisation equation</li><li>Explains the decrease in the <math>H_3O^+</math> concentration increases the pH of the <math>HPO_4^{2-}</math> solution</li></ul>	1 – 4
<b>Total</b>	<b>4</b>

(b) When  $HSO_4^-$  ionises in solution, it prefers to **act as an acid**, meaning it will form  $H_3O^+$  ions:  $HSO_4^-(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)$  (1). This will therefore **increase** the  $H_3O^+$  concentration and **decrease the pH** (1). Therefore, **Tyler is correct** and he will in the competition (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>Explains that <math>HSO_4^-</math> prefers to act as an acid and correctly states its ionisation equation</li><li>Explains the increase in the <math>H_3O^+</math> concentration decreases the pH</li><li>States that Tyler wins the competition</li></ul>	1 – 3
<b>Total</b>	<b>3</b>

## Concept 5

# K<sub>w</sub> and the Ionisation of Water – Progressive Questions Answers

1. [6 marks]

Statement	True	False
“Water with a pH less than 7 will have $[H_3O^+] > [OH^-]$ ”	<input type="checkbox"/>	<input checked="" type="checkbox"/> (1)
<b>Explanation (For the box you ticked):</b> Water always produces $H_3O^+$ and $OH^-$ ions in a <b>1 : 1</b> ratio, so it will always be $[H_3O^+] = [OH^-]$ (1).		
“Water with a temperature below $25^\circ C$ will have a <b>pH greater than 7</b> ”	<input checked="" type="checkbox"/> (1)	<input type="checkbox"/>
<b>Explanation (For the box you ticked):</b> The ionisation of water is <b>endothermic</b> , so a temperature below $25^\circ C$ will favour the <b>reverse reaction</b> and <b>decrease</b> the $H_3O^+$ concentration, which will make the <b>pH greater than 7</b> (1).		
“ <b>Water</b> is <b>not always neutral</b> , because an increase in temperature can cause it to become <b>acidic</b> ”	<input type="checkbox"/>	<input checked="" type="checkbox"/> (1)
<b>Explanation (For the box you ticked):</b> For water to be <b>acidic</b> the $[H_3O^+] > [OH^-]$ , which is <b>not possible</b> for water as it always produces $H_3O^+$ and $OH^-$ ions in a <b>1 : 1</b> ratio (1). Therefore this statement is false.		

Marking Criteria	Marks Allocated
• Ticks the correct true/false box	1 – 3
• Provides an explanation along the lines of the example provided	1 – 3
<b>Total</b>	<b>6</b>

2. [8 marks]



(b) An enthalpy of  $\Delta H > 0$ , indicates that the **forward reaction** is **endothermic** (1) and that the **reverse reaction** is **exothermic** (1).

Marking Criteria	Marks Allocated
• States the forward reaction is endothermic	1 – 2
• States the reverse reaction is endothermic	
<b>Total</b>	<b>2</b>

(c) When Neil places the beaker in ice-bath and the water starts to cool down, the system will favour the **reverse exothermic reaction** to partially oppose the temperature decrease (1). This will result in the  $[H_3O^+]$  **decreasing** (1), meaning the pH of the solution will **increase** (1).

Marking Criteria	Marks Allocated
• States that the system will favour the reverse exothermic reaction to partially oppose the temperature decrease	1 – 3
• States this will decrease the $[H_3O^+]$	
• States the $[H_3O^+]$ decrease will increase the pH	
<b>Total</b>	<b>3</b>

(d) Neutral (1)

3. [4 marks]

Glenda is **correct in certain parts** of her reasoning, but is also **incorrect in other parts (1)**. She is correct in saying that as the temperatures of our oceans continue to rise, the **endothermic reaction** will be **favoured (1)**. She is also correct in saying that a favoured forward reaction will **increase the  $H_3O^+$  concentration** and therefore **decrease the pH** of the ocean **(1)**. However, she is **incorrect** in saying that the ocean will become **acidic**, since water produces  $H_3O^+$  and  $OH^-$  ions in a **1 : 1** ratio it will always be  **$[H_3O^+] = [OH^-]$** , meaning the **water will never be acidic (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>States Glenda both partly correct and incorrect</li> <li>Explains why she is correct in saying the endothermic forward reaction will be favoured</li> <li>Explains why she is correct in saying this will decrease the pH</li> <li>Explains why she is incorrect in saying this will make the ocean acidic</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

4. [7 marks]

(a) If the  $K_w$  value is decreasing, this means that the **reverse reaction** must be favoured **(1)**. As the temperature is **decreasing**, this means the reverse reaction is **exothermic**, meaning the **enthalpy** of the **forward reaction** is **positive** (i.e.  $\Delta H > 0$ ) **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains that the reverse reaction is being favoured and it must be exothermic</li> <li>Explains the forward reaction must have a positive enthalpy (i.e. <math>\Delta H &gt; 0</math>)</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(b)

$$\begin{aligned}
 [H_3O^+] &= \sqrt{K_w} \\
 &= \sqrt{0.38 \times 10^{-14}} \\
 &= 6.164 \times 10^{-8} \quad (1)
 \end{aligned}$$

↓

$$\begin{aligned}
 pH &= -\log[H_3O^+] \\
 &= -\log[6.164 \times 10^{-8}] \\
 &= 7.21 \quad (1)
 \end{aligned}$$

**Point to note:** The first equation  $[H_3O^+] = \sqrt{K_w}$ , is derived from the original equation. Since  $K_w = [H_3O^+][OH^-]$  and we know that  $[H_3O^+] = [OH^-]$ , this means  $K_w = [H_3O^+]^2$ , which can be re-arranged to:  $[H_3O^+] = \sqrt{K_w}$ .

(c) A solution is acidic when  **$[H_3O^+] > [OH^-]$  (1)**, which is not possible for water as it always produces  $H_3O^+$  and  $OH^-$  ions in a **1 : 1** ratio **(1)**. Thus water will **always be neutral** at any pH, including a pH of 7.5 **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains what it means for a solution/water to be acidic</li> <li>Explains that for water, the <b><math>[H_3O^+]</math> will always equal <math>[OH^-]</math></b></li> <li>States water is always neutral</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

## Concept 6

# pH Calculations – Progressive Questions Answers

1.

[8 marks]

(a)

$$\begin{aligned} \text{(i) } pH &= -\log [H_3O^+] \\ &= -\log [0.1] \\ &= \mathbf{1} \quad \mathbf{(1)} \end{aligned}$$

$$\begin{aligned} \text{(ii) } pH &= -\log [H_3O^+] \\ &= -\log [2.54 \times 10^{-13}] \\ &= \mathbf{12.6} \quad \mathbf{(1)} \end{aligned}$$

$$\begin{aligned} \text{(iii) } pH &= -\log [H_3O^+] \\ &= -\log [1.53 \times 10^{-4}] \\ &= \mathbf{3.82} \quad \mathbf{(1)} \end{aligned}$$

$$\begin{aligned} \text{(iv) } pH &= -\log [H_3O^+] \\ &= -\log [3 \times 10^{-8}] \\ &= \mathbf{7.52} \quad \mathbf{(1)} \end{aligned}$$

(b)

$$\begin{aligned} \text{(i) } [H_3O^+] &= 10^{-pH} \\ &= 10^{-0.3} \\ &= \mathbf{0.501 \text{ mol L}^{-1}} \quad \mathbf{(1)} \end{aligned}$$

$$\begin{aligned} \text{(ii) } [H_3O^+] &= 10^{-pH} \\ &= 10^{-13} \\ &= \mathbf{1 \times 10^{-13} \text{ mol L}^{-1}} \quad \mathbf{(1)} \end{aligned}$$

$$\begin{aligned} \text{(iii) } [H_3O^+] &= 10^{-pH} \\ &= 10^{-7} \\ &= \mathbf{1 \times 10^{-7} \text{ mol L}^{-1}} \quad \mathbf{(1)} \end{aligned}$$

$$\begin{aligned} \text{(iv) } [H_3O^+] &= 10^{-pH} \\ &= 10^0 \\ &= \mathbf{1 \text{ mol L}^{-1}} \quad \mathbf{(1)} \end{aligned}$$

2.

[8 marks]

$$\begin{aligned} \text{(a) } [H_3O^+] &= [HCl] \\ &= \mathbf{0.2 \text{ mol L}^{-1}} \quad \mathbf{(1)} \\ pH &= -\log [H_3O^+] \\ &= -\log [0.2] \\ &= \mathbf{0.7} \quad \mathbf{(1)} \end{aligned}$$

$$\begin{aligned} \text{(b) } [H_3O^+] &= \frac{n}{V} \\ &= \frac{0.692}{0.150} \\ &= \mathbf{0.769 \text{ mol L}^{-1}} \quad \mathbf{(1)} \\ pH &= -\log [H_3O^+] \\ &= -\log [0.769] \\ &= \mathbf{0.11} \quad \mathbf{(1)} \end{aligned}$$

$$\begin{aligned} \text{(c) } [H_3O^+] &= [Triprotic \text{ acid}] \times 3 \\ &= 4.73 \times 10^{-6} \times 3 \\ &= \mathbf{1.42 \times 10^{-5} \text{ mol L}^{-1}} \quad \mathbf{(1)} \\ pH &= -\log [H_3O^+] \\ &= -\log [1.42 \times 10^{-5}] \\ &= \mathbf{4.85} \quad \mathbf{(1)} \end{aligned}$$

$$\begin{aligned} \text{(d) } [HNO_3] &= \frac{n}{V} \\ &= \frac{0.183}{0.250} \\ &= \mathbf{0.732 \text{ mol L}^{-1}} \\ [H_3O^+] &= [HNO_3] \\ &= \mathbf{0.732 \text{ mol L}^{-1}} \quad \mathbf{(1)} \\ pH &= -\log [H_3O^+] \\ &= -\log [0.732] \\ &= \mathbf{0.135} \quad \mathbf{(1)} \end{aligned}$$

pH Calculations of a Single Base: Q3, Q4

3.

[7 marks]

$$\begin{aligned} \text{(a) } [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\ &= \frac{1 \times 10^{-14}}{0.2} \\ &= 5 \times 10^{-14} \text{ mol L}^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log [H_3O^+] \\ &= -\log [5 \times 10^{-14}] \\ &= 13.3 \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(b) } [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\ &= \frac{1 \times 10^{-14}}{1.42 \times 10^{-12}} \\ &= 7.04 \times 10^{-3} \text{ mol L}^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log [H_3O^+] \\ &= -\log [7.04 \times 10^{-3}] \\ &= 2.15 \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(c) } [OH^-] &= \frac{n}{V} \\ &= \frac{0.262}{0.350} \\ &= 0.749 \text{ mol L}^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\ &= \frac{1 \times 10^{-14}}{0.749} \\ &= 1.34 \times 10^{-14} \text{ mol L}^{-1} \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log [H_3O^+] \\ &= -\log [1.34 \times 10^{-14}] \\ &= 13.9 \quad (1) \end{aligned}$$

4.

[12 marks]

$$\begin{aligned} \text{(a) } [OH^-] &= [NaOH] \\ &= 0.05 \text{ mol L}^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\ &= \frac{1 \times 10^{-14}}{0.05} \\ &= 2 \times 10^{-13} \text{ mol L}^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log [H_3O^+] \\ &= -\log [2 \times 10^{-13}] \\ &= 12.7 \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(b) } [OH^-] &= \frac{n}{V} \\ &= \frac{2 \times 10^{-3}}{2.5} \\ &= 8 \times 10^{-4} \text{ mol L}^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\ &= \frac{1 \times 10^{-14}}{8 \times 10^{-4}} \\ &= 1.25 \times 10^{-11} \text{ mol L}^{-1} \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log [H_3O^+] \\ &= -\log [1.25 \times 10^{-11}] \\ &= 10.9 \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(c) } [OH^-] &= [Ca(OH)_2] \times \text{molar ratio} \\ &= 1 \times 10^{-4} \times 2 \\ &= 2 \times 10^{-4} \text{ mol L}^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\ &= \frac{1 \times 10^{-14}}{2 \times 10^{-4}} \\ &= 5 \times 10^{-11} \text{ mol L}^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log [H_3O^+] \\ &= -\log [5 \times 10^{-11}] \\ &= 10.3 \quad (1) \end{aligned}$$

$$\begin{aligned} \text{(d) } [OH^-] &= [Ni(OH)_3] \times \text{molar ratio} \\ &= 0.003 \times 3 \\ &= 9 \times 10^{-3} \text{ mol L}^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\ &= \frac{1 \times 10^{-14}}{9 \times 10^{-3}} \\ &= 1.11 \times 10^{-12} \text{ mol L}^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log [H_3O^+] \\ &= -\log [1.11 \times 10^{-12}] \\ &= 11.95 \quad (1) \end{aligned}$$



5.

[6 marks]

(a)

(i) **Decreased** by a factor of 1000 (1)(ii) **Increased** by a factor of 10 (1)(iii) **Decreased** by a factor of 1.26 (1)(iv) **Decreased** by a factor of 100 (1)

**Point to note:** pH follows a logarithmic scale, meaning every time pH increases/decreases by 1, 2, 3 etc. the  $H_3O^+$  concentration increases/decreases by a factor of  $10^1, 10^2, 10^3$  etc. which is 10, 100, 1000 etc. For (iii), this change can be calculated:  $\frac{Final\ pH}{Initial\ pH} =$

$$\frac{10^{-9.5}}{10^{-9.4}} = 10^{0.1} \text{ which is } 1.26.$$

(b)

$$(i) \frac{Final\ pH}{Initial\ pH} - 1 = \frac{10^{-10}}{10^{-9.8}} - 1 = 10^{-0.2} - 1 = -36.9\% \quad (ii) \frac{Final\ pH}{Initial\ pH} - 1 = \frac{10^{-0.6}}{10^{-1}} - 1 = 10^{0.2} - 1 = 151\%$$

∴ there has been a **36.9% decrease** (1)∴ there has been a **151% increase** (1)

6.

[5 marks]

$$n(HCl) = cV$$

$$= 0.1 \times 0.03$$

$$= \mathbf{0.003\ mol}$$

$$n(NaOH) = cV$$

$$= 0.1 \times 0.015$$

$$= \mathbf{0.0015\ mol\ (1)}$$

$$n(H_3O^+) = n(HCl)$$

$$= \mathbf{0.003\ mol}$$

$$n(OH^-) = n(NaOH)$$

$$= \mathbf{0.0015\ mol\ (1)}$$



$$\therefore n(H_3O^+)_{in\ excess} = \mathbf{0.003 - 0.0015} \\ = \mathbf{0.0015\ mol\ (1)}$$

$$[H_3O^+] = \frac{n(H_3O^+)_{in\ excess}}{V_a + V_b} \\ = \frac{\mathbf{0.0015}}{\mathbf{0.03 + 0.015}} \\ = \mathbf{3.33 \times 10^{-2}\ mol\ L^{-1}\ (1)}$$

$$pH = -\log [H_3O^+]$$

$$= -\log [3.33 \times 10^{-2}]$$

$$= \mathbf{1.48\ (1)}$$

7.

[6 marks]

$$n(HCl) = cV$$

$$= 0.1 \times 0.03$$

$$= \mathbf{0.003\ mol}$$

$$n(NaOH) = cV$$

$$= 0.063 \times 0.05$$

$$= \mathbf{0.00315\ mol\ (1)}$$

$$n(H_3O^+) = n(HCl)$$

$$= \mathbf{0.003\ mol}$$

$$n(OH^-) = n(Ba(OH_2)) \times 2$$

$$= 0.00315 \times 2$$

$$= \mathbf{0.0063\ mol\ (1)}$$



$$\begin{aligned}\therefore n(OH^-)_{in\ excess} &= 0.0063 - 0.003 \\ &= 0.0033\ mol \quad (1)\end{aligned}$$

$$\begin{aligned}[OH^-] &= \frac{n(OH^-)_{in\ excess}}{V_a + V_b} \\ &= \frac{0.0033}{0.03 + 0.05} \\ &= 4.125 \times 10^{-2}\ mol\ L^{-1} \quad (1)\end{aligned}$$

$$\begin{aligned}[H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\ &= \frac{1 \times 10^{-14}}{4.125 \times 10^{-2}} \\ &= 2.42 \times 10^{-13}\ mol\ L^{-1} \quad (1)\end{aligned}$$

$$\begin{aligned}pH &= -\log [H_3O^+] \\ &= -\log [2.42 \times 10^{-13}] \\ &= 12.6\end{aligned}$$

$\therefore$  Luke wins the bet (1)

8.

[17 marks]

$$\begin{aligned}(a) \quad n(CH_3COOH) &= cV & n(Ca(OH)_2) &= cV \\ &= 0.21 \times 0.072 & &= 0.14 \times 0.036 \\ &= 0.01512\ mol & &= 0.00504\ mol \quad (1) \\ n(H_3O^+) &= n(CH_3COOH) & n(OH^-) &= n(Ca(OH)_2) \times 2 \\ &= 0.01512\ mol & &= 0.00504 \times 2 \\ & & &= 0.01008\ mol \quad (1)\end{aligned}$$



$$\begin{aligned}\therefore n(H_3O^+)_{in\ excess} &= 0.01512 - 0.01008 \\ &= 0.00504\ mol \quad (1)\end{aligned}$$

$$\begin{aligned}[H_3O^+] &= \frac{n(H_3O^+)_{in\ excess}}{V_a + V_b} \\ &= \frac{0.00504}{0.072 + 0.036} \\ &= 4.67 \times 10^{-2}\ mol\ L^{-1} \quad (1)\end{aligned}$$

$$\begin{aligned}pH &= -\log [H_3O^+] \\ &= -\log [4.67 \times 10^{-2}] \\ &= 1.33 \quad (1)\end{aligned}$$

$$\begin{aligned}(b) \quad n(H_3PO_4) &= cV & n(KOH) &= cV \\ &= 0.05 \times 0.03 & &= 0.06 \times 0.12 \\ &= 0.0015\ mol & &= 0.0072\ mol \quad (1) \\ n(H_3O^+) &= n(H_3PO_4) \times 3 & n(OH^-) &= n(KOH) \\ &= 0.0015 \times 3 & &= 0.0072\ mol \quad (1) \\ &= 0.0045\ mol & &20\end{aligned}$$



$$\begin{aligned} \therefore n(OH^-)_{in\ excess} &= 0.0072 - 0.0045 \\ &= 0.0027\ mol \quad (1) \end{aligned}$$

$$\begin{aligned} [OH^-] &= \frac{n(OH^-)_{in\ excess}}{V_a + V_b} \\ &= \frac{0.0027}{0.03+0.12} \\ &= 0.018\ mol\ L^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\ &= \frac{1 \times 10^{-14}}{4.125 \times 10^{-2}} \\ &= 2.42 \times 10^{-13}\ mol\ L^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} pH &= -\log [H_3O^+] \\ &= -\log [2.42 \times 10^{-13}] \\ &= 12.6 \quad (1) \end{aligned}$$

(c)

$$\begin{aligned} n(H_2SO_4) &= cV & n(NaOH) &= cV \\ &= 0.1 \times 0.01 & &= 0.07 \times 0.03 \\ &= 0.001\ mol & &= 0.0021\ mol \quad (1) \end{aligned}$$

$$\begin{aligned} n(H_3O^+) &= n(H_2SO_4) \times 2 & n(OH^-) &= n(NaOH) \\ &= 0.001 \times 2 & &= 0.0021\ mol \quad (1) \\ &= 0.002\ mol \end{aligned}$$



$$\begin{aligned} \therefore n(OH^-)_{in\ excess} &= 0.0021 - 0.002 \\ &= 1 \times 10^{-4}\ mol \quad (1) \end{aligned}$$

$$\begin{aligned} [OH^-] &= \frac{n(OH^-)_{in\ excess}}{V_a + V_b} \\ &= \frac{1 \times 10^{-4}}{0.01+0.07} \\ &= 0.00125\ mol\ L^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\ &= \frac{1 \times 10^{-14}}{0.00125} \\ &= 8 \times 10^{-12}\ mol\ L^{-1} \quad (1) \end{aligned}$$

$$\begin{aligned} pH &= -\log [H_3O^+] \\ &= -\log [8 \times 10^{-12}] \\ &= 11.1 \quad (1) \end{aligned}$$

9.

[9 marks]

$$(a) n(\text{HNO}_3) = cV$$

$$= 0.1 \times 0.025$$

$$= \mathbf{0.0025 \text{ mol}}$$

$$n(\text{H}_2\text{SO}_4) = cV$$

$$= 0.06 \times 0.061$$

$$= \mathbf{0.00366 \text{ mol}}$$

$$n(\text{Ba}(\text{OH})_2) = cV$$

$$= 0.07 \times 0.03$$

$$= \mathbf{0.0021 \text{ mol}} \quad (2)$$

$$n(\text{H}_3\text{O}^+) = n(\text{HNO}_3)$$

$$= \mathbf{0.0025 \text{ mol}}$$

$$n(\text{H}_3\text{O}^+) = n(\text{H}_2\text{SO}_4) \times 2$$

$$= 0.00366 \times 2$$

$$= \mathbf{0.00732 \text{ mol}}$$

$$n(\text{OH}^-) = n(\text{Ba}(\text{OH})_2) \times 2$$

$$= 0.0021 \times 2$$

$$= \mathbf{0.0042 \text{ mol}} \quad (2)$$



$$\therefore n(\text{H}_3\text{O}^+)_{\text{in excess}} = \mathbf{0.0025 + 0.00732 - 0.0042}$$

$$= \mathbf{0.00562 \text{ mol}} \quad (1)$$

$$[\text{H}_3\text{O}^+] = \frac{n(\text{H}_3\text{O}^+)_{\text{in excess}}}{V_a + V_b}$$

$$= \frac{\mathbf{0.00562}}{\mathbf{0.025 + 0.061 + 0.032}}$$

$$= \mathbf{4.763 \times 10^{-2} \text{ mol L}^{-1}} \quad (1)$$

$$\text{pH} = -\log [\text{H}_3\text{O}^+]$$

$$= -\log [4.763 \times 10^{-2}]$$

$$= \mathbf{1.32} \quad (1)$$

$\therefore$  Glenda will not reach her target pH of 6.2 (1)

(b) At a pH of 1.32, this would **not be safe to drink** and should not be recommended to other divers to consume (1).

10.

[9 marks]

$$n(\text{H}_2\text{SO}_4) = cV$$

$$= 2 \times 0.030$$

$$= \mathbf{0.06 \text{ mol}}$$

$$n(\text{NaOH}) = cV$$

$$= 1 \times 0.03$$

$$= \mathbf{0.03 \text{ mol}}$$

$$n(\text{Ca}(\text{OH})_2) = cV$$

$$= 0.5 \times 0.15$$

$$= \mathbf{0.075 \text{ mol}} \quad (2)$$

$$n(\text{H}_3\text{O}^+) = n(\text{H}_2\text{SO}_4) \times 2$$

$$= 0.06 \times 2$$

$$= \mathbf{0.12 \text{ mol}}$$

$$n(\text{OH}^-) = n(\text{NaOH})$$

$$= \mathbf{0.03 \text{ mol}}$$

$$n(\text{OH}^-) = n(\text{Ca}(\text{OH})_2) \times 2$$

$$= 0.075 \times 2$$

$$= \mathbf{0.15 \text{ mol}} \quad (2)$$



$$\therefore n(\text{OH}^-)_{\text{in excess}} = \mathbf{0.15 + 0.03 - 0.12}$$

$$= \mathbf{0.06 \text{ mol}} \quad (1)$$

$$[\text{OH}^-] = \frac{n(\text{OH}^-)_{\text{in excess}}}{V_a + V_b}$$

$$= \frac{\mathbf{0.06}}{\mathbf{0.03 + 0.03 + 0.15}}$$

$$= \mathbf{0.2857 \text{ mol L}^{-1}} \quad (1)$$

$$[\text{H}_3\text{O}^+] = \frac{1 \times 10^{-14}}{[\text{OH}^-]}$$

$$= \frac{1 \times 10^{-14}}{\mathbf{0.2857}}$$

$$= \mathbf{3.5 \times 10^{-14} \text{ mol L}^{-1}} \quad (1)$$

$$\text{pH} = -\log [\text{H}_3\text{O}^+]$$

$$= -\log [3.5 \times 10^{-14}]$$

$$= \mathbf{13.46} \quad (1)$$

$\therefore$  Neil is correct and will win the Scuba Diving World Championships (1)

## Concept 7

# Buffers and Buffer Capacity – Progressive Questions Answers

### Forming Buffers and Writing Buffer Equations: Q1, Q2, Q3

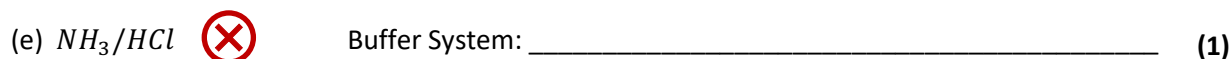
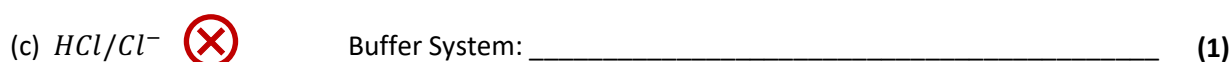
1. [8 marks]
- (a) Buffers are formed by either a **combination** of a **weak acid** and its **conjugate base** (1), or a **weak base** and its **conjugate acid** (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• States first combination as a weak acid and its conjugate base</li> <li>• States second combination as a weak base and its conjugate acid</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

- (b) In order for a buffer to be able to properly perform its purpose, it must form a **dynamic equilibrium** system (1). By using a **strong acid** or **strong base**, this will cause the reaction to **occur to completion** and a dynamic equilibrium system will not form (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Explains that a dynamic equilibrium system is needed</li> <li>• Explains that a strong acid or strong base cannot form a dynamic equilibrium</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

2. [10 marks]



3. [4 marks]



**Point to note:** The key is to select weak acids and bases, and find their conjugate acid-base pairs. Strong acids and bases such as  $HF$  or  $HCl$  should be automatically ignored.

## Buffer Response and Buffer Capacity : Q4, Q5

4.

[5 marks]

- (a) When  $HCl$  is added drop-by-drop, the added  $H_3O^+$  ions will cause the  $H_3O^+$  concentration to **increase (1)**. With an **increased**  $[H_3O^+]$ , the carbonic acid buffer will act to **resist the pH change** by favouring the **reverse** reaction, in order to consume most of the added  $H_3O^+$  ions **(1)**. This will mean the pH will not change significantly **(1)**, until all the  $HCO_3^-$  has been used up.

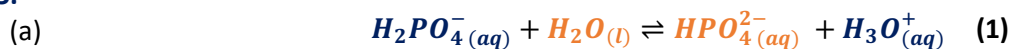
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains there is a <math>H_3O^+</math> concentration increase</li> <li>Applies LCP to show reverse reaction is favoured to consume the added <math>H_3O^+</math> ions</li> <li>Explains that the <math>H_3O^+</math> concentration does not change significantly so pH doesn't change significantly</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

- (b) Tyler can: (1) **increase the amounts** of  $H_2CO_3$  and  $HCO_3^-$  in the buffer solution, so there is more acid and base that needs to be consumed before the buffer can no longer operate **(1)**, and (2) ensure the  $H_2CO_3$  and  $HCO_3^-$  are in **equal concentrations** so they can equally accommodate to any pH change **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Increase the amount of <math>H_2CO_3</math> and <math>HCO_3^-</math></li> <li>Ensure equal amounts of <math>H_2CO_3</math> and <math>HCO_3^-</math></li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

5.

[10 marks]



- (b) In order for a system to be able to resist pH changes, it needs to be in a state of dynamic equilibrium so that it is able to **consume/produce**  $H_3O^+$  ions and **stop the pH** from changing **(1)**. Buffers are formed by either a **combination** of a **weak acid** and its **conjugate base**, or a **weak base** and its **conjugate acid (1)**, because these form dynamic equilibrium systems that respond to pH changes. A  $HCl/Cl^-$  system would **not work** as a buffer, because the  $HCl$  would **react to completion** and therefore **not form** a dynamic equilibrium system that can respond to pH changes **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains that a dynamic equilibrium system allows the system to respond to both increases and decreases in pH</li> <li>States buffers are formed through a weak acid and its conjugate-base, or a weak base and its conjugate-acid</li> <li>Explains a <math>HCl/Cl^-</math> system does not work because it does not form a dynamic equilibrium system</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

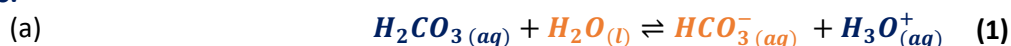
- (c) When a few drops of  $HNO_3$  is added, the added  $H_3O^+$  ions will cause the  $H_3O^+$  concentration to **increase (1)**. With an **increased**  $[H_3O^+]$ , the  $H_2PO_4^-/HPO_4^{2-}$  buffer will act to **resist the pH change** by favouring the **reverse** reaction, in order to consume most of the added  $H_3O^+$  ions **(1)**. This will mean the pH will not change significantly **(1)**, until all the  $HPO_4^{2-}$  has been used up.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains there is a <math>H_3O^+</math> concentration increase</li> <li>Applies LCP to show reverse reaction is favoured to consume the added <math>H_3O^+</math> ions</li> <li>Explains that the <math>H_3O^+</math> concentration does not change significantly so pH doesn't change significantly</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

- (d) Rupert can: (1) **increase the amounts** of  $H_2PO_4^-$  and  $HPO_4^{2-}$  in the buffer solution, so there is more acid and base that needs to be consumed before the buffer can no longer operate (1), and (2) ensure the  $H_2PO_4^-$  and  $HPO_4^{2-}$  are in **equal concentrations** so they can equally accommodate to any pH change (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Increase the amount of <math>H_2PO_4^-</math> and <math>HPO_4^{2-}</math></li> <li>Ensure equal amounts of <math>H_2PO_4^-</math> and <math>HPO_4^{2-}</math></li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

6. [7 marks]



- (b) When a few drops of **strong base** is added, the added  $OH^-$  ions will consume the  $H_3O^+$  ions and cause the  $H_3O^+$  concentration to **decrease** (1). With an **decreased**  $[H_3O^+]$ , the  $H_2CO_3/HCO_3^-$  buffer will act to **resist the pH change** by favouring the **forward reaction**, in order to **replace** some of the lost  $H_3O^+$  ions (1). This will mean the pH will not change significantly (1), until all the  $H_2CO_3$  has been used up.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains there is a <math>OH^-</math> concentration increase that causes a <math>H_3O^+</math> concentration decrease</li> <li>Applies LCP to show forward reaction is favoured to replace the lost <math>H_3O^+</math> ions</li> <li>Explains that the <math>H_3O^+</math> concentration does not change significantly so pH doesn't change significantly</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

- (c) By increasing the concentration of dissolved  $CO_2$  this will favour the forward reaction of:  $CO_{2(aq)} + H_2O_{(l)} \rightleftharpoons H_2CO_3$ , producing more carbonic acid in our bloodstream. With more carbonic acid, this will favour the forward reaction of:  $H_2CO_{3(aq)} + H_2O_{(l)} \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)$ , therefore increasing the concentration of  $HCO_3^-$  (1). With a higher concentration of both  $H_2CO_3$  and  $HCO_3^-$  in the buffer solution, there is more of each that will need to be consumed before the buffer can no longer operate (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains how an increased concentration of <math>CO_2</math> will increase the concentrations of both <math>H_2CO_3</math> and <math>HCO_3^-</math></li> <li>Explains how an increased concentrations of <math>H_2CO_3</math> and <math>HCO_3^-</math> increases the buffer capacity</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

# Problem Set 6 – Acids and Bases

## Repetitive Questions

### Concept 1

### Acid-Base History – Repetitive Question Answers

#### Arrhenius vs Brønsted-Lowry Theory of Acids and Bases: Qs 1.7, 1.71

1.7

[4 marks]

- (a)  $CO_3^{2-}$ : **Brønsted-Lowry Base (1)**  
 (b)  $HS^-$ : **Brønsted-Lowry Acid (1)**  
 (c)  $NaOH$ : **Neither (1)**  
 (d)  $CrO_4^{2-}$ : **Neither (1)**

**Point to note:** For reactions (c) and (d) there is no transfer of protons, so  $NaOH$  and  $CrO_4^{2-}$  are not Brønsted-Lowry acids/bases in these equations.

1.71

[4 marks]

- (a)
- (i)  $NH_4^+(aq) + H_2O(l) \rightarrow NH_3(aq) + H_3O^+(aq)$  (1)  
 (ii)  $PO_4^{3-}(aq) + H_2O(l) \rightarrow HPO_4^{2-}(aq) + OH^-(aq)$  (1)  
 (iii)  $H_3BO_3(aq) + H_2O(l) \rightarrow H_2BO_3^-(aq) + H_3O^+(aq)$  (1)  
 (iv)  $CH_3COO^-(aq) + H_2O(l) \rightarrow CH_3COOH(aq) + OH^-(aq)$  (1)  
 (v)  $NO_3^-(aq) + H_2O(l) \rightarrow HNO_3(aq) + OH^-(aq)$  (1)

(b) The Arrhenius model can be applied to reactions (i) and (iii):

- (i)  $NH_4^+(aq) \rightarrow NH_3(aq) + H^+(aq)$  (1)  
 (iii)  $H_3BO_3(aq) \rightarrow H_2BO_3^-(aq) + H^+(aq)$  (1)

(c) The Arrhenius model requires the acid or base to produce a  $H^+$  ion or  $OH^-$  ion in aqueous solution (1), and since  $PO_4^{3-}$ ,  $CH_3COO^-$  and  $NO_3^-$  do not contain a  $H^+$  ion or  $OH^-$  ion they cannot be shown under the Arrhenius model (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains how the Arrhenius model requires a representation through <math>H^+</math> or <math>OH^-</math> ions</li> <li>Explains how reactions (ii), (iv) and (v) are unable to show this <math>H^+</math> or <math>OH^-</math> ion production</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>



## Concept 2

# Conjugate acid-base pairs – Repetitive Question Answers

### Identifying Conjugate Acid-Base Pairs: Qs: 2.1, 2.2, 2.3, 2.4

2.1

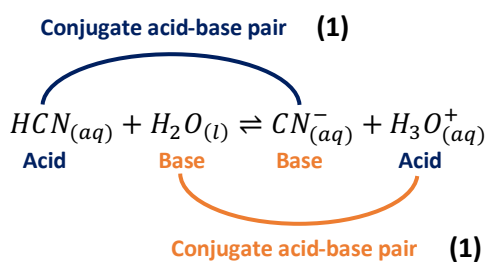
[6 marks]

- (a)  $HF$  (1)      (b)  $NO_3^-$  (1)      (c)  $ClO_4^-$  (1)      (d)  $OH^-$  (1)      (e)  $C_6H_5O_2^-$  (1)

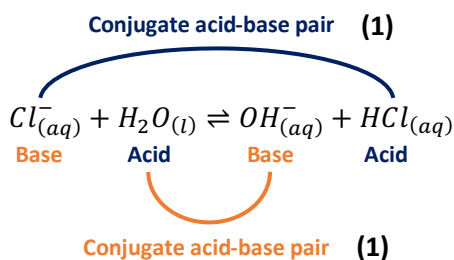
2.2

[8 marks]

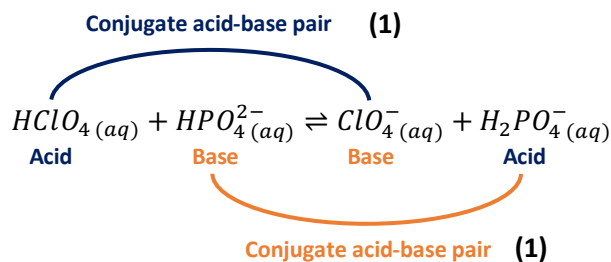
(a)



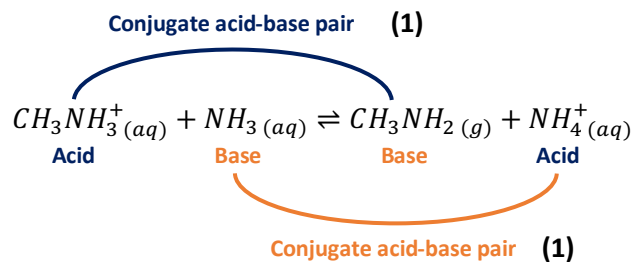
(b)



(c)



(d)



2.3	Conjugate Base	Amphiprotic Substance	Conjugate Acid	[8 marks]
(a)	$SO_4^{2-}$	← $HSO_4^-$ →	$H_2SO_4$	
(b)	$C_2O_4^{2-}$	← $HC_2O_4^-$ →	$H_2C_2O_4$	
(c)	$CO_3^{2-}$	← $HCO_3^-$ →	$H_2CO_3$	
(d)	$C_6H_6O_7^{2-}$	← $C_6H_7O_7^-$ →	$C_6H_8O_7$	

2.4 [10 marks]

	Amphiprotic (Yes/No)	Acid equation	Base equation
$HCO_3^-$	Yes (1)	$HCO_3^-(aq) + H_2O(l) \rightleftharpoons CO_3^{2-}(aq) + H_3O^+(aq)$	$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$ (1)
$PO_4^{3-}$	No (1)		
$HC_2O_4^-$	Yes (1)	$HC_2O_4^-(aq) + H_2O(l) \rightleftharpoons C_2O_4^{2-}(aq) + H_3O^+(aq)$	$HC_2O_4^-(aq) + H_2O(l) \rightleftharpoons H_2C_2O_4(aq) + OH^-(aq)$ (1)
$NaHSO_4$	Yes (1)	$HSO_4^-(aq) + H_2O(l) \rightleftharpoons SO_4^{2-}(aq) + H_3O^+(aq)$	$HSO_4^-(aq) + H_2O(l) \rightleftharpoons H_2SO_4(aq) + OH^-(aq)$ (1)
$KHPO_4$	Yes (1)	$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons PO_4^{3-}(aq) + H_3O^+(aq)$	$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons H_2PO_4^-(aq) + OH^-(aq)$ (1)
$C_2O_4^{2-}$	No (1)		

**Point to note:** To be amphiprotic, it must be capable of donating and accepting a  $H^+$  ion.

### Concept 3

## Acid-Base Strength – Repetitive Question Answers

3.3 [8 marks]

- (a)  
 (i) **Acid-base strength** is a **measure** of the **extent** to which an **acidic** or **basic** reaction occurs (1). It has the formula of:

$$K_a \text{ or } K_b = \frac{[C]^c [D]^d}{[A]^a [B]^b} \quad (1)$$

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Defines acid-base strength appropriately, mentioning 'reaction extent'</li> <li>Provides the correct formula</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

- (ii) **Acid-base concentration** is a measure of the **number of moles** of **acid/base** in a **given volume** (1). It has the formula of:

$$c = \frac{n}{V} \quad (1)$$

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Defines acid-base concentration appropriately</li> <li>Provides the correct formula</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(iii) pH is a measure of the **hydronium ion concentration** in a solution **(1)**. It is measured using the formula:

$$pH = -\log [H_3O^+] \quad (1)$$

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Defines pH appropriately</li> <li>Provides the correct formula</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(b) The **strength** of an **acid ( $K_a$ )** or **base ( $K_b$ )** is not dependent on concentration, because concentration does not affect whether an acid or base is classified as strong or weak **(1)**. In contrast, pH is dependent on **acid/base concentration** because it is **dependent on the  $H_3O^+$  ion concentration**, which is directly affected by the acid-base concentration **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains why acid-base strength is not dependent on concentration</li> <li>Explains why pH is dependent on concentration</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

**3.31** **[6 marks]**

(a) The order of strength of these acids are **acid 1** as the **strongest**, then **acid 3** and then **acid 2** as the **weakest** acid **(1)**. In terms of reaction extent, for acid 1, a  $K_a$  value of  $K_a = 5.43 \times 10^8$  indicates the acid ionises to a **near complete/ complete extent**, and therefore typically has a **high  $H_3O^+$  concentration** **(1)**. For **acid 2**, a  $K_a$  value of  $K_a = 9.11 \times 10^{-13}$  indicates the acid ionises to a **negligible extent**, and therefore typically has a **low  $H_3O^+$  concentration** **(1)**. For **acid 3**, a  $K_a$  value of  $K_a = 9.11 \times 10^{-2}$  indicates the acid ionises to a **moderate extent**, and therefore typically has a **moderate  $H_3O^+$  concentration** **(1)**.

**Point to note:** Remember, for  $K_c, K_a$  and  $K_b$  values, there are the following guidelines:

- If  $K_c < 10^{-4}$ : the reaction occurs to a **negligible extent**, so **mostly/entirely reactant particles** are present
- If  $10^{-4} < K_c < 10^4$ : the reaction occurs to a **moderate extent**, with **considerable amounts** of both **reactant particles** and **product** present
- If  $K_c > 10^4$ : the reaction occurs to **near completion/completion**, so **mostly/entirely products** are present

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correctly states strength order of acid 1, acid 3 and then acid 2 from strongest to weakest</li> <li>Explains acid 1 ionises completely and typically has a high <math>H_3O^+</math> concentration</li> <li>Explains acid 2 ionises negligibly and typically has a low <math>H_3O^+</math> concentration</li> <li>Explains acid 3 ionises moderately and typically has a moderate <math>H_3O^+</math> concentration</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

(b) When acid 2 is placed over the Bunsen burner, the system will favour the endothermic reaction to partially oppose the temperature increase, which was the reverse reaction **(1)**. Therefore if the reverse reaction is endothermic, the forward reaction must be exothermic and therefore have a negative enthalpy.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains that endothermic reverse reaction is favoured</li> <li>Explains that forward reaction must be exothermic and have a negative enthalpy</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

Statement	True	False
"The <b>strength</b> of an <b>acid</b> is a direct result of its <b>concentration</b> "		✓ (1)
<b>Explanation (For the box you ticked):</b> Acid-base strength is <b>not the result</b> of concentration, the extent to which an acid or base ionises/dissociates is <b>based on its strength</b> , not its concentration (1).		
"A <b>weak base</b> can have a higher pH than a <b>strong base</b> "	✓ (1)	
<b>Explanation (For the box you ticked):</b> Yes, if the <b>weak base</b> is in a <b>high concentration</b> and the <b>strong base</b> is in a <b>low concentration</b> , then it is possible the weak base will have a higher pH than the strong base (1).		
"A <b>strong acid</b> in a <b>low concentration</b> , will have a lower pH than the same one with a <b>higher concentration</b> "	✓ (1)	
<b>Explanation (For the box you ticked):</b> The pH of an acid or base has a <b>direct relationship</b> to its <b>concentration</b> , so yes, a <b>higher concentration</b> will mean a <b>lower pH</b> for this strong acid (1).		

Marking Criteria	Marks Allocated
• Ticks the correct true/false box	1 – 3
• Provides an explanation along the lines of the explanation provided	1 – 3
<b>Total</b>	<b>6</b>

## 3.4

[5 marks]

(a)

Ethanoic acid

Nitric acid

$$K_a = \frac{[CH_3COO^-][H_3O^+]}{[CH_3COOH]} \quad (1) \qquad K_a = \frac{[NO_3^-][H_3O^+]}{[HNO_3]} \quad (1)$$

- (b) Whilst both acids are of **equal concentrations**, the **strength** of **ethanoic acid** is **significantly lower** than the strength of nitric acid (1). Since nitric acid completely ionises in solution and **ethanoic acid** only **partially ionises** in solution, the concentration of  $H_3O^+$  ions it produces will be significantly lower (1). A **lower  $H_3O^+$  concentration** will cause the pH of **ethanoic acid** to be **higher** than the pH of nitric acid (1).

Marking Criteria	Marks Allocated
• Explains the strength of ethanoic acid is lower than the strength of nitric acid	1 – 3
• Explains ethanoic acid only partially ionises	
• Explains that less $H_3O^+$ ions results in a higher pH	
<b>Total</b>	<b>3</b>

## 3.5

[5 marks]

- (a) Whilst both bases are of **equal concentrations**, the **strength** of **sodium fluoride** is **lower** than the strength of sodium hydroxide (1). As a result, the **sodium hydroxide** will **fully ionise** in solution and **sodium fluoride** will only **partially ionise**, meaning the concentration of  $OH^-$  ions will be **greater** for sodium hydroxide (1). This means the **sodium hydroxide** will have a **lower  $H_3O^+$  concentration** because its  $OH^-$  ions will have neutralised more of them (1)

Marking Criteria	Marks Allocated
• Explains the strength of sodium fluoride is lower than the strength of sodium hydroxide	1 – 3
• Explains sodium hydroxide has a higher $OH^-$ concentration	
• Explains that sodium hydroxide will therefore have less $H_3O^+$ ions	
<b>Total</b>	<b>3</b>

(b) The strength of an acid or a base is **not dependent** on its **concentration (1)**, therefore the **strength** of **sodium fluoride** has not changed **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>Explains strength is not dependent on concentration</li><li>Explains the strength of sodium fluoride has not changed</li></ul>	1 – 2
<b>Total</b>	<b>2</b>

(c) Again, the strength of an acid or a base is **not dependent** on its **concentration (1)**, therefore the **strength** of **sodium fluoride** and **sodium hydroxide** has not changed **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>Explains strength is not dependent on concentration</li><li>Explains the strength of sodium fluoride has not changed</li></ul>	1 – 2
<b>Total</b>	<b>2</b>

## Concept 4

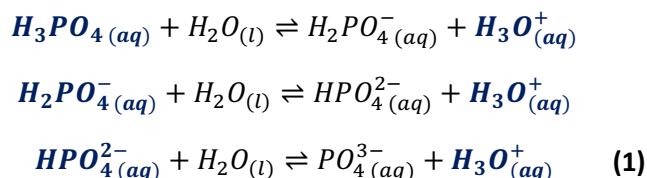
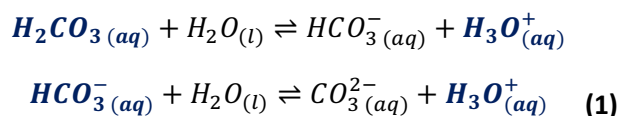
# Monoprotic & Polyprotic Acids – Repetitive Question Answers

### Monoprotic and Polyprotic Acids: Qs 4.1, 4.3, 4.31

4.1

[4 marks]

Both  $H_2CO_3$  and  $H_3PO_4$  are **polyprotic acids**, as they are both capable of **donating two or more** protons per molecule (1).  $H_2CO_3$  is **diprotic** because it is capable of donating **two protons** per molecule, and  $H_3PO_4$  is **triprotic** because it is capable of donating **three protons** per molecule (1). This is shown through their ionisation equations:



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains why both acids are polyprotic</li> <li>Explains that <math>H_2CO_3</math> is diprotic and <math>H_3PO_4</math> is triprotic</li> <li>States the ionisation equations for <math>H_2CO_3</math></li> <li>States the ionisation equations for <math>H_3PO_4</math></li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

4.3

[3 marks]

When hydrogen carbonate ( $HCO_3^-$ ) ionises in solution, it prefers to act as a base (1). This means it will form  $OH^-$  ions:  $HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$  (1). This will therefore decrease the  $H_3O^+$  concentration and **increase the pH**, making the class wrong about their statement (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains that <math>HCO_3^-</math> prefers to act as a base</li> <li>States the basic equation for <math>HCO_3^-</math></li> <li>Explains a decrease in the <math>H_3O^+</math> concentration will increase the pH</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

4.31

[3 marks]

When  $HSO_4^-$  ionises in solution, it prefers to **act as an acid** (1), meaning it will form  $H_3O^+$  ions:  $HSO_4^-(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)$  (1). This will therefore **increase** the  $H_3O^+$  concentration and cause Janet to observe a **decrease** in the **pH** (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains that <math>HSO_4^-</math> prefers to act as an acid</li> <li>Correctly states its acidic ionisation equation</li> <li>Explains the increase in the <math>H_3O^+</math> concentration decreases the pH</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

## Concept 5

# K<sub>w</sub> and the Ionisation of Water – Repetitive Question Answers

### Monoprotic and Polyprotic Acids: Qs 5.1, 5.2, 5.3

5.1

[4 marks]

- (a) At a temperature > 25°C the pH of the water will be **less than 7** Yes or  No (1)
- (b) At temperatures greater than 90°C water is **highly acidic** Yes or  No (1)
- (c) Between a **temperature range of 15°C to 35°C water will remain neutral** however on either side of this spectrum it will no longer be neutral Yes or  No (1)
- (d) A solution with  $[H_3O^+] = [OH^-]$  is considered to be neutral  Yes or No (1)
- (e) If the forward reaction **was instead exothermic**, the solution would **become more acidic** as the temperature of the water is increased Yes or  No (1)

5.2

[8 marks]

(a) 
$$K_w = [H_3O^+][OH^-] \quad (1)$$

- (b) As the **forward reaction** is **endothermic**, it will be favoured from a temperature increase (1), so the K<sub>w</sub> value will **increase (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains why forward reaction is favoured</li> <li>States that K<sub>w</sub> will increase</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

- (c) When the temperature is **increased**, the system will favour the **forward endothermic reaction** to partially oppose the temperature change (1). This will result in the  $[H_3O^+]$  **increasing (1)**, meaning the pH of the solution will **decrease (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>States that the system will favour the forward endothermic reaction</li> <li>States this will increase the <math>[H_3O^+]</math></li> <li>States the <math>[H_3O^+]</math> increase will decrease the pH</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

5.3

[8 marks]

When the water is placed over the open flame and the temperature is **increased**, the system will favour the **forward endothermic reaction** to partially oppose the temperature change (1). This will result in the  $[H_3O^+]$  **increasing (1)**, meaning the pH of the solution will **decrease (1)**. However, the reason the water is not observed as becoming **acidic**, is because water produces H<sub>3</sub>O<sup>+</sup> and OH<sup>-</sup> ions in a **1 : 1** ratio, so it will always be  $[H_3O^+] = [OH^-]$ , meaning the **water will never be acidic (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains that the forward reaction is favoured</li> <li>Explains a H<sub>3</sub>O<sup>+</sup> concentration increase, will decrease the pH</li> <li>Explains water can never be acidic because it is always <math>[H_3O^+] = [OH^-]</math></li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

## Concept 6

# pH Calculations – Progressive Questions Answers

### pH Calculations of a Single Acid: Qs 6.2

6.2

[8 marks]

$$\begin{aligned}
 \text{(a)} \quad [H_3O^+] &= 0.097 \text{ mol L}^{-1} \quad (1) \\
 pH &= -\log [H_3O^+] \\
 &= -\log [0.097] \\
 &= \mathbf{1.01} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{(b)} \quad [H_3O^+] &= [H_2CO_3] \times 2 \\
 &= 8.4 \times 10^{-3} \times 2 \\
 &= \mathbf{1.42 \times 10^{-5} \text{ mol L}^{-1}} \quad (1) \\
 pH &= -\log [H_3O^+] \\
 &= -\log [1.42 \times 10^{-5}] \\
 &= \mathbf{4.85} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{(c)} \quad [H_3O^+] &= \frac{n}{V} \\
 &= \frac{0.0435}{0.333} \\
 &= \mathbf{0.1306 \text{ mol L}^{-1}} \quad (1) \\
 pH &= -\log [H_3O^+] \\
 &= -\log [0.1306] \\
 &= \mathbf{0.884} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{(d)} \quad [H_3O^+] &= \mathbf{2 \text{ mol L}^{-1}} \quad (1) \\
 pH &= -\log [H_3O^+] \\
 &= -\log [2] \\
 &= \mathbf{-0.3} \quad (1)
 \end{aligned}$$

**Point to note:** As shown in part (d), pH can be negative when the  $H_3O^+$  concentration exceeds  $1 \text{ mol L}^{-1}$

### pH Calculations of a Single Base: Qs 6.4

6.4

[9 marks]

$$\begin{aligned}
 \text{(a)} \quad [OH^-] &= [AgOH] \\
 &= \mathbf{0.004 \text{ mol L}^{-1}} \quad (1) \\
 [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\
 &= \frac{1 \times 10^{-14}}{\mathbf{0.004}} \\
 &= \mathbf{2.5 \times 10^{-12} \text{ mol L}^{-1}} \quad (1) \\
 pH &= -\log [H_3O^+] \\
 &= -\log [2.5 \times 10^{-12}] \\
 &= \mathbf{11.6} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{(b)} \quad [OH^-] &= \frac{n}{V} \\
 &= \frac{0.132}{0.156} \\
 &= \mathbf{0.8462 \text{ mol L}^{-1}} \quad (1) \\
 [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\
 &= \frac{1 \times 10^{-14}}{\mathbf{0.8462}} \\
 &= \mathbf{1.18 \times 10^{-14} \text{ mol L}^{-1}} \\
 pH &= -\log [H_3O^+] \\
 &= -\log [1.18 \times 10^{-14}] \\
 &= \mathbf{13.9} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{(c)} \quad [OH^-] &= [Sr(OH)_2] \times \text{molar ratio} \\
 &= 6.79 \times 10^{-3} \times \mathbf{2} \\
 &= \mathbf{0.01358 \text{ mol L}^{-1}} \quad (1) \\
 [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\
 &= \frac{1 \times 10^{-14}}{\mathbf{0.01358}} \\
 &= \mathbf{7.364 \times 10^{-13} \text{ mol L}^{-1}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 pH &= -\log [H_3O^+] \\
 &= -\log [7.364 \times 10^{-13}] \\
 &= \mathbf{12.1} \quad (1)
 \end{aligned}$$



## pH Scale Questions: Qs 6.5

6.5

[6 marks]

- (a)
- (i) **Decreased** by a factor of 10 **(1)**      (ii) **Increased** by a factor of 1.26 **(1)**
- (iii) **Decreased** by a factor of 100,000 **(1)**      (iv) **Increased** by a factor of 100 **(1)**
- (b)
- (i)  $\frac{\text{Final pH}}{\text{Initial pH}} - 1 = \frac{10^{-0.8}}{10^{-1}} - 1 = 10^{0.2} - 1 = 58.5\%$       (ii)  $\frac{\text{Final pH}}{\text{Initial pH}} - 1 = \frac{10^{-7}}{10^{-6.5}} - 1 = 10^{-0.5} - 1 = -68.4\%$
- $\therefore$  there has been a **58.5% increase** **(1)**       $\therefore$  there has been a **68.4% decrease** **(1)**

## pH Calculations Involving an Acid and Base: Qs 6.6, 6.7, 6.71, 6.8, 6.9, 6.101

6.6

[5 marks]

$$\begin{aligned} n(\text{HCl}) &= cV & n(\text{NaOH}) &= cV \\ &= 0.1 \times 0.05 & &= 0.2 \times 0.02 \\ &= \mathbf{0.005 \text{ mol}} & &= \mathbf{0.004 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{H}_3\text{O}^+) &= n(\text{HCl}) & n(\text{OH}^-) &= n(\text{NaOH}) \\ &= \mathbf{0.005 \text{ mol}} & &= \mathbf{0.004 \text{ mol}} \quad (1) \end{aligned}$$

$$\text{H}_3\text{O}^+_{(\text{aq})} + \text{OH}^-_{(\text{aq})} \rightarrow 2\text{H}_2\text{O}_{(\text{l})}$$

$$\therefore n(\text{H}_3\text{O}^+)_{\text{in excess}} = \mathbf{0.005 - 0.004} \\ = \mathbf{0.001 \text{ mol}} \quad (1)$$

$$\begin{aligned} [\text{H}_3\text{O}^+] &= \frac{n(\text{H}_3\text{O}^+)_{\text{in excess}}}{V_a + V_b} \\ &= \frac{\mathbf{0.001}}{\mathbf{0.05 + 0.02}} \\ &= \mathbf{1.429 \times 10^{-2} \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log [\text{H}_3\text{O}^+] \\ &= -\log [1.429 \times 10^{-2}] \\ &= \mathbf{1.84} \quad (1) \end{aligned}$$

6.7

[7 marks]

$$\begin{aligned} n(\text{HNO}_3) &= cV & n(\text{Ba}(\text{OH})_2) &= cV \\ &= 0.3 \times 0.015 & &= 0.05 \times 0.05 \\ &= \mathbf{0.0045 \text{ mol}} & &= \mathbf{0.0025 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{H}_3\text{O}^+) &= n(\text{HNO}_3) & n(\text{OH}^-) &= n(\text{Ba}(\text{OH})_2) \times 2 \\ &= \mathbf{0.0045 \text{ mol}} & &= 0.0025 \times 2 \\ & & &= \mathbf{0.005 \text{ mol}} \quad (1) \end{aligned}$$



$$\begin{aligned}\therefore n(\text{OH}^-)_{\text{in excess}} &= 0.005 - 0.0045 \\ &= 5 \times 10^{-4} \text{ mol} \quad (1)\end{aligned}$$

$$\begin{aligned}[\text{OH}^-] &= \frac{n(\text{OH}^-)_{\text{in excess}}}{V_a + V_b} \\ &= \frac{5 \times 10^{-4}}{0.015 + 0.05} \\ &= 7.692 \times 10^{-3} \text{ mol L}^{-1} \quad (1)\end{aligned}$$

$$\begin{aligned}[\text{H}_3\text{O}^+] &= \frac{1 \times 10^{-14}}{[\text{OH}^-]} \\ &= \frac{1 \times 10^{-14}}{7.692 \times 10^{-3}} \\ &= 1.3 \times 10^{-12} \text{ mol L}^{-1} \quad (1)\end{aligned}$$

$$\begin{aligned}\text{pH} &= -\log [\text{H}_3\text{O}^+] \\ &= -\log [1.3 \times 10^{-12}] \\ &= 11.89 \quad (1)\end{aligned}$$

$\therefore$  Dylan is incorrect, as his predicted pH of 4.5 does not match the actual pH of 11.89 (1)

6.71

$\begin{aligned}n(\text{H}_2\text{SO}_4) &= cV \\ &= 0.0878 \times 0.112 \\ &= 9.83 \times 10^{-3} \text{ mol}\end{aligned}$	$\begin{aligned}n(\text{Ca}(\text{OH})_2) &= cV \\ &= 0.121 \times 0.1 \\ &= 0.0121 \text{ mol} \quad (1)\end{aligned}$
$\begin{aligned}n(\text{H}_3\text{O}^+) &= n(\text{H}_2\text{SO}_4) \times 2 \\ &= 9.83 \times 10^{-3} \times 2 \\ &= 0.01966 \text{ mol}\end{aligned}$	$\begin{aligned}n(\text{OH}^-) &= n(\text{Ca}(\text{OH})_2) \times 2 \\ &= 0.0121 \times 2 \\ &= 0.0242 \text{ mol} \quad (1)\end{aligned}$

[6 marks]



$$\begin{aligned}\therefore n(\text{OH}^-)_{\text{in excess}} &= 0.0242 - 0.01966 \\ &= 0.00454 \text{ mol} \quad (1)\end{aligned}$$

$$\begin{aligned}[\text{OH}^-] &= \frac{n(\text{OH}^-)_{\text{in excess}}}{V_a + V_b} \\ &= \frac{0.00454}{0.121 + 0.1} \\ &= 0.0205 \text{ mol L}^{-1} \quad (1)\end{aligned}$$

$$\begin{aligned}[\text{H}_3\text{O}^+] &= \frac{1 \times 10^{-14}}{[\text{OH}^-]} \\ &= \frac{1 \times 10^{-14}}{0.0205} \\ &= 4.878 \times 10^{-13} \text{ mol L}^{-1} \quad (1)\end{aligned}$$

$$\begin{aligned}\text{pH} &= -\log [\text{H}_3\text{O}^+] \\ &= -\log [4.878 \times 10^{-13}] \\ &= 12.3 \quad (1)\end{aligned}$$

$\therefore$  Jamie will predict a pH of 12.3

(a)

$$n(\text{H}_2\text{SO}_4) = cV$$

$$= 0.02 \times 0.02$$

$$= \mathbf{0.0004 \text{ mol}}$$

$$n(\text{H}_3\text{O}^+) = n(\text{H}_2\text{SO}_4) \times 2$$

$$= 0.0004 \times 2$$

$$= \mathbf{0.0008 \text{ mol}}$$

$$n(\text{Ca}(\text{OH})_2) = cV$$

$$= 0.0414 \times 0.03$$

$$= \mathbf{0.001242 \text{ mol}} \quad (1)$$

$$n(\text{OH}^-) = n(\text{Ca}(\text{OH})_2) \times 2$$

$$= 0.001242 \times 2$$

$$= \mathbf{0.002484 \text{ mol}} \quad (1)$$



$$\begin{aligned} \therefore n(\text{OH}^-)_{\text{in excess}} &= \mathbf{0.002484 - 0.0008} \\ &= \mathbf{0.001684 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{OH}^-] &= \frac{n(\text{OH}^-)_{\text{in excess}}}{V_a + V_b} \\ &= \frac{\mathbf{0.001684}}{\mathbf{0.02 + 0.03}} \\ &= \mathbf{0.003368 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{H}_3\text{O}^+] &= \frac{1 \times 10^{-14}}{[\text{OH}^-]} \\ &= \frac{1 \times 10^{-14}}{\mathbf{0.003368}} \\ &= \mathbf{2.969 \times 10^{-12} \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log [\text{H}_3\text{O}^+] \\ &= -\log [2.969 \times 10^{-12}] \\ &= \mathbf{11.5} \quad (1) \end{aligned}$$

(b)

$$n(\text{H}_2\text{CO}_3) = cV$$

$$= 0.31 \times 1$$

$$= \mathbf{0.31 \text{ mol}}$$

$$n(\text{H}_3\text{O}^+) = n(\text{H}_2\text{CO}_3) \times 2$$

$$= 0.31 \times 2$$

$$= \mathbf{0.62 \text{ mol}}$$

$$n(\text{Ba}(\text{OH})_2) = cV$$

$$= 0.612 \times 0.530$$

$$= \mathbf{0.3244 \text{ mol}} \quad (1)$$

$$n(\text{OH}^-) = n(\text{Ca}(\text{OH})_2) \times 2$$

$$= 0.3244 \times 2$$

$$= \mathbf{0.6488 \text{ mol}} \quad (1)$$



$$\begin{aligned} \therefore n(\text{OH}^-)_{\text{in excess}} &= \mathbf{0.6488 - 0.62} \\ &= \mathbf{0.0288 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{OH}^-] &= \frac{n(\text{OH}^-)_{\text{excess}}}{V_a + V_b} \\ &= \frac{\mathbf{0.0288}}{\mathbf{1 + 0.530}} \\ &= \mathbf{0.0188 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{H}_3\text{O}^+] &= \frac{1 \times 10^{-14}}{[\text{OH}^-]} \\ &= \frac{1 \times 10^{-14}}{\mathbf{0.0188}} \\ &= \mathbf{5.32 \times 10^{-13} \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log [\text{H}_3\text{O}^+] \\ &= -\log [5.32 \times 10^{-13}] \\ &= \mathbf{12.3} \quad (1) \end{aligned}$$

$$\begin{aligned}
 \text{(c)} \quad n(\text{HNO}_3) &= cV & n(\text{Ca}(\text{OH})_2) &= cV \\
 &= 0.05 \times 0.01 & &= 0.04 \times 0.005 \\
 &= \mathbf{5 \times 10^{-4} \text{ mol}} & &= \mathbf{2 \times 10^{-4} \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(\text{H}_3\text{O}^+) &= n(\text{HNO}_3) & n(\text{OH}^-) &= n(\text{Ca}(\text{OH})_2) \times 2 \\
 &= \mathbf{5 \times 10^{-4} \text{ mol}} & &= 2 \times 10^{-4} \times 2 \\
 & & &= \mathbf{4 \times 10^{-4} \text{ mol}} \quad (1)
 \end{aligned}$$



$$\begin{aligned}
 \therefore n(\text{H}_3\text{O}^+)_{\text{in excess}} &= \mathbf{5 \times 10^{-4} - 4 \times 10^{-4}} \\
 &= \mathbf{1 \times 10^{-4} \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 [\text{H}_3\text{O}^+] &= \frac{n(\text{H}_3\text{O}^+)_{\text{in excess}}}{V_a + V_b} \\
 &= \frac{\mathbf{1 \times 10^{-4}}}{\mathbf{0.01 + 0.005}} \\
 &= \mathbf{6.67 \times 10^{-3} \text{ mol L}^{-1}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{pH} &= -\log [\text{H}_3\text{O}^+] \\
 &= -\log [6.67 \times 10^{-3}] \\
 &= \mathbf{2.18} \quad (1)
 \end{aligned}$$

6.9

[8 marks]

$$\begin{array}{lll}
 n(\text{HNO}_3) = cV & n(\text{H}_2\text{SO}_4) = cV & n(\text{Ba}(\text{OH})_2) = cV \\
 = 0.1 \times 0.025 & = 0.06 \times 0.061 & = 0.152 \times 0.032 \\
 = \mathbf{0.0025 \text{ mol}} & = \mathbf{0.00366 \text{ mol}} & = \mathbf{0.004864 \text{ mol}} \quad (2) \\
 \\ 
 n(\text{H}_3\text{O}^+) = n(\text{HNO}_3) & n(\text{H}_3\text{O}^+) = n(\text{H}_2\text{SO}_4) \times 2 & n(\text{OH}^-) = n(\text{Ba}(\text{OH})_2) \times 2 \\
 = \mathbf{0.0025 \text{ mol}} & = 0.00366 \times 2 & = 0.004864 \times 2 \\
 & = \mathbf{0.00732 \text{ mol}} & = \mathbf{0.009728 \text{ mol}} \quad (2)
 \end{array}$$



$$\begin{aligned}
 \therefore n(\text{H}_3\text{O}^+)_{\text{in excess}} &= \mathbf{0.0025 + 0.00732 - 0.009728} \\
 &= \mathbf{9.2 \times 10^{-5} \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 [\text{H}_3\text{O}^+] &= \frac{n(\text{H}_3\text{O}^+)_{\text{in excess}}}{V_a + V_b} \\
 &= \frac{\mathbf{9.2 \times 10^{-5}}}{\mathbf{0.025 + 0.061 + 0.032}} \\
 &= \mathbf{7.797 \times 10^{-4} \text{ mol L}^{-1}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{pH} &= -\log [\text{H}_3\text{O}^+] \\
 &= -\log [7.797 \times 10^{-4}] \\
 &= \mathbf{3.11} \quad (1)
 \end{aligned}$$

$\therefore$  Glenda and Tom will not reach their target pH of 6.2 (1)

**Error 1:** In the first step, for calculating  $n(H_3O^+)$ , the  $n(H_2SO_4)$  should be multiplied by two, instead of one (1)

**Error 2:** In the third step, for calculating  $n(H_3O^+)_{in\ excess}$ , the  $n(OH^-)$  should be subtracted not added (1)

**Error 3:** In the fourth step, for calculating  $[H_3O^+]$ , they should also add the  $V(Ba(OH)_2)$  (1)

**Error 4:** In the final step, for calculating the pH, the pH formula should have a negative sign:  $pH = -\log [H_3O^+]$  (1)

$$n(HCl) = cV$$

$$= 0.05 \times 0.02$$

$$= 1 \times 10^{-3} \text{ mol}$$

$$n(H_3O^+) = n(HCl)$$

$$= 1 \times 10^{-3} \text{ mol}$$

$$n(H_2SO_4) = cV$$

$$= 0.02 \times 0.01$$

$$= 2 \times 10^{-4} \text{ mol}$$

$$n(H_3O^+) = n(H_2SO_4) \times 2$$

$$= 2 \times 10^{-4} \times 2$$

$$= 4 \times 10^{-4} \text{ mol} \quad (1)$$

$$n(Ba(OH)_2) = cV$$

$$= 0.02 \times 0.03$$

$$= 6 \times 10^{-4} \text{ mol}$$

$$n(OH^-) = n(Ba(OH)_2) \times 2$$

$$= 6 \times 10^{-4} \times 2$$

$$= 1.2 \times 10^{-3} \text{ mol}$$



$$\therefore n(H_3O^+)_{in\ excess} = 1 \times 10^{-3} + 4 \times 10^{-4} - 1.2 \times 10^{-3}$$

$$= 2 \times 10^{-4} \text{ mol} \quad (1)$$

$$[H_3O^+] = \frac{n(H_3O^+)_{in\ excess}}{V_a + V_b}$$

$$= \frac{2 \times 10^{-4}}{0.02 + 0.01 + 0.03}$$

$$= 3.33 \times 10^{-3} \text{ mol L}^{-1} \quad (1)$$

$$pH = \log [H_3O^+]$$

$$= -\log [3.33 \times 10^{-3}]$$

$$= 2.48 \quad (1)$$

## Concept 7

# Buffers and Buffer Capacity – Progressive Questions Answers

### Forming Buffers and Writing Buffer Equations: Qs 7.1, 7.2, 7.3

7.1

[4 marks]

- (a) A very **weak acid** paired with a **very strong base** can produce a buffer Yes or  No (1)
- (b) A **weak base** paired with its **conjugate acid** is capable of making a buffer  Yes or No (1)
- (c) A buffer system is made from an acid and base that **differ by one hydrogen ion** Yes or  No (1)
- (d) A **weak acid** paired with any **weak base** can produce a buffer system Yes or  No (1)

7.2

[6 marks]

Acid-base pair	Buffer Solution (Yes/No)	Buffer Equation
$NaCH_3COO/CH_3COOH$	Yes (1)	$CH_3COO^-_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3COOH_{(aq)} + OH^-_{(aq)}$ (1)
$H_2SO_4/KHSO_4$	No (1)	
$KH_2PO_4/K_3PO_4$	No (1)	
$NaHCO_3/Na_2CO_3$	Yes (1)	$H_2CO_{3(aq)} + H_2O_{(l)} \rightleftharpoons HCO_3^-_{(aq)} + H_3O^+_{(aq)}$ (1)

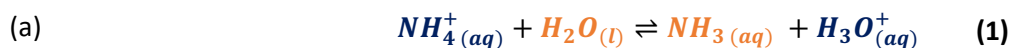
7.3

[3 marks]

Pairs:  $KHSO_4/Na_2SO_4$  (1)  $K_2HPO_4/K_3PO_4$  (1)  $CH_3COOH/CH_3COO^-$  (1)

7.4

[7 marks]



- (b) When a few drops of **strong base** is added, the added **OH<sup>-</sup> ions** will consume the **H<sub>3</sub>O<sup>+</sup> ions** and cause the **H<sub>3</sub>O<sup>+</sup> concentration** to **decrease (1)**. With an **decreased [H<sub>3</sub>O<sup>+</sup>]**, the **NH<sub>4</sub><sup>+</sup>/NH<sub>3</sub>** buffer will act to **resist the pH change** by favouring the **forward reaction**, in order to **replace** some of the lost **H<sub>3</sub>O<sup>+</sup> ions (1)**. This will mean the pH will not change significantly **(1)**, until all the **NH<sub>4</sub><sup>+</sup>** has been used up.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Explains there is a <b>OH<sup>-</sup> concentration</b> increase that causes a <b>H<sub>3</sub>O<sup>+</sup> concentration</b> decrease</li> <li>• Applies LCP to show forward reaction is favoured to replace the lost <b>H<sub>3</sub>O<sup>+</sup> ions</b></li> <li>• Explains that the <b>H<sub>3</sub>O<sup>+</sup> concentration</b> does not change significantly so pH doesn't change significantly</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

- (c) In order for a system to be able to resist pH changes, it must be in a state of dynamic equilibrium so that it is able to **consume/produce  $H_3O^+$  ions** and **stop the pH** from changing (1). When a  $HNO_3/NO_3^-$  system is used, the  $HNO_3$  will react to completion and not be able to form a dynamic equilibrium (1). With no dynamic equilibrium, the  $HNO_3/NO_3^-$  system cannot reproduce the lost  $H_3O^+$  ions and therefore **stop the pH** from changing (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains that a dynamic equilibrium system allows the system to respond to both increases and decreases in pH</li> <li>Explains a <math>HNO_3/NO_3^-</math> system does not work because it does not form a dynamic equilibrium system</li> <li>Explains that it will not reproduce the lost <math>H_3O^+</math> ions and therefore stop the pH from changing</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

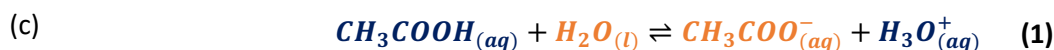
**7.5** **[10 marks]**

- (a) Jamie's  $H_2CO_3/KHCO_3$  buffer and Alexa's  $CH_3COOH/NaCH_3COO$  buffer will **both make successful buffers** because they are weak acid/bases and their conjugate pairs (2). Dylan's buffer will not work because  $K_2CO_3$  is **not the conjugate base** of  $H_2CO_3$  (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains why Jamie's buffer will work</li> <li>Explains why Alexa's buffer will work</li> <li>Explains why Dylan's buffer won't work</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

- (b) **Alexa's** solution will provide the **greatest buffering capacity** (1), because her buffer contains the **highest concentrations** of both the weak acid and its conjugate base (1), along with having **equal concentrations** of the acid and conjugate base so they can equally accommodate for any change (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>States that Alexa's buffer has the greatest buffering capacity</li> <li>Explains why in terms of highest concentrations</li> <li>Explains why in terms of equal concentrations</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>



When a few drops of  $HCl$  is added, the added  $H_3O^+$  ions will cause the  $H_3O^+$  concentration to **increase** (1). With an **increased  $[H_3O^+]$** , the  $CH_3COOH/CH_3COO^-$  buffer will act to **resist the pH change** by favouring the **reverse** reaction, in order to consume most of the added  $H_3O^+$  ions (1). This will mean the pH will not change significantly (1), until all the  $CH_3COO^-$  has been used up.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains there is a <math>H_3O^+</math> concentration increase</li> <li>Applies LCP to show reverse reaction is favoured to consume the added <math>H_3O^+</math> ions</li> <li>Explains that the <math>H_3O^+</math> concentration does not change significantly so pH doesn't change significantly</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

## 7.6

[6 marks]



- (b) When a few drops of **NaOH** is added, the added **OH<sup>-</sup> ions** will consume the **H<sub>3</sub>O<sup>+</sup> ions** and cause the **H<sub>3</sub>O<sup>+</sup> concentration** to **decrease (1)**. With an **decreased [H<sub>3</sub>O<sup>+</sup>]**, the **CH<sub>3</sub>(CH<sub>2</sub>)<sub>4</sub>COOH/CH<sub>3</sub>(CH<sub>2</sub>)<sub>4</sub>COO<sup>-</sup>** buffer will act to **resist the pH change** by favouring the **forward reaction**, in order to **replace** some of the lost **H<sub>3</sub>O<sup>+</sup> ions (1)**. This will mean the **H<sub>3</sub>O<sup>+</sup> concentration** will not change significantly **(1)**, until all the **CH<sub>3</sub>(CH<sub>2</sub>)<sub>4</sub>COOH** has been used up.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains there is a <b>OH<sup>-</sup> concentration</b> increase that causes a <b>H<sub>3</sub>O<sup>+</sup> concentration</b> decrease</li> <li>Applies LCP to show forward reaction is favoured to replace the lost <b>H<sub>3</sub>O<sup>+</sup> ions</b></li> <li>Explains that the <b>H<sub>3</sub>O<sup>+</sup> concentration</b> does not change significantly so pH doesn't change significantly</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

- (c) They can: (1) **increase the amounts** of **CH<sub>3</sub>(CH<sub>2</sub>)<sub>4</sub>COOH** and **CH<sub>3</sub>(CH<sub>2</sub>)<sub>4</sub>COO<sup>-</sup>** in the buffer solution, so there is more acid and base that needs to be consumed before the buffer can no longer operate **(1)**, and (2) ensure the **CH<sub>3</sub>(CH<sub>2</sub>)<sub>4</sub>COOH** and **CH<sub>3</sub>(CH<sub>2</sub>)<sub>4</sub>COO<sup>-</sup>** are in **equal concentrations** so they can equally accommodate to any pH change **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Increase the amount of <b>CH<sub>3</sub>(CH<sub>2</sub>)<sub>4</sub>COOH</b> and <b>CH<sub>3</sub>(CH<sub>2</sub>)<sub>4</sub>COO<sup>-</sup></b></li> <li>Ensure equal amounts of <b>CH<sub>3</sub>(CH<sub>2</sub>)<sub>4</sub>COOH</b> and <b>CH<sub>3</sub>(CH<sub>2</sub>)<sub>4</sub>COO<sup>-</sup></b></li> </ul>	1 – 2
<b>Total</b>	<b>2</b>





---

# Chapter 4

---

## Volumetric Analysis Answers

Problem Set 7 Progressive Answers – Volumetric Analysis ..... 1

Problem Set 7 Repetitive Answers – Volumetric Analysis ..... 26

# Problem Set 7 – Volumetric Analysis

## Progressive Questions

### Concept 1

### Nature of Salts – Progressive Questions Answers

Determining whether a salt is acidic, **basic** or neutral: Q1, Q2, Q3

1.

[10 marks]

Ion	Student's Prediction	Actual nature of the ion	Correct or <b>Incorrect</b> (✓ or X)
$Cl^-$	Jamie – <b>Basic</b>	Neutral	X
$OH^-$	Jamie – <b>Basic</b>	<b>Basic</b>	✓
$HSO_4^-$	Jamie – Neutral	<b>Acidic</b>	X
$PO_4^{3-}$	Dylan – <b>Basic</b>	<b>Basic</b>	✓
$NO_3^-$	Dylan – <b>Basic</b>	Neutral	X
$NH_4^+$	Dylan – <b>Acidic</b>	<b>Acidic</b>	✓
$F^-$	Alexa – Neutral	<b>Basic</b>	X
$HPO_4^{2-}$	Alexa – <b>Acidic</b>	<b>Basic</b>	X
$HCO_3^-$	Alexa – <b>Acidic</b>	<b>Basic</b>	X
$H_2PO_4^-$	Alexa – <b>Basic</b>	<b>Acidic</b>	X

Marking Criteria	Marks Allocated
• Determines nature of ion and if the student is correct	1 – 10
<b>Total</b>	<b>10</b>

2.

[10 marks]

Ion	Student's Prediction	Actual nature of the salt	Correct or <b>Incorrect</b> (✓ or X)
$AlCl_3$	Jamie – Neutral	Neutral	✓
$NaH_2PO_4$	Jamie – <b>Acidic</b>	<b>Acidic</b>	✓
$LiOH$	Jamie – <b>Basic</b>	<b>Basic</b>	✓
$Ca(CH_3COO)_2$	Dylan – Neutral	<b>Basic</b>	X
$MgCO_3$	Dylan – <b>Basic</b>	<b>Basic</b>	✓
$LiHSO_4$	Dylan – <b>Acidic</b>	<b>Acidic</b>	✓
$Mg_3(PO_4)_2$	Alexa – Neutral	<b>Basic</b>	X
$NaCN$	Alexa – <b>Acidic</b>	<b>Basic</b>	X

$NH_4Cl$	Alexa – Neutral	Acidic	X
$NaF$	Alexa – Acidic	Basic	X

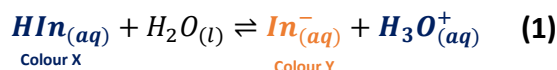
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Determines nature of ion and if the student is correct</li> </ul>	1 – 10
<b>Total</b>	<b>10</b>

## Concept 2

# Indicators – Progressive Questions Answers

### Understanding Indicators: Q1, Q2, Q3, Q4

1. [2 marks]  
 Indicators are **weak acids** or **weak bases** with a **conjugate acid/base** with a **different colour**, and therefore establish the **equilibrium system** that changes colour in response to  $H_3O^+$  concentration changes and can therefore be used to track pH (1):



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Indicators are a weak acid/weak base system that change colour in response to <math>H_3O^+</math> concentration changes, so it can be used to track pH changes</li> <li>Correct indicator equation</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

2. [6 marks]  
 (a) The colourless solution would **turn blue** when the drops are added. (1)

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>The colourless solution will turn blue</li> </ul>	1
<b>Total</b>	<b>1</b>

(b) The colourless water will **turn yellow** when the drops are added (1)

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>The colourless solution will turn blue</li> </ul>	1
<b>Total</b>	<b>1</b>

(c)  $pH = -\log(1 \times 10^{-5}) = 5$  (1). Based on this pH, the colourless solution will **turn yellow** when the drops are added (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Calculates pH of 5</li> <li>The colourless solution will turn yellow</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(d)

$$\begin{aligned}
 [H_3O^+] &= \frac{1 \times 10^{-14}}{[OH^-]} \\
 &= \frac{1 \times 10^{-14}}{1 \times 10^{-6}} \\
 &= 1 \times 10^{-8} \text{ mol L}^{-1} \\
 pH &= -\log [H_3O^+] \\
 &= -\log [1 \times 10^{-8}] \\
 &= 8 \quad (1)
 \end{aligned}$$

Based on this pH, the colourless solution will **remain colourless** when the drops are added (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Calculates pH of 5</li> <li>The colourless solution will turn yellow</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

3. [5 marks]



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correct indicator equation</li> </ul>	1
<b>Total</b>	<b>1</b>

(b) Phenolphthalein has a pH range of **8.2 – 10**, where it is colourless below a pH of 8.2 (1). As the solution of *HCl* has a pH of 1, the solution will remain colourless because it is below a pH of 8.2 (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Phenolphthalein is colourless below a pH of 8.2</li> <li>Therefore the <i>HCl</i> remains colourless because it has a pH of 1</li> </ul>	1
<b>Total</b>	<b>1</b>

4. [8 marks]

(a) Alexa can divide up each of the solutions into three beakers each (12 in total), and test each of the indicators in each of the solutions (1). From these results she can determine which solution is which based on the indicator pH ranges (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Set-up twelve beakers and fill three beakers with each solution</li> <li>Using the indicator pH ranges, she can identify each solution based on the results</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(b)

	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>
<b>Methyl orange</b> (3.1 – 4.4)	Yellow	Yellow	Yellow	Red
<b>Bromothymol blue</b> (6.0 – 7.6)	Blue	Blue	Yellow	Yellow
<b>Phenolphthalein</b> (8.2 – 10)	Pink	Colourless	Colourless	Colourless
<b>Solution</b>	$0.5 \text{ mol L}^{-1} \text{ NaOH}$ (1)	$1.5 \times 10^{-6} \text{ mol L}^{-1} \text{ NaOH}$ (1)	$8 \times 10^{-6} \text{ mol L}^{-1} \text{ HCl}$ (1)	$0.1 \text{ mol L}^{-1} \text{ HCl}$ (1)

**Point to note:** You don't need to calculate the pH of each solution in this question, you can simply use a process of elimination to figure out which solution is which.

- For solutions A and D you can see these are the extremes, with phenolphthalein being pink for solution A and methyl orange being red for solution D. You can therefore deduce these are the strongest base  $0.5 \text{ mol L}^{-1} \text{ NaOH}$  and the strongest acid  $0.1 \text{ mol L}^{-1} \text{ HCl}$  respectively.
- For solutions B and C, the bromothymol blue results show that solution B is more basic and solution C is more acidic. Therefore, we can deduce that solution B is the weaker base  $1.5 \times 10^{-6} \text{ mol L}^{-1} \text{ NaOH}$  and solution C is the weaker acid  $8 \times 10^{-6} \text{ mol L}^{-1} \text{ HCl}$

Marking Criteria	Marks Allocated
• Correctly classifies each solution	1 – 4
<b>Total</b>	<b>4</b>

### Titration Curves: Q5, Q6, Q7, Q8, Q9

5.

[2 marks]

The **equivalence point** is the **point** in a titration when there is **exactly** enough **acid** and **base** are in the conical flask to **neutralise one another (1)**, whereas the **end point** is the point in a titration where the **indicator changes colour (1)**. Whilst the goal is to have the end point match the equivalence point, they are two different points.

Marking Criteria	Marks Allocated
• Defines equivalence point • Defines end point	1 – 2
<b>Total</b>	<b>2</b>

6.

[4 marks]

(a) The **yellow solution** in the conical flask will slowly turn **red (1)**.

Marking Criteria	Marks Allocated
• Red solution in conical flask will slowly turn orange	1
<b>Total</b>	<b>1</b>

(b) The **colourless solution** in the conical flask will slowly turn **pink (1)**.

Marking Criteria	Marks Allocated
• Colourless solution in conical flask will slowly turn pink	1
<b>Total</b>	<b>1</b>

(c) The **yellow solution** in the conical flask will slowly turn **blue** (1).

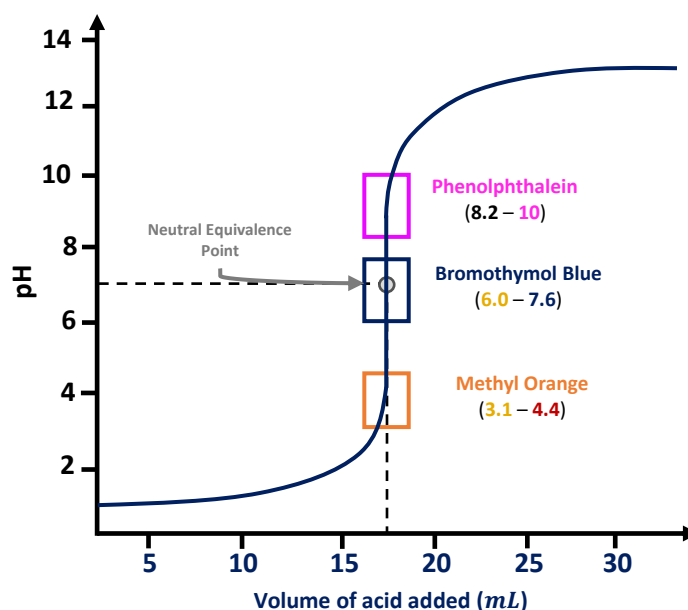
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Yellow solution in conical flask will slowly turn blue</li> </ul>	1
<b>Total</b>	<b>1</b>

(d) The **blue solution** in the conical flask will slowly turn **yellow** (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Blue solution in conical flask will slowly turn yellow</li> </ul>	1
<b>Total</b>	<b>1</b>

7.

[7 marks]



(a) The equivalence point was labelled at a pH of 7, because the equivalence point of a strong acid and strong base is always **neutral** (1).

(b) Labelled as above ^^^ (3)

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correct labelling of equivalence point</li> <li>Explains that it is placed at a pH of 7 because a strong acid and strong base produces a neutral equivalence point</li> </ul>	1 – 2
<ul style="list-style-type: none"> <li>Correct labelling of end points for methyl orange, bromothymol blue and phenolphthalein</li> </ul>	1 – 3
<b>Total</b>	<b>5</b>

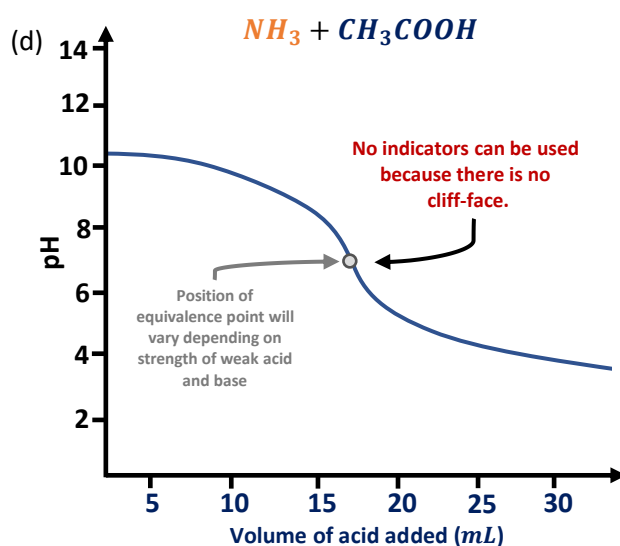
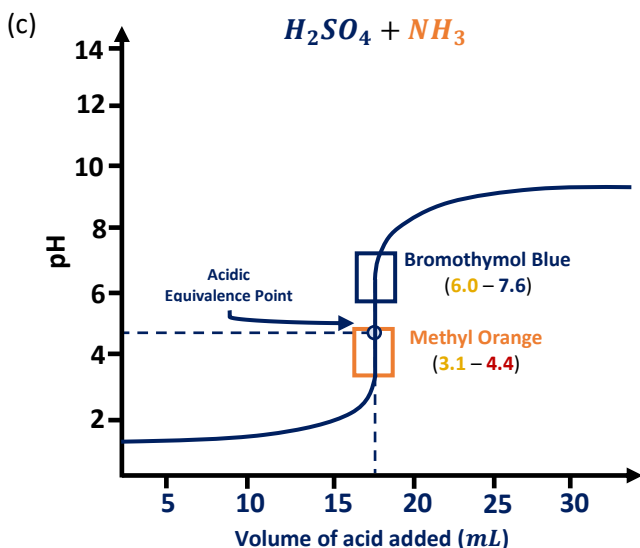
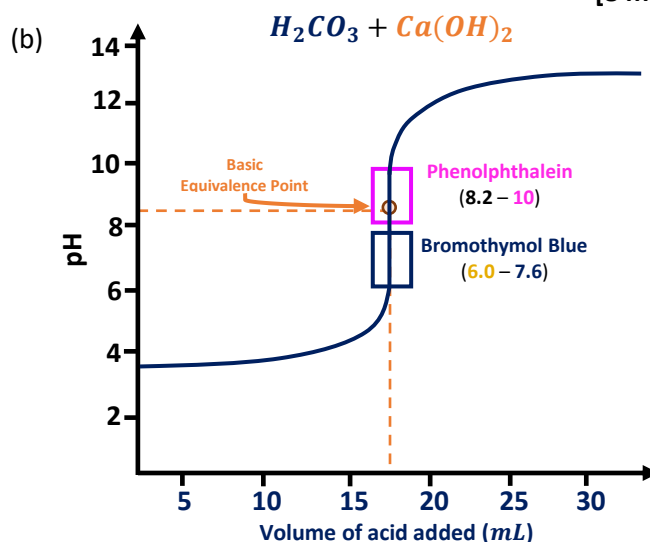
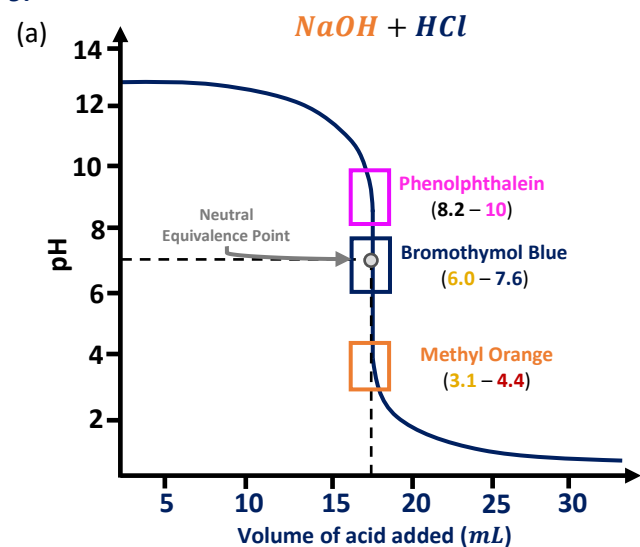
(c) The most suitable indicator would be **bromothymol blue** because it has an end point that is closest to the equivalence point of 7 (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Bromothymol Blue</li> </ul>	1
<b>Total</b>	<b>1</b>

8. [8 marks]
- (a) Equivalence point: **Neutral**      Appropriate indicator: **Bromothymol blue**    (1)
- (b) Equivalence point: **Basic**      Appropriate indicator: **Phenolphthalein**    (1)
- (c) Equivalence point: **Acidic**      Appropriate indicator: **Methyl orange**    (1)
- (d) Equivalence point: **Varying/none**      Appropriate indicator: **None**    (1)

Marking Criteria	Marks Allocated
• Correct equivalence point and suggested indicator	1 – 4
<b>Total</b>	<b>4</b>

9. [8 marks]



**Point to note:** Whilst you can choose from multiple indicators, the best indicator is always the one with the end point closest to the equivalence point

Marking Criteria	Marks Allocated
• Correct equivalence point labelled	1 – 4
• Appropriate indicator labelled	1 – 4
<b>Total</b>	<b>8</b>

## Difficult Indicator Questions: Q10, Q11

10.

[12 marks]

- (a) (i) Before the equivalence point (2) (ii) Before the equivalence point (2)
- (iii) After the equivalence point (2) (iv) Before the equivalence point (2)

**Point to note:** The key with this question is to imagine the titration curve for each scenario, and where the equivalence point and end point will be for the titration. Based on this you can see if the end point occurs before or after the equivalence point and therefore successfully answer the question.

Also note that many of these indicators are suitable for these scenarios, but they will never exactly capture the equivalence point, so the end point will always technically occur before or after the equivalence point.

Marking Criteria	Marks Allocated
• Correctly determines 'before' or 'after' equivalence point	2 – 8
<b>Total</b>	<b>8</b>

- (b) (i) Smaller titre volume (1) (ii) Smaller titre volume (1)
- (iii) Larger titre volume (1) (iv) Smaller titre volume (1)

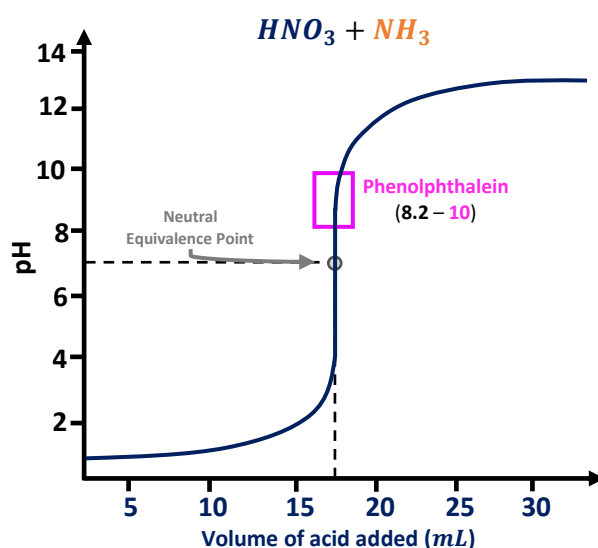
**Point to note:** The key point is that if the end point occurs before the equivalence point, then the titre volume will be smaller than it actually should be, and if the end point occurs after the equivalence point, then the titre volume will be larger than it should be.

Marking Criteria	Marks Allocated
• Correctly determines 'smaller' or 'larger' titre volume	1 – 4
<b>Total</b>	<b>4</b>

11.

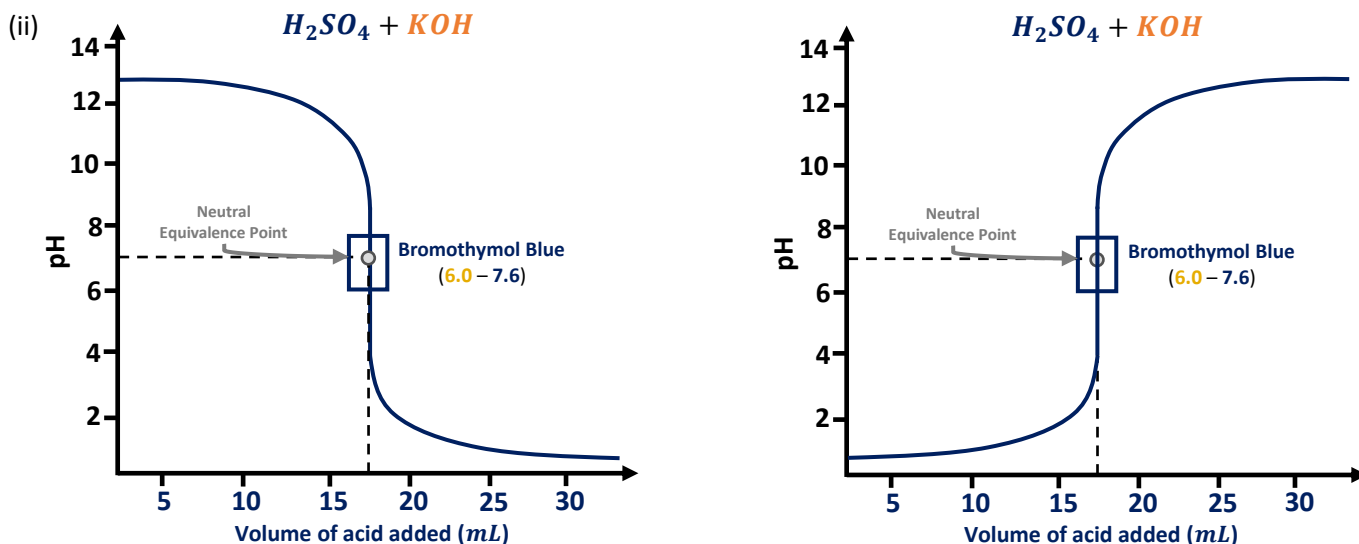
[16 marks]

- (a)  
(i)

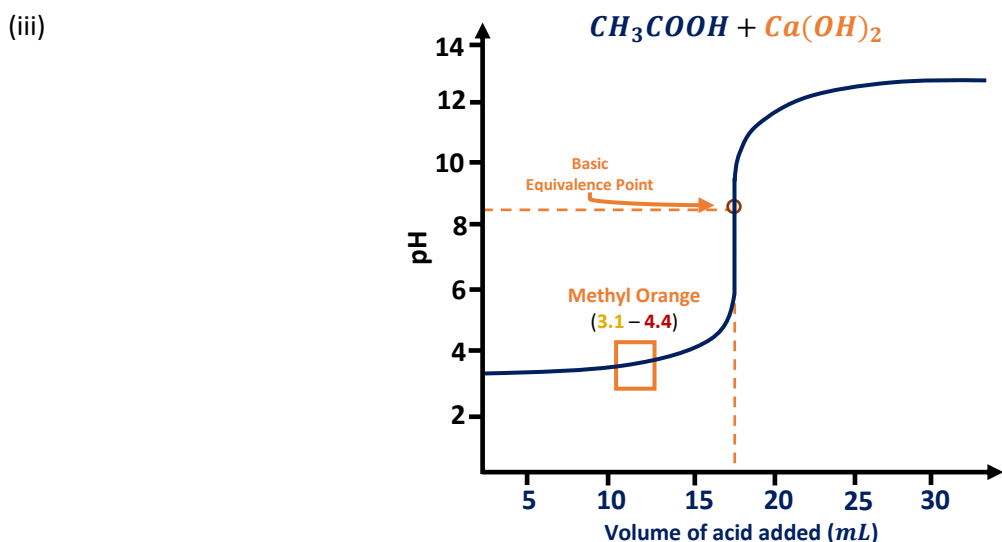


As seen from the titration curves (1),  $HNO_3$  should be placed in the conical flask (1) and  $NH_3$  should be placed in the burette (1).

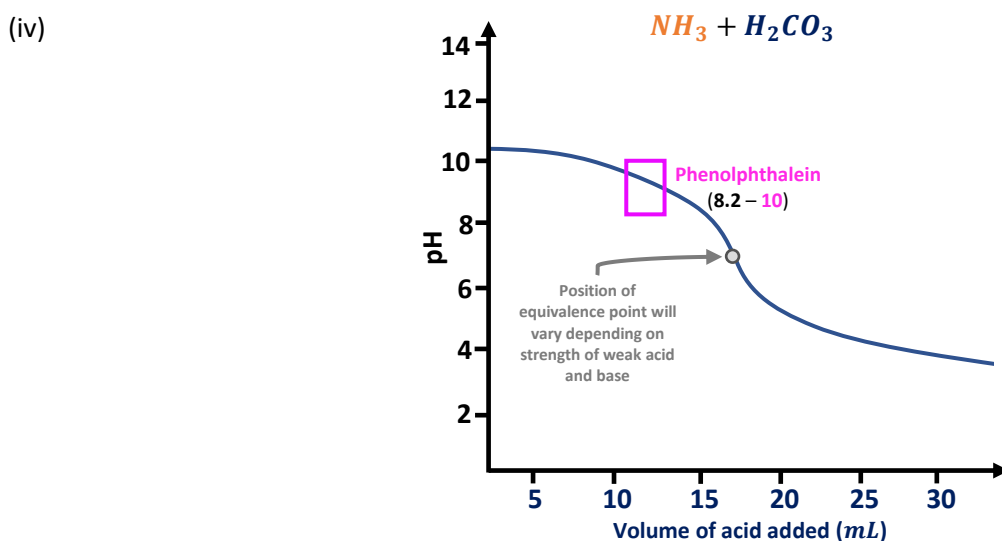




As seen from both titration curves (1),  $H_2SO_4$  and  $KOH$  can be placed in either the burette or conical flask (1), the equivalence point will always match the end point (1).



As seen from the titration curve (1),  $CH_3COOH$  should be placed in the conical flask (1) and  $Ca(OH)_2$  should be placed in the burette (1).



As seen from the titration curve (1),  $NH_3$  should be placed in the conical flask (1) and  $H_2CO_3$  should be placed in the burette (1), however this answer may vary depending on the strength of acid and base used.

Marking Criteria	Marks Allocated
• Draws appropriate titration curve with end point and equivalence point	1 – 4
• Determines which solution should be in conical flask	1 – 4
• Determines which solution should be in burette	1 – 4
<b>Total</b>	<b>4</b>

- (b)
- (i) Burette: **Deionised water** Conical Flask:  $NH_3$  (1)
- (ii) Burette: **Deionised water** Conical Flask:  $H_2SO_4$  or  $KOH$  (1)
- (iii) Burette: **Deionised water** Conical Flask:  $Ca(OH)_2$  (1)
- (iv) Burette: **Deionised** Conical Flask:  $H_2CO_3$  (1)

Marking Criteria	Marks Allocated
• Correctly determines solutions for burette and conical flask	1 – 4
<b>Total</b>	<b>4</b>

## Concept 3

# Titration Theory - Progressive Questions Answers

### Primary Standards: Q1, Q2

1. [7 marks]

(a) The four criteria for a substance to be classified as a primary standard are:

- Readily available in its pure form with a precise, known formula
- Does not react with its surroundings e.g. hygroscopic (should not absorb moisture from atmosphere)
- Has a relatively high molar mass (so that it can be accurately weighed with minimal error)
- Must be soluble in water

Marking Criteria	Marks Allocated
• States the four correct criteria	1 – 4
<b>Total</b>	<b>4</b>

(b) Even though it is soluble in water and has a relatively high molar mass **(1)**, normal sodium carbonate is hygroscopic, which means it absorbs moisture from the atmosphere **(1)**. This means its molar mass cannot be accurately determined, making it unsuitable to use as a primary standard **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Sodium carbonate is soluble in water, and has a relatively high molar mass</li> <li>• Sodium carbonate absorbs moisture from atmosphere so therefore it also doesn't have a precise formula</li> <li>• This gives it a varying molar mass, making it unsuitable as a primary standard</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(c) In order to make the  $Na_2CO_3$  anhydrous, you can place it in an oven to evaporate the water inside it and then store the sodium carbonate in a desiccator to prevent absorption of more water from the air **(1)**.

Marking Criteria	Marks Allocated
• Place sodium carbonate in an oven and then store in a desiccator	1
<b>Total</b>	<b>1</b>

2. [7 marks]

(a) The following criteria are correct: (ii), (iii), (iv), (vii)

Marking Criteria	Marks Allocated
• Circles the four correct criteria	1 – 4
<b>Total</b>	<b>4</b>

(b)  $NaOH$  cannot be used as a primary standard because:

- Reacts with surrounding environment – reacts with carbon dioxide in the air and absorbs moisture (hygroscopic) forming sodium carbonate ( $Na_2CO_3$ ) **(1)**
- Relatively low molar mass ( $39.998g\ mol^{-1}$ ), making it prone to calculation inaccuracies **(1)**

Marking Criteria	Marks Allocated
• Reacts with surrounding environment and relatively low molar mass	1 – 2
<b>Total</b>	<b>2</b>

3.  
(a)

[10 marks]

Mistake	Random/Systematic Error	Larger/Smaller Titre Volume
“Water is used to rinse the pipette”	Random/ <b>Systematic</b> <b>Explanation:</b> Pipette must be rinsed with the same concentrated aliquot it holds, so rinsing with water will consistently dilute the solution	<b>Larger/Smaller</b> <b>Explanation:</b> Water will dilute the aliquot solution, so less titre will be able to neutralise the aliquot
“Vinegar is used to rinse the conical flask”	Random/ <b>Systematic</b> <b>Explanation:</b> Conical flask must be rinsed with water, so rinsing with vinegar means increases the number of moles in the conical flask, so consistently incorrect titre volumes	<b>Larger/Smaller</b> <b>Explanation:</b> Rinsing with acid will add extra moles of hydronium ions, so higher titre volume of base is required to neutralise this
“Methyl Orange is used as an indicator”	Random/ <b>Systematic</b> <b>Explanation:</b> Incorrect indicator is used since methyl orange is in the acidic range and the equivalence point is basic – this will result in consistently incorrect titre volumes	<b>Larger/Smaller</b> <b>Explanation:</b> Acidic-range indicator is used rather than a basic-range indicator, since conical flask is initially acidic, the titre volume will be significantly lower than it should be
“Luke reads <b>top</b> of meniscus for <b>initial reading</b> and then <b>bottom</b> of meniscus for <b>final reading</b> ”	Random/ <b>Systematic</b> <b>Explanation:</b> This is a systematic error because initial and final readings are <u>consistently</u> being taken at different locations at the meniscus during each trial	<b>Larger/Smaller</b> <b>Explanation:</b> Reading at the top of the first meniscus and then the bottom of the second meniscus will result in extra volume being recorded (the size of which is equal to the size of the meniscus)

Marking Criteria	Marks Allocated
• ½ mark each for circling the correct option	1 – 4
• ½ mark for each explanation (refer to the table above)	1 – 4
<b>Total</b>	<b>8</b>

(b) Only the effect of random errors can be minimised (i.e. cancelled out) by conducting multiple trials (1). Since all of the mistakes are systematic errors, no errors can be minimised with more trials (1).

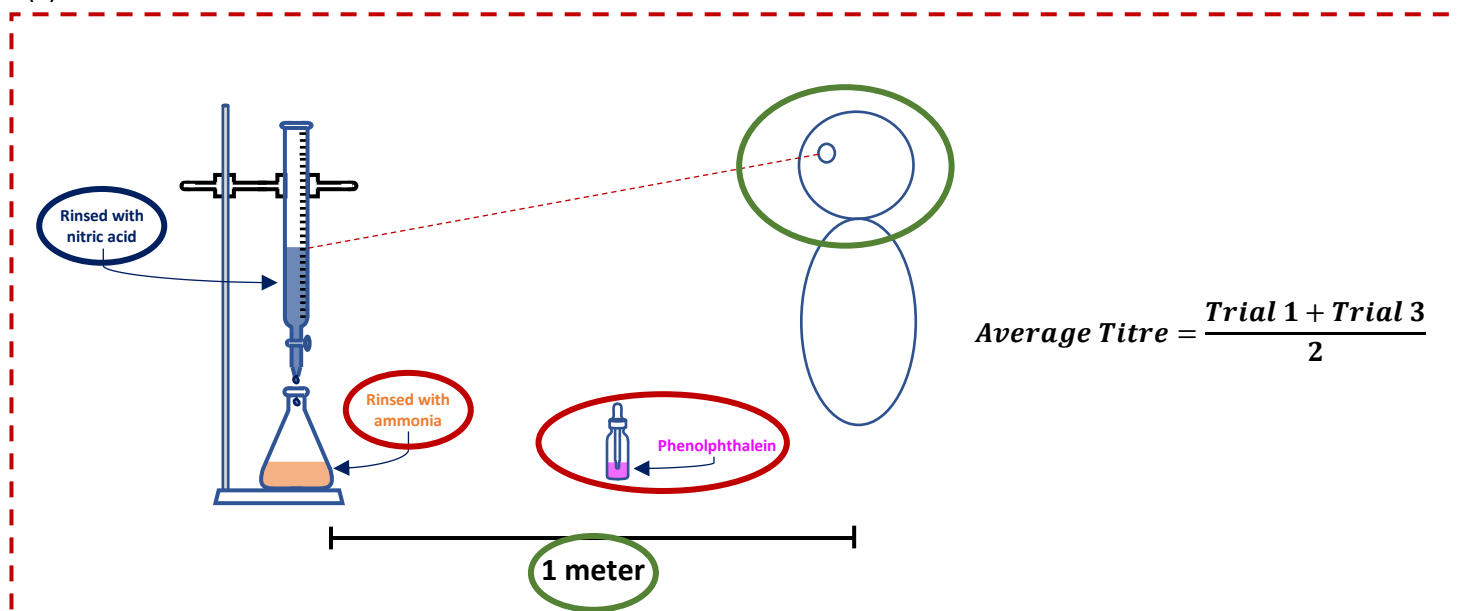
Marking Criteria	Marks Allocated
• Conducting more trials only minimises the effect of <b>random</b> errors	1 – 2
• There are no errors which could be minimised by conducting multiple trials	
<b>Total</b>	<b>2</b>

Note: No marks for including any incorrect answers

4.

[5 marks]

(a)



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Circles the 2 systematic errors correctly</li> <li>• Circles the 2 random errors correctly</li> <li>• Circles the 1 correct practice correctly</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>

**Points to note:**

1. Normally you should read from the bottom of the meniscus, and while Nick measured from the top of the meniscus, he did this for both initial and final burette readings (so technically the burette volume is still correct)
2. Whilst it is **not** an experiment error, only 2 concordant trials were determined instead of 3 so this has been classified as an “incorrect practice”

(b) **Using phenolphthalein:** The equivalence point is acidic, yet phenolphthalein changes in the basic pH range. Since the conical flask initially contains basic ammonia solution, the end point will be reached with a **smaller titre volume** (1).

**Rinsing conical flask with ammonia:** Conical flask should be rinsed with water and rinsing with ammonia will add extra moles of ammonia in the flask, so there will be more nitric acid needed to neutralise, so a **larger titre volume** (1).

**Reading volume from 1m away:** Glassware measurements should be taken closer to avoid any random errors from human inaccuracies when too far out – these errors may result in **randomly larger or smaller** titre volumes (1).

**Not measuring at eye-level:** If not taken at eye-level, titre volume may be randomly incorrectly gauged as **larger or smaller** (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• <b>Using phenolphthalein:</b> Decrease</li> <li>• <b>Rinsing conical flask with ammonia:</b> Increase</li> <li>• <b>Reading volume from 1m away:</b> May increase or decrease (random error)</li> <li>• <b>Not measuring at eye-level:</b> May increase or decrease (random error)</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

Note: A brief explanation is still required to be awarded marks

5.

[5 marks]

(a) (i) They both have the **same  $OH^-$  concentration** (regardless of the bases' different extents of ionisation) so the **same amount** of hydrochloric acid will be required to neutralise **(1)**

(ii) Since  $Ba(OH)_2 \rightarrow Ba^{2+} + 2OH^-$ , the  $OH^-$  concentration in the barium hydroxide solution is **twice** the concentration of sodium hydroxide, so **sodium hydroxide** will **require less** hydrochloric acid to neutralise **(1)**

(iii) Since  $Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$  both calcium hydroxide and ammonia solutions have the same  $OH^-$  concentration ( $0.2 \text{ mol L}^{-1}$ ), so they require the **same amount** **(1)**.

**Point to note:** For (iii), the fact that ammonia is a weak base makes no difference because this is a neutralisation reaction. In a neutralisation reaction all of the  $H^+$  and  $OH^-$  will react, so the strength of the acid/base is not important in this case.

Marking Criteria	Marks Allocated
• Correctly states whether it is more, less or the same amount	1 – 3
<b>Total</b>	<b>3</b>

(b) (i) Phosphoric acid is triprotic, so its  $H^+$  concentration is actually  $0.15 \text{ mol L}^{-1}$ , still short of the monoprotic hydrochloric acid solution of  $0.2 \text{ mol L}^{-1}$ ,

(ii) Even though ethanoic acid solution is twice as concentrated, sulfuric acid is diprotic so both solutions have a  $H^+$  concentration of  $0.3 \text{ mol L}^{-1}$ .

**Point to note:** For (ii), the fact that ethanoic acid is a weak acid makes no difference because this is a neutralisation reaction. In a neutralisation reaction all of the  $H^+$  and  $OH^-$  will react, so the strength of the acid/base is not important in this case.

Marking Criteria	Marks Allocated
• Correctly states whether it is more, less or the same amount	1 – 2
<b>Total</b>	<b>2</b>

6. (i) **False (1)** – The balanced equation tells us that we need twice as many moles of  $HNO_3$  to neutralise  $Ba(OH)_2$ . As concentrations are equal (considering  $n = cV$ ), we actually need  $30 \text{ mL}$  of  $HNO_3$  instead of  $15 \text{ mL}$  **(1)**

(ii) **False (1)** – Neutralisation of hydroxide/hydrogen ions is irrelevant, the equivalence point is neutral because it is a case of strong acid/strong base **(1)** – the salt produced in this case is  $BaNO_3$ , which is neutral

(i) **False (1)** – The equivalence point will still be neutral because sulfuric is a strong acid and so is nitric acid, the titration would still involve a strong acid/strong base **(1)**

(ii) **True (1)** – There is  $[CH_3COOH] = 0.006 \text{ mol}$  and  $[Ba(OH)_2] = 0.003 \text{ mol}$  and so  $[OH^-] = 0.006 \text{ mol}$  **(1)**

Marking Criteria	Marks Allocated
• Correctly classifies each statement as true/false	1 – 4
• Provides brief justification to answer	1 – 4
<b>Total</b>	<b>8</b>

## Concept 4

# Titration Calculations - Progressive Questions Answers

### Simple Titrations: Q1, Q2, Q3, Q4

1. [4 marks]
- (a) Titration – calculating a secondary standard (1)
- (b) Titration – calculating a primary standard and calculating a secondary standard (1)
- (c) Back titration (1)
- (d) Titration – calculating a primary standard and secondary standard; and back titration – with a dilution calculation (1)

Marking Criteria	Marks Allocated
• States correct classification and calculations	1 – 4
<b>Total</b>	<b>4</b>

2. [4 marks]

(a)(i)

$$n(\text{Na}_2\text{CO}_3) = \frac{m}{M}$$

$$= \frac{2.06}{2 \times 22.99 + 12.01 + 3 \times 16}$$

$$= \mathbf{0.01944 \text{ mol}} \quad (1)$$

$$[\text{Na}_2\text{CO}_3] = \frac{n}{V}$$

$$= \frac{0.0194}{0.500}$$

$$= \mathbf{0.0388 \text{ mol L}^{-1}} \quad (1)$$

(a)(ii)

$$n(\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}) = \frac{m}{M}$$

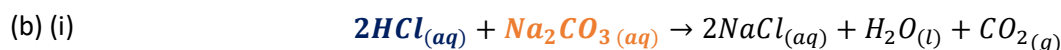
$$= \frac{9}{6 \times 1.008 + 2 \times 12.01 + 6 \times 16}$$

$$= \mathbf{0.07139 \text{ mol}} \quad (1)$$

$$[\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}] = \frac{n}{V}$$

$$= \frac{0.07139}{0.250}$$

$$= \mathbf{0.286 \text{ mol L}^{-1}} \quad (1)$$



$$n(\text{Na}_2\text{CO}_3) = cV$$

$$= 0.0388 \times 0.025$$

$$= \mathbf{9.7 \times 10^{-4} \text{ mol}}$$

$$n(\text{HCl}) = n(\text{Na}_2\text{CO}_3) \times 2$$

$$= 9.7 \times 10^{-4} \times 2$$

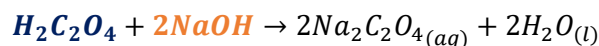
$$= \mathbf{1.94 \times 10^{-3} \text{ mol}} \quad (1)$$

$$[\text{HCl}] = \frac{n}{V}$$

$$= \frac{1.94 \times 10^{-3}}{0.060}$$

$$= \mathbf{0.032 \text{ mol L}^{-1}} \quad (1)$$

(b)(ii)



$$\begin{aligned}n(\text{H}_2\text{C}_2\text{O}_4) &= cV \\ &= 0.0286 \times 0.025 \\ &= 7.15 \times 10^{-4} \text{ mol}\end{aligned}$$

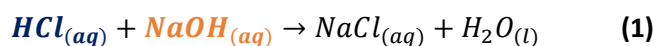
$$\begin{aligned}n(\text{NaOH}) &= n(\text{H}_2\text{C}_2\text{O}_4) \times 2 \\ &= 7.15 \times 10^{-4} \times 2 \\ &= 1.43 \times 10^{-3} \text{ mol}\end{aligned} \quad (1)$$

$$\begin{aligned}[\text{NaOH}] &= \frac{n}{V} \\ &= \frac{1.43 \times 10^{-3}}{0.040} \\ &= 0.036 \text{ mol L}^{-1}\end{aligned} \quad (1)$$

3.

[12 marks]

(a)

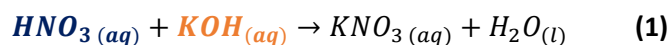


$$\begin{aligned}n(\text{HCl}) &= cV \\ &= 0.1 \times 0.02836 \\ &= 0.002836 \text{ mol}\end{aligned} \quad (1)$$

$$\begin{aligned}n(\text{NaOH}) &= n(\text{HCl}) \\ &= 0.002836 \text{ mol}\end{aligned} \quad (1)$$

$$\begin{aligned}[\text{NaOH}] &= \frac{n}{V} \\ &= \frac{0.002836}{0.025} \\ &= 0.113 \text{ mol L}^{-1}\end{aligned} \quad (1)$$

(b)

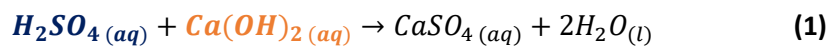


$$\begin{aligned}n(\text{KOH}) &= cV \\ &= 0.05 \times 0.01772 \\ &= 8.86 \times 10^{-4} \text{ mol}\end{aligned} \quad (1)$$

$$\begin{aligned}n(\text{HNO}_3) &= n(\text{KOH}) \\ &= 8.86 \times 10^{-4} \text{ mol}\end{aligned} \quad (1)$$

$$\begin{aligned}[\text{HNO}_3] &= \frac{n}{V} \\ &= \frac{8.86 \times 10^{-4} \text{ mol}}{0.025} \\ &= 0.035 \text{ mol L}^{-1}\end{aligned} \quad (1)$$

(c)



$$\begin{aligned}n(\text{H}_2\text{SO}_4) &= cV \\ &= 0.5 \times 0.02210 \\ &= 0.01105 \text{ mol}\end{aligned} \quad (1)$$

$$\begin{aligned}n(\text{Ca}(\text{OH})_2) &= n(\text{H}_2\text{SO}_4) \\ &= 0.01105 \text{ mol}\end{aligned} \quad (1)$$

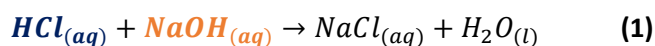
$$\begin{aligned}[\text{Ca}(\text{OH})_2] &= \frac{n}{V} \\ &= \frac{0.01105}{0.025} \\ &= 0.442 \text{ mol L}^{-1}\end{aligned} \quad (1)$$



4.

[18 marks]

(a) (i)

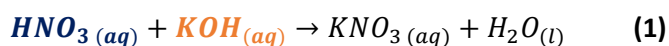


$$\begin{aligned} n(\text{HCl}) &= cV \\ &= 0.150 \times 0.0214 \\ &= \mathbf{0.00321 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{NaOH}) &= n(\text{HCl}) \\ &= \mathbf{0.00321 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{NaOH}] &= \frac{n}{V} \\ &= \frac{\mathbf{0.00321}}{0.025} \\ &= \mathbf{0.128 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

(a) (ii)



$$\begin{aligned} n(\text{KOH}) &= cV \\ &= 0.3 \times 0.00670 \\ &= \mathbf{0.00201 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{HNO}_3) &= n(\text{KOH}) \\ &= \mathbf{0.00201 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{HNO}_3] &= \frac{n}{V} \\ &= \frac{\mathbf{0.00201}}{0.025} \\ &= \mathbf{0.08 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

(b) No (1)

Marking Criteria	Marks Allocated
• No	1
<b>Total</b>	<b>1</b>

(c) When there is only a small titre volume, the **random effect of the uncertainty** in measurements is **amplified** to create large error (1). This is because there will **always be a degree of error** in a measurement (1), and when you are dealing with small titre volumes the effect of this error is **much greater** than if the titre volume was larger (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• There will always be uncertainty in measurements</li> <li>• Small titre volumes amplify the effect of uncertainty in measurements</li> <li>• If a larger titre volume is used, the effect of this uncertainty can be reduced</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

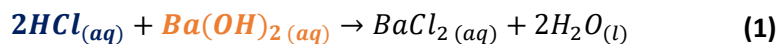
**Titrations Involving Dilution: Q5, Q6**

5.

[12 marks]

(a)

$$\begin{aligned}
 [\text{HCl}]_{\text{dilute}} &= \frac{[\text{HCl}]_{\text{original}}}{\text{Dilution Factor}} \\
 &= \frac{10.0}{20} \\
 &= 0.50 \text{ mol L}^{-1} \quad (1)
 \end{aligned}$$



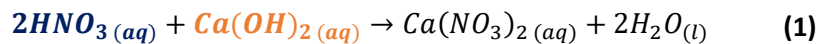
$$\begin{aligned}
 V(\text{HCl}) &= \frac{18.35 + 18.30 + 18.35}{3} \\
 &= 18.33\text{mL} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(\text{HCl}) &= cV \\
 &= 0.50 \times 0.01833 \\
 &= 9.165 \times 10^{-3} \text{ mol} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(\text{Ba}(\text{OH})_2) &= n(\text{HCl}) \times \frac{1}{2} \\
 &= 9.165 \times 10^{-3} \times \frac{1}{2} \\
 &= 0.00458 \text{ mol} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 [\text{Ba}(\text{OH})_2] &= \frac{n}{V} \\
 &= \frac{0.00458}{0.02500} \\
 &= 0.183 \text{ mol L}^{-1} \quad (1)
 \end{aligned}$$

(b)

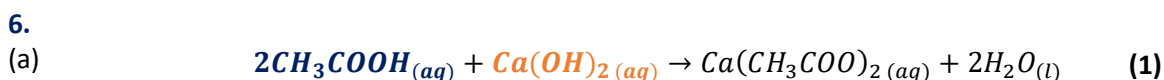


$$\begin{aligned}
 n(\text{Ca}(\text{OH})_2) &= cV \\
 &= 0.256 \times 0.02676 \\
 &= 6.851 \times 10^{-3} \text{ mol} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(\text{HNO}_3)_{\text{dilute}} &= n(\text{Ca}(\text{OH})_2) \times 2 \\
 &= 0.006851 \times 2 \\
 &= 0.01370 \text{ mol} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 [\text{HNO}_3]_{\text{dilute}} &= \frac{n}{V} \\
 &= \frac{0.01370}{0.025} \\
 &= 0.548 \text{ mol L}^{-1} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 [\text{HNO}_3]_{\text{original}} &= [\text{HNO}_3]_{\text{dilute}} \times \text{Dilution Factor} \\
 &= 0.548 \times \frac{250}{25} \\
 &= 5.48 \text{ mol L}^{-1} \quad (1)
 \end{aligned}$$



$$\begin{aligned} n(\text{Ca}(\text{OH})_2) &= cV \\ &= 0.078 \times 0.01321 \\ &= \mathbf{1.03 \times 10^{-3} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{CH}_3\text{COOH})_{\text{dilute}} &= n(\text{Ca}(\text{OH})_2) \times 2 \\ &= 1.03 \times 10^{-3} \times 2 \\ &= \mathbf{2.06 \times 10^{-3} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{CH}_3\text{COOH}]_{\text{dilute}} &= \frac{n}{V} \\ &= \frac{2.06 \times 10^{-3}}{0.025} \\ &= \mathbf{0.0824 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{CH}_3\text{COOH}]_{\text{original}} &= [\text{CH}_3\text{COOH}]_{\text{dilute}} \times \text{Dilution Factor} \\ &= 0.0824 \times \frac{250}{25} \\ &= \mathbf{0.824 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$



$$\begin{aligned} n(\text{H}_2\text{SO}_4) &= cV \\ &= 0.372 \times 0.02623 \\ &= \mathbf{9.758 \times 10^{-3} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{NaOH})_{\text{dilute}} &= n(\text{H}_2\text{SO}_4) \times 2 \\ &= 9.758 \times 10^{-3} \times 2 \\ &= \mathbf{0.01952 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{NaOH}]_{\text{dilute}} &= \frac{n}{V} \\ &= \frac{0.01952}{0.025} \\ &= \mathbf{0.7808 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{NaOH}]_{\text{original}} &= [\text{NaOH}]_{\text{dilute}} \times \text{Dilution Factor} \\ &= 0.7808 \times \frac{100}{10} \\ &= \mathbf{7.81 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

∴ Glenda's oven cleaner **does** meet the  $3 \text{ mol L}^{-1}$  requirement (1).



$$\begin{aligned} V(\text{HNO}_3) &= \frac{18.80 + 18.75 + 18.85}{3} \\ &= \mathbf{18.80 \text{ mL}} \end{aligned}$$

$$\begin{aligned} n(\text{HNO}_3) &= cV \\ &= 0.580 \times 0.01880 \\ &= \mathbf{0.0109 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned}
 n(\text{Ca}(\text{OH})_2)_{\text{dilute}} &= n(\text{HNO}_3) \times \frac{1}{2} \\
 &= 0.0109 \times \frac{1}{2} \\
 &= \mathbf{5.45 \times 10^{-3} \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 [\text{Ca}(\text{OH})_2]_{\text{dilute}} &= \frac{n}{V} \\
 &= \frac{5.45 \times 10^{-3}}{0.025} \\
 &= \mathbf{0.218 \text{ mol L}^{-1}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 [\text{Ca}(\text{OH})_2]_{\text{original}} &= [\text{Ca}(\text{OH})_2]_{\text{dilute}} \times \text{Dilution Factor} \\
 &= 0.218 \times \frac{250}{50} \\
 &= \mathbf{1.09 \text{ mol L}^{-1}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(\text{Ca}(\text{OH})_2)_{\text{original}} &= cV \\
 &= 1.09 \times 0.250 \\
 &= \mathbf{0.2725 \text{ mol}}
 \end{aligned}$$

$$\begin{aligned}
 m(\text{Ca}(\text{OH})_2) &= nM \\
 &= 0.2725 \times (40.08 + 32 + 2.016) \\
 &= \mathbf{20.2 \text{ g}} \quad (1)
 \end{aligned}$$

### Back Titrations: Q7, Q8, Q9

7.

[8 marks]

(a) The workings have been corrected below:

$$\begin{aligned}
 n(\text{HCl})_{\text{total}} &= cV \\
 &= 0.63 \times 0.1 \\
 &= \mathbf{0.063 \text{ mol}} \\
 \\ 
 \mathbf{2HCl}_{(aq)} + \mathbf{NaOH}_{(aq)} &\rightarrow \mathbf{NaCl}_{2(aq)} + \mathbf{H_2O}_{(l)} \quad (1) \\
 \\ 
 n(\text{NaOH}) &= cV \\
 &= 0.05 \times \mathbf{23.33} \quad \mathbf{0.02333} \\
 &= \mathbf{0.001167 \text{ mol}} \quad (1) \\
 \\ 
 \therefore n(\text{HCl})_{\text{aliquot}} &= n(\text{NaOH}) \times \mathbf{2} \quad \mathbf{1} \\
 &= \mathbf{0.001167 \text{ mol}} \quad (1) \\
 \\ 
 \therefore n(\text{HCl})_{\text{in excess}} &= 4 \times n(\text{HCl})_{\text{aliquot}} \\
 &= \mathbf{0.004668 \text{ mol}} \\
 \\ 
 n(\text{HCl})_{\text{initially used}} &= n(\text{HCl})_{\text{total}} - n(\text{HCl})_{\text{in excess}} \\
 &= 0.063 - \mathbf{0.004668} \\
 &= \mathbf{0.0583 \text{ mol}}
 \end{aligned}$$

(b)



$$\begin{aligned}
 n(\text{CaCO}_3) &= n(\text{HCl})_{\text{initially used}} \times \text{molar ratio} \\
 &= 0.0583 \times \frac{1}{2} \\
 &= \mathbf{0.02915 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(\text{CaCO}_3) &= Mn \\
 &= 100.09 \times 0.02915 \\
 &= \mathbf{2.917\text{ g}} \quad (1)
 \end{aligned}$$

(c)

$$\begin{aligned}
 \text{Percentage by Mass} &= \frac{m(\text{CaCO}_3)}{m(\text{Sample})} \times 100 \\
 &= \frac{2.917}{4.76} \times 100 \\
 &= \mathbf{61.3\%} \quad (1)
 \end{aligned}$$

8. Titration:  $2\text{HNO}_3(\text{aq}) + \text{Ca}(\text{OH})_2(\text{aq}) \rightarrow \text{Ca}(\text{NO}_3)_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$  (1) [8 marks]

$$n_{\text{excess}} = \text{unknown}$$

$$\begin{aligned}
 c &= 0.1 \text{ mol L}^{-1} \\
 V &= 23.37 \text{ mL}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{Ca}(\text{OH})_2) &= cV \\
 &= 0.1 \times 0.02337 \\
 &= \mathbf{2.337 \times 10^{-3} \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(\text{HNO}_3)_{\text{aliquot}} &= n(\text{Ca}(\text{OH})_2) \times 2 \\
 &= 2.337 \times 10^{-3} \times 2 \\
 &= \mathbf{4.674 \times 10^{-3} \text{ mol}}
 \end{aligned}$$

$$\begin{aligned}
 \therefore n(\text{HNO}_3)_{\text{in excess}} &= n(\text{HNO}_3)_{\text{aliquot}} \times \frac{150}{25} \\
 &= \mathbf{0.02804 \text{ mol}} \quad (1)
 \end{aligned}$$

Dissolving of cheese:  $\text{NH}_3(\text{aq}) + \text{HNO}_3(\text{aq}) \rightarrow \text{NH}_4\text{NO}_3(\text{aq})$  (1)

$$n(\text{NH}_3) = \text{unknown}$$

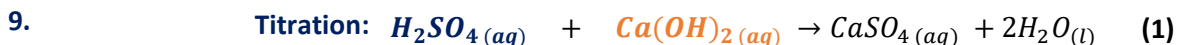
$$\begin{aligned}
 n_{\text{initially reacted}} &= \text{unknown} \\
 n_{\text{total}} &= 0.3 \times 0.15 = 0.045 \text{ mol}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{HNO}_3)_{\text{initially reacted}} &= n(\text{HNO}_3)_{\text{total}} - n(\text{HNO}_3)_{\text{in excess}} \\
 &= 0.045 - 0.02804 \\
 &= \mathbf{0.01696 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(\text{NH}_3) &= n(\text{HCl})_{\text{initially reacted}} \\
 &= \mathbf{0.01696 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(\text{NH}_3) &= nM \\
 &= 0.01696 \times (14.01 + 3 \times 1.008) \\
 &= \mathbf{0.2889 \text{ g}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{Percentage by Mass} &= \frac{m(\text{NH}_3)}{m(\text{Cheese})} \times 100 \\
 &= \frac{0.2889}{1.23} \times 100 \\
 &= \mathbf{23.5\%} \quad (1)
 \end{aligned}$$



[8 marks]

$$n_{\text{excess}} = \text{unknown}$$

$$c = 0.02 \text{ mol L}^{-1}$$

$$V = 28.08 \text{ mL}$$

$$n(Ca(OH)_2) = cV$$

$$= 0.02 \times 0.02808$$

$$= 5.616 \times 10^{-4} \text{ mol} \quad (1)$$

$$n(H_2SO_4)_{\text{aliquot}} = n(Ca(OH)_2)$$

$$= 5.616 \times 10^{-4} \text{ mol}$$

$$\therefore n(H_2SO_4)_{\text{in excess}} = n(H_2SO_4)_{\text{aliquot}} \times \frac{100}{25}$$

$$= 0.002246 \text{ mol} \quad (1)$$



$$n(MgO) = \text{unknown}$$

$$n_{\text{initially reacted}} = \text{unknown}$$

$$n_{\text{total}} = 0.04 \times 0.1 = 0.004 \text{ mol}$$

$$n(H_2SO_4)_{\text{initially reacted}} = n(H_2SO_4)_{\text{total}} - n(H_2SO_4)_{\text{in excess}}$$

$$= 0.004 - 0.002246$$

$$= 0.001754 \text{ mol} \quad (1)$$

$$n(MgO) = n(H_2SO_4)_{\text{initially reacted}}$$

$$= 0.001754 \text{ mol} \quad (1)$$

$$m(MgO) = nM$$

$$= 0.001754 \times (24.31 + 16)$$

$$= 0.0707 \text{ g} \quad (1)$$

$$\text{Percentage by Mass} = \frac{m(MgO)}{m(\text{Antacid})} \times 100$$

$$= \frac{0.0707}{1.02} \times 100$$

$$= 6.93\% \quad (1)$$

$\therefore$  Tom's luck **will** hold up (1).

### Difficult Titrations: Q10, Q11, Q12

10.

[10 marks]



$$V(Ba(OH)_2) = \frac{24.15 + 24.10 + 24.10}{3}$$

$$= 24.12 \text{ mL} \quad (1)$$

$$n(Ba(OH)_2) = cV$$

$$= 0.0650 \times 0.02412$$

$$= 0.001568 \text{ mol} \quad (1)$$

$$n(C_6H_8O_7)_{\text{dilute}} = n(Ba(OH)_2) \times \frac{2}{3}$$

$$= 0.001568 \times \frac{2}{3}$$

$$= 1.045 \times 10^{-3} \text{ mol} \quad (1)$$

$$\begin{aligned}
 [C_6H_8O_7]_{dilute} &= \frac{n}{V} \\
 &= \frac{1.045 \times 10^{-3}}{0.025} \\
 &= \mathbf{0.0418 \text{ mol L}^{-1}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 [C_6H_8O_7]_{original} &= [C_6H_8O_7]_{dilute} \times \text{Dilution Factor} \\
 &= 0.0418 \times \frac{500}{100} \\
 &= \mathbf{0.209 \text{ mol L}^{-1}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(C_6H_8O_7)_{original} &= cV \\
 &= 0.209 \times 0.100 \\
 &= \mathbf{0.0209 \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(C_6H_8O_7) &= nM \\
 &= 0.0209 \times 192.124 \\
 &= \mathbf{4.015 \text{ g}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \% \text{ Purity} &= \frac{m(C_6H_8O_7)}{m(\text{Orange Juice})} \times 100 \\
 &= \frac{4.015}{100 \times 1.6} \times 100 \\
 &= \mathbf{2.51\%} \quad (1)
 \end{aligned}$$

(b) Neil and Rabea's estimate is closer (2.4%) than Jamie and Nick's (4.72%), so Neil and Rabea will progress **(1)**

Marking Criteria	Marks Allocated
• Neil and Rabea will progress	1
<b>Total</b>	<b>1</b>

11. Titration:  $2HCl_{(aq)} + Ba(OH)_{2(aq)} \rightarrow BaCl_{2(aq)} + 2H_2O_{(l)}$  **(1)** [10 marks]

$$\begin{array}{|l|} \hline n_{excess} = unknown \\ \hline \end{array}
 \quad
 \begin{array}{|l|} \hline c = 0.0126 \text{ mol L}^{-1} \\ V = 21.26 \text{ mL} \\ \hline \end{array}$$

$$\begin{aligned}
 n(Ba(OH)_2) &= cV \\
 &= 0.0126 \times 0.02126 \\
 &= \mathbf{2.679 \times 10^{-4} \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(HCl)_{aliquot} &= n(Ba(OH)_2) \times 2 \\
 &= 2.679 \times 10^{-4} \times 2 \\
 &= \mathbf{5.358 \times 10^{-4} \text{ mol}}
 \end{aligned}$$

$$\begin{aligned}
 \therefore n(HCl)_{in\ excess} &= n(HCl)_{aliquot} \times \frac{250}{25} \\
 &= \mathbf{5.358 \times 10^{-3} \text{ mol}} \quad (1)
 \end{aligned}$$

Dissolving of chalk:  $CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$  **(1)**

$$\begin{array}{|l|} \hline n(CaCO_3) = unknown \\ \hline \end{array}
 \quad
 \begin{array}{|l|} \hline n_{initially\ reacted} = unknown \\ n_{total} = 0.516 \times 0.15 = 0.0774 \text{ mol} \\ \hline \end{array}$$

$$\begin{aligned}n(\text{HCl})_{\text{initially reacted}} &= n(\text{HCl})_{\text{total}} - n(\text{HCl})_{\text{in excess}} \\ &= 0.0774 - 0.005358 \\ &= \mathbf{0.07204 \text{ mol}} \quad (1)\end{aligned}$$

$$\begin{aligned}n(\text{CaCO}_3) &= n(\text{HCl})_{\text{initially reacted}} \times \frac{1}{2} \\ &= \mathbf{0.03602 \text{ mol}} \quad (1)\end{aligned}$$

$$\begin{aligned}m(\text{CaCO}_3) &= nM \\ &= 0.03602 \times (40.08 + 12.01 + 48) \\ &= \mathbf{3.605 \text{ g}} \quad (1)\end{aligned}$$

$$\begin{aligned}m(\text{CaCl}_2) &= m(\text{Chalk}) - m(\text{CaCO}_3) \\ &= 4.127 - 3.605 \\ &= \mathbf{0.522 \text{ g}} \quad (1)\end{aligned}$$

$$\begin{aligned}\text{Percentage by Mass} &= \frac{m(\text{CaCl}_2)}{m(\text{Chalk})} \times 100 \\ &= \frac{0.522}{4.127} \times 100 \\ &= \mathbf{12.65\%} \quad (1)\end{aligned}$$

$\therefore$  **Rupert** will progress to face Neil and Rabea **(1)**.

**Point to note:** This question is tricky because of the mixture being between  $\text{CaCl}_2$  and  $\text{CaCO}_3$ . The key with this question is to realise that the calcium chloride doesn't react with the  $\text{HCl}$  because the  $\text{CaCl}_2$  is soluble and will just dissolve in the water.  $\text{HCl}$  and  $\text{CaCl}_2$  also both have the same anion, so if they were to react it would just produce  $\text{CaCl}_2$  again.

By understanding this you can determine how much  $\text{CaCO}_3$  reacted with the  $\text{HCl}$ , and subtract this from the mass of the chalk to get the mass of  $\text{CaCl}_2$ .

**12.**

**[10 marks]**

(a)



$n_{\text{excess}} = \text{unknown}$

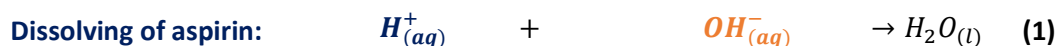
$$\begin{aligned}c &= 0.0383 \text{ mol L}^{-1} \\ V &= 18.70 \text{ mL}\end{aligned}$$

$$\begin{aligned}V(\text{H}_2\text{SO}_4) &= \frac{18.65 + 18.70 + 18.75}{3} \\ &= \mathbf{18.70 \text{ mL}} \quad (1)\end{aligned}$$

$$\begin{aligned}n(\text{H}_2\text{SO}_4) &= cV \\ &= 0.0383 \times 0.01870 \\ &= \mathbf{7.162 \times 10^{-4} \text{ mol}} \quad (1)\end{aligned}$$

$$\begin{aligned}n(\text{KOH})_{\text{aliquot}} &= n(\text{H}_2\text{SO}_4) \times 2 \\ &= 7.162 \times 10^{-4} \times 2 \\ &= \mathbf{1.432 \times 10^{-3} \text{ mol}}\end{aligned}$$

$$\begin{aligned}\therefore n(\text{KOH})_{\text{in excess}} &= n(\text{KOH})_{\text{aliquot}} \times \frac{500}{25} \\ &= \mathbf{0.02864 \text{ mol}} \quad (1)\end{aligned}$$



$n(\text{C}_9\text{H}_8\text{O}_4) = \text{unknown}$

$$\begin{aligned}n_{\text{initially reacted}} &= \text{unknown} \\ n_{\text{total}} &= 0.2 \times 0.15 = 0.03 \text{ mol}\end{aligned}$$



or



$$n(C_9H_8O_4) = \text{unknown}$$

$$n_{\text{initially reacted}} = \text{unknown}$$
$$n_{\text{total}} = 0.2 \times 0.15 = 0.03 \text{ mol}$$

$$n(KOH)_{\text{initially reacted}} = n(KOH)_{\text{total}} - n(KOH)_{\text{in excess}}$$
$$= 0.03 - 0.02864$$
$$= 0.00136 \text{ mol} \quad (1)$$

$$n(C_9H_8O_4) = n(KOH)_{\text{initially reacted}}$$
$$= 0.00136 \text{ mol} \quad (1)$$

$$m(C_9H_8O_4) = nM$$
$$= 0.00136 \times (9 \times 12.01 + 8 \times 1.008 + 4 \times 16)$$
$$= 0.245 \text{ g} \quad (1)$$

$$\text{Percentage by Mass} = \frac{m(C_9H_8O_4)}{m(\text{Aspirin})} \times 100$$
$$= \frac{0.245}{2.89} \times 100$$
$$= 8.48\% \quad (1)$$

$\therefore$  Rupert will take out the first round (1).

**Point to note:** For the average titre volume of  $H_2SO_4$ , whilst you could choose to include the first titre volume, it should be ignored because the first trial is the 'test' trial and used to approximate where the end point is about. Therefore, although it is concordant in this case, it should be ignored.

(b)

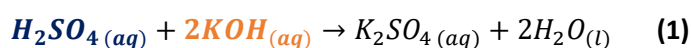
Statements	Neil and Rabea	Rupert	Your Response
Adding a $0.01 \text{ mol L}^{-1}$ solution of sulfuric acid to neutralise a $0.01 \text{ mol L}^{-1}$ solution of barium hydroxide, would require a smaller volume than a $0.02 \text{ mol L}^{-1}$ of hydrochloric acid.	True	False	False
A titration between ammonia and ethanoic acid will be accurate if both substances have high concentrations.	True	True	False
A diprotic acid will always cause the equivalence point to be acidic, which must be factored in when choosing an indicator.	False	True	False
Using an incorrect indicator is considered to be a systematic error because it causes a constant bias in the titre results.	True	False	True

$\therefore$  Neil and Rabea will take out the second round (1).

**Point to note:** The reasoning behind each statement is as follows:

- Hydrochloric acid that is double the concentration of the  $H_2SO_4$  will produce an equal amount of  $H^+$  ions, and therefore require the same volume of  $Ba(OH)_2$  to neutralise them.
- A titration between a weak acid and weak base will never be accurate because there is no 'cliff-face' that will allow the end point to accurately match the equivalence point
- This is not true in any manner. It is the strength of the acid (i.e. strong or weak) that is important to consider.
- Using an incorrect indicator does create a constant bias in the results, so this is a systematic error.

(c) First start by determining the concentration of the sulfuric acid:

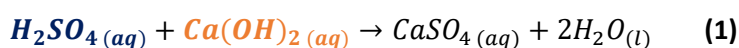


$$\begin{aligned} n(\mathbf{KOH}) &= cV \\ &= 0.421 \times 0.02820 \\ &= \mathbf{0.01187 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\mathbf{H_2SO_4}) &= n(\mathbf{KOH}) \times \frac{1}{2} \\ &= 0.01187 \times \frac{1}{2} \\ &= \mathbf{5.935 \times 10^{-3} \text{ mol}} \end{aligned} \quad \begin{aligned} \mathbf{[H_2SO_4]} &= \frac{n}{V} \\ &= \frac{\mathbf{5.935 \times 10^{-3}}}{0.035} \\ &= \mathbf{0.1696 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

Now we can do the second titration:

Trial	1	2	3	4
Final Reading (mL)	20.90	40.45	19.60	39.10
Initial Reading (mL)	0.00	20.90	0.00	19.60
Titre (mL)	<b>20.90</b>	<b>19.55</b>	<b>19.60</b>	<b>19.50</b>



$$\begin{aligned} V(\mathbf{H_2SO_4}) &= \frac{\mathbf{19.55 + 19.60 + 19.50}}{3} \\ &= \mathbf{19.55 \text{ mL}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\mathbf{H_2SO_4}) &= cV \\ &= 0.1696 \times 0.01955 \\ &= \mathbf{3.316 \times 10^{-3} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\mathbf{Ca(OH)_2})_{\text{aliquot}} &= n(\mathbf{H_2SO_4}) \\ &= \mathbf{3.316 \times 10^{-3} \text{ mol}} \end{aligned}$$

$$\begin{aligned} n(\mathbf{Ca(OH)_2})_{\text{original}} &= n(\mathbf{Ca(OH)_2})_{\text{aliquot}} \times \frac{500}{25} \\ &= \mathbf{0.06632 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} M(\mathbf{Ca(OH)_2 \cdot xH_2O}) &= \frac{m}{n} \\ &= \frac{7.303}{0.06632} \\ &= \mathbf{110.12 \text{ g}} \quad (1) \end{aligned}$$

$$\begin{aligned} M(\mathbf{xH_2O}) &= M(\mathbf{Ca(OH)_2 \cdot xH_2O}) - M(\mathbf{Ca(OH)_2}) \\ &= 110.12 - (40.08 + 32 + 2.016) \\ &= \mathbf{36.02 \text{ g}} \quad (1) \end{aligned} \quad \begin{aligned} \mathbf{x} &= \frac{M(\mathbf{xH_2O})}{M(\mathbf{H_2O})} \\ &= \frac{36.02}{16 + 2.016} \\ &= \mathbf{2} \quad (1) \end{aligned}$$

$\therefore$  **Rupert** will take out the final round and win the million dollars **(1)!!!**

# Problem Set 7 – Volumetric Analysis

## Repetitive Questions

### Concept 1

### Nature of Salts – Repetitive Questions Answers

Determining whether a salt is acidic, basic or neutral: Q1, Q2, Q3

1.1

[6 marks]

Statement	True	False
"A <b>strong acid</b> or <b>strong base</b> will always produce a <b>conjugate acid/conjugate base</b> that is <b>neutral</b> "	True	
<b>Explanation (For the box you ticked):</b> As strong acids and bases <b>fully ionise</b> in solution, it is generally said that the conjugate ions they produce <b>will be neutral (1)</b> .		
"A <b>weak acid</b> can produce a <b>neutral conjugate base</b> if <b>enough weak acid is added</b> initially to the beaker"		False
<b>Explanation (For the box you ticked):</b> Adding more weak acid will <b>never make the weak acid ionise completely</b> , so the conjugate base will <b>never be neutral (1)</b> .		
"A <b>weak base</b> will always produce a <b>conjugate base that is basic</b> "		False
<b>Explanation (For the box you ticked):</b> Weak bases will always produce <b>conjugate acids</b> (not conjugate bases), and these will always be <b>acidic (1)</b>		

Marking Criteria	Marks Allocated
• Selects correct true/false explanation	1 – 3
• Provides adequate explanation of the correct parts/issues with the statement	1 – 3
<b>Total</b>	<b>6</b>

1.2

[8 marks]

Acidic	Neutral	Basic
	<i>NaCl, KNO<sub>3</sub> (2)</i>	<i>KOH, MgCO<sub>3</sub>, Na<sub>3</sub>PO<sub>4</sub>, KCH<sub>3</sub>COO, NiSO<sub>4</sub> (6)</i>

Marking Criteria	Marks Allocated
• Correctly classifies nature of each salt	1 – 8
<b>Total</b>	<b>8</b>

1.21

[8 marks]

Acidic	Neutral	Basic
<i>NH<sub>4</sub>NO<sub>3</sub>, KHSO<sub>4</sub> (2)</i>	<i>Ni(NO<sub>3</sub>)<sub>2</sub> (1)</i>	<i>CoHPO<sub>4</sub>, Mg(CN)<sub>2</sub>, NaHCO<sub>3</sub>, CuHPO<sub>4</sub>, LiHPO<sub>4</sub> (5)</i>

Marking Criteria	Marks Allocated
• Correctly classifies nature of each salt	1 – 8
<b>Total</b>	<b>8</b>

## Concept 2

### Indicators – Repetitive Questions Answers

#### Titration Curves: 2.8, 2.81

##### 2.8

[4 marks]

- (a) The **yellow solution** in the conical flask will slowly turn **red** (1).
- (b) The **pink solution** in the conical flask will slowly turn **colourless** (1).
- (c) The **purple solution** in the conical flask will slowly turn **yellow** (1).
- (d) The **blue solution** in the conical flask will slowly turn **yellow** (1).

Marking Criteria	Marks Allocated
• States correct observations of each titration	1 – 4
<b>Total</b>	<b>4</b>

##### 2.81

[4 marks]

- (a) Equivalence point: **Neutral**                      Appropriate indicator: **Bromothymol blue** (1)
- (b) Equivalence point: **Basic**                         Appropriate indicator: **Phenolphthalein** (1)
- (c) Equivalence point: **Acidic**                        Appropriate indicator: **Methyl orange** (1)
- (d) Equivalence point: **Basic**                         Appropriate indicator: **Phenolphthalein** (1)

Marking Criteria	Marks Allocated
• Correct equivalence point and suggested indicator	1 – 4
<b>Total</b>	<b>4</b>

#### Difficult Indicator Questions: 2.101

##### 2.101

[8 marks]

- (a)
- (i) **HCl** and **NH<sub>3</sub>** will have an **acidic equivalence point** (1), so the end point will occur **inaccurately before** the equivalence point (1).
- (ii) **CH<sub>3</sub>COOH** and **NaOH** will have a **basic equivalence point** (1), so the end point will occur **close to** the equivalence point (1).
- (iii) **H<sub>2</sub>SO<sub>4</sub>** and **Ba(OH)<sub>2</sub>** will have an **neutral equivalence point** (1), so the end point will occur **inaccurately before** the equivalence point (1).
- (iv) **HCl** and **NH<sub>3</sub>** will have an **basic equivalence point** (1), so the end point will occur **inaccurately after** the equivalence point (1).

Marking Criteria	Marks Allocated
• Determines equivalence point of titration	1 – 4
• Determines if end point will occur at, before or after the equivalence point	1 – 4
<b>Total</b>	<b>8</b>

- (b) (i) **Smaller titre volume (1)** (ii) **Accurate titre volume (1)**  
 (iii) **Smaller titre volume (1)** (iv) **Larger titre volume (1)**

Marking Criteria	Marks Allocated
• Determines 'accurate', 'smaller' or 'larger' titre volume	1 – 4
<b>Total</b>	<b>4</b>

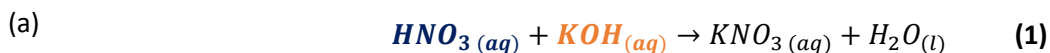
### Concept 4

## Titration Calculations - Repetitive Questions Answers

### Simple Titrations: 4.3

4.3

[16 marks]



$$\begin{aligned} n(KOH) &= cV \\ &= 0.2 \times 0.01720 \\ &= \mathbf{0.00344 mol} \quad (1) \end{aligned}$$

$$\begin{aligned} n(HNO_3) &= n(KOH) \\ &= \mathbf{0.00344 mol} \quad (1) \end{aligned}$$

$$\begin{aligned} [HNO_3] &= \frac{n}{V} \\ &= \frac{\mathbf{0.00344}}{0.025} \\ &= \mathbf{0.138 mol L^{-1}} \quad (1) \end{aligned}$$



$$\begin{aligned} n(Ba(OH)_2) &= cV \\ &= 0.081 \times 0.0301 \\ &= \mathbf{0.002438 mol} \quad (1) \end{aligned}$$

$$\begin{aligned} n(CH_3COOH) &= n(Ba(OH)_2) \times 2 \\ &= 0.002438 \times 2 \\ &= \mathbf{0.004876 mol} \quad (1) \end{aligned}$$

$$\begin{aligned} [CH_3COOH] &= \frac{n}{V} \\ &= \frac{\mathbf{0.004876}}{0.025} \\ &= \mathbf{0.195 mol L^{-1}} \quad (1) \end{aligned}$$



$$\begin{aligned} n(\text{HCl}) &= cV \\ &= 0.313 \times 0.02526 \\ &= \mathbf{0.007906 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{Ca}(\text{OH})_2) &= n(\text{HCl}) \times \frac{1}{2} \\ &= 0.007906 \times \frac{1}{2} \\ &= \mathbf{0.003953 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{Ca}(\text{OH})_2] &= \frac{n}{V} \\ &= \frac{\mathbf{0.003953}}{0.025} \\ &= \mathbf{0.158 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$



$$\begin{aligned} n(\text{H}_2\text{SO}_4) &= cV \\ &= 0.4 \times 0.01849 \\ &= \mathbf{0.007396 \text{ mol}} \quad (1) \end{aligned}$$

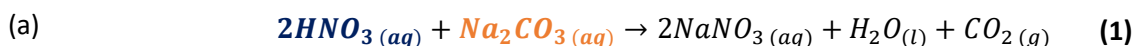
$$\begin{aligned} n(\text{Ba}(\text{OH})_2) &= n(\text{H}_2\text{SO}_4) \\ &= \mathbf{0.007396 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{Ba}(\text{OH})_2] &= \frac{n}{V} \\ &= \frac{\mathbf{0.007396}}{0.025} \\ &= \mathbf{0.296 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

#### Titration involving Dilutions: 4.6

4.6

[16 marks]



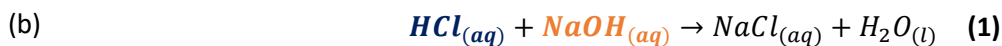
$$\begin{aligned} n(\text{HNO}_3) &= cV \\ &= 0.200 \times 0.02836 \\ &= \mathbf{5.672 \times 10^{-3} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(\text{Na}_2\text{CO}_3)_{\text{dilute}} &= n(\text{HNO}_3) \times \frac{1}{2} \\ &= 5.672 \times 10^{-3} \times \frac{1}{2} \\ &= \mathbf{2.836 \times 10^{-3} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [\text{Na}_2\text{CO}_3]_{\text{dilute}} &= \frac{n}{V} \\ &= \frac{\mathbf{2.836 \times 10^{-3}}}{0.025} \\ &= \mathbf{0.1134 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

$$[\text{Na}_2\text{CO}_3]_{\text{original}} = [\text{Na}_2\text{CO}_3]_{\text{dilute}} \times \text{Dilution Factor}$$

$$\begin{aligned} &= 0.1134 \times \frac{500}{50} \\ &= \mathbf{1.13 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$



$$\begin{aligned} n(NaOH) &= cV \\ &= 0.344 \times 0.02430 \\ &= \mathbf{8.359 \times 10^{-3} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(HCl)_{dilute} &= n(NaOH) \\ &= \mathbf{8.359 \times 10^{-3} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [HCl]_{dilute} &= \frac{n}{V} \\ &= \frac{8.359 \times 10^{-3}}{0.01} \\ &= \mathbf{0.8359 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} [HNO_3]_{original} &= [HNO_3]_{dilute} \times \text{Dilution Factor} \\ &= 0.8359 \times \frac{250}{25} \\ &= \mathbf{8.36 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$



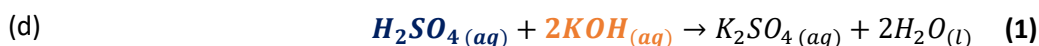
$$\begin{aligned} n(H_2SO_4) &= cV \\ &= 0.736 \times 0.01473 \\ &= \mathbf{0.01084 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(NaOH)_{dilute} &= n(H_2SO_4) \times 2 \\ &= 0.01084 \times 2 \\ &= \mathbf{0.02168 \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [Na_2CO_3]_{dilute} &= \frac{n}{V} \\ &= \frac{0.02168}{0.025} \\ &= \mathbf{0.8673 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

$$\begin{aligned} [NaOH]_{original} &= [NaOH]_{dilute} \times \text{Dilution Factor} \\ &= 0.8673 \times \frac{500}{10} \\ &= \mathbf{43.4 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

∴ The oven cleaner is **clearly of a high enough concentration** (1).



$$\begin{aligned} n(KOH) &= cV \\ &= 0.176 \times 0.01626 \\ &= \mathbf{2.862 \times 10^{-3} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} n(H_2SO_4)_{dilute} &= n(KOH) \times \frac{1}{2} \\ &= 2.862 \times 10^{-3} \times \frac{1}{2} \\ &= \mathbf{1.431 \times 10^{-3} \text{ mol}} \quad (1) \end{aligned}$$

$$\begin{aligned} [H_2SO_4]_{dilute} &= \frac{n}{V} \\ &= \frac{1.431 \times 10^{-3}}{0.025} \\ &= \mathbf{0.05724 \text{ mol L}^{-1}} \quad (1) \end{aligned} \quad \begin{aligned} [H_2SO_4]_{original} &= [H_2SO_4]_{dilute} \times \text{Dilution Factor} \\ &= 0.05724 \times \frac{250}{10} \\ &= \mathbf{1.43 \text{ mol L}^{-1}} \quad (1) \end{aligned}$$

∴ The sulfuric acid is **below** the typical concentration of  $4 \text{ mol L}^{-1}$  (1).

## Back Titrations: 4.7, 4.8, 4.9

4.7



[8 marks]

$$n_{\text{excess}} = \text{unknown}$$

$$c = 0.575 \text{ mol L}^{-1}$$

$$V = 17.56 \text{ mL}$$

$$n(\text{NaOH}) = cV$$

$$= 0.575 \times 0.01756$$

$$= \mathbf{0.0101 \text{ mol}} \quad (1)$$

$$n(\text{HNO}_3)_{\text{aliquot}} = n(\text{NaOH})$$

$$= \mathbf{0.0101 \text{ mol}}$$

$$\therefore n(\text{HNO}_3)_{\text{in excess}} = n(\text{HNO}_3)_{\text{aliquot}} \times \frac{100}{25}$$

$$= \mathbf{0.0404 \text{ mol}} \quad (1)$$



$$n(\text{CaCO}_3) = \text{unknown}$$

$$n_{\text{initially reacted}} = \text{unknown}$$

$$n_{\text{total}} = 1 \times 0.1 = \mathbf{0.1 \text{ mol}}$$

$$n(\text{HNO}_3)_{\text{initially reacted}} = n(\text{HNO}_3)_{\text{total}} - n(\text{HNO}_3)_{\text{in excess}}$$

$$= 0.1 - 0.0404$$

$$= \mathbf{0.0596 \text{ mol}} \quad (1)$$

$$n(\text{CaCO}_3) = n(\text{HNO}_3) \times \frac{1}{2}$$

$$= 0.0596 \times \frac{1}{2}$$

$$= \mathbf{0.0298 \text{ mol}} \quad (1)$$

$$m(\text{CaCO}_3) = nM$$

$$= 0.0298 \times (40.08 + 12.01 + 48)$$

$$= \mathbf{2.983 \text{ g}} \quad (1)$$

$$\text{Percentage by Mass} = \frac{m(\text{CaCO}_3)}{m(\text{Egg shell})} \times 100$$

$$= \frac{2.983}{3.06} \times 100$$

$$= \mathbf{97.5\%} \quad (1)$$

4.8



[8 marks]

$$n_{\text{excess}} = \text{unknown}$$

$$c = 0.130 \text{ mol L}^{-1}$$

$$V = 23.15 \text{ mL}$$

$$n(\text{Ba}(\text{OH})_2) = cV$$

$$= 0.130 \times 0.02315$$

$$= \mathbf{3.01 \times 10^{-3} \text{ mol}} \quad (1)$$

$$n(\text{HCl})_{\text{aliquot}} = n(\text{Ba}(\text{OH})_2) \times 2$$

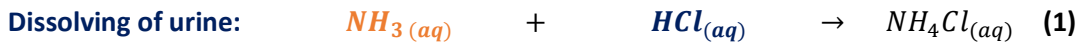
$$= 3.01 \times 10^{-3} \times 2$$

$$= \mathbf{0.00602 \text{ mol}} \quad (1)$$

$$\therefore n(\text{HCl})_{\text{in excess}} = n(\text{HCl})_{\text{aliquot}} \times \frac{40}{15}$$

$$= \mathbf{0.01605 \text{ mol}} \quad (1)$$





$$n(NH_3) = \text{unknown}$$

$$n_{\text{initially reacted}} = \text{unknown}$$

$$n_{\text{total}} = 0.89 \times 0.04 = 0.0356 \text{ mol}$$

$$n(HCl)_{\text{initially reacted}} = n(HCl)_{\text{total}} - n(HCl)_{\text{in excess}}$$

$$= 0.0356 - 0.01605$$

$$= 0.01955 \text{ mol} \quad (1)$$

$$n(NH_3) = n(HCl)$$

$$= 0.01955 \text{ mol} \quad (1)$$

$$m(NH_3) = nM$$

$$= 0.01955 \times (14.01 + 3 \times 1.008)$$

$$= 0.333 \text{ g} \quad (1)$$

$$[NH_3] = \frac{m}{V}$$

$$= \frac{0.333}{0.02}$$

$$= 16.7 \text{ g L}^{-1} \quad (1)$$

4.9



[8 marks]

$$n_{\text{excess}} = \text{unknown}$$

$$c = 0.0500 \text{ mol L}^{-1}$$

$$V = 20.75 \text{ mL}$$

$$V(KOH) = \frac{20.80 + 20.75 + 20.70}{3}$$

$$= 20.75 \text{ mL} \quad (1)$$

$$n(KOH) = cV$$

$$= 0.05 \times 0.02075$$

$$= 1.038 \times 10^{-3} \text{ mol} \quad (1)$$

$$n(HNO_3)_{\text{aliquot}} = n(KOH)$$

$$= 1.038 \times 10^{-3} \text{ mol} \quad (1)$$

$$\therefore n(HNO_3)_{\text{in excess}} = n(HNO_3)_{\text{aliquot}} \times \frac{150}{25}$$

$$= 6.228 \times 10^{-3} \text{ mol} \quad (1)$$



$$n(PbSO_4) = \text{unknown}$$

$$n_{\text{initially reacted}} = \text{unknown}$$

$$n_{\text{total}} = 0.082 \times 0.15 = 0.0123 \text{ mol}$$

$$n(HNO_3)_{\text{initially reacted}} = n(HNO_3)_{\text{total}} - n(HNO_3)_{\text{in excess}}$$

$$= 0.0123 - 0.006228$$

$$= 0.006072 \text{ mol} \quad (1)$$

$$n(PbSO_4) = n(HNO_3) \times \frac{1}{2}$$

$$= 0.006072 \times \frac{1}{2}$$

$$= 0.003036 \text{ mol} \quad (1)$$

$$m(PbSO_4) = nM$$

$$= 0.003036 \times (207.2 + 32.07 + 64)$$

$$= 0.921 \text{ g} \quad (1)$$

$$\text{Percentage by Mass} = \frac{m(PbSO_4)}{m(\text{Sample})} \times 100$$

$$= \frac{0.921}{4.11} \times 100$$

$$= 22.4\% \quad (1)$$

$\therefore$  Battery does not need to undergo a slow recharging (1).

## Difficult Titrations: 4.101, 4.111, 4.121, 4.122

4.101

[8 marks]



$$n_{\text{excess}} = \text{unknown}$$

$$c = 0.00117 \text{ mol L}^{-1}$$

$$V = 22.32 \text{ mL}$$

$$n(\text{H}_2\text{SO}_4) = cV$$

$$= 0.00117 \times 0.02232$$

$$= 2.611 \times 10^{-5} \text{ mol} \quad (1)$$

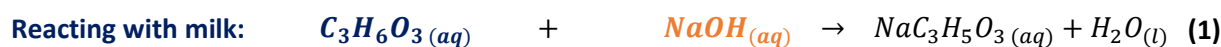
$$n(\text{NaOH})_{\text{aliquot}} = n(\text{H}_2\text{SO}_4) \times 2$$

$$= 2.611 \times 10^{-5} \times 2$$

$$= 5.222 \times 10^{-5} \text{ mol} \quad (1)$$

$$\therefore n(\text{NaOH})_{\text{in excess}} = n(\text{NaOH})_{\text{aliquot}} \times \frac{100}{25}$$

$$= 2.088 \times 10^{-4} \text{ mol} \quad (1)$$



$$n(\text{C}_3\text{H}_6\text{O}_3) = \text{unknown}$$

$$n_{\text{initially reacted}} = \text{unknown}$$

$$n_{\text{total}} = 0.012 \times 0.075 = 9 \times 10^{-4} \text{ mol}$$

$$n(\text{NaOH})_{\text{initially reacted}} = n(\text{NaOH})_{\text{total}} - n(\text{NaOH})_{\text{in excess}}$$

$$= 9 \times 10^{-4} - 2.088 \times 10^{-4}$$

$$= 6.912 \times 10^{-4} \text{ mol} \quad (1)$$

$$n(\text{C}_3\text{H}_6\text{O}_3) = n(\text{NaOH})$$

$$= 6.912 \times 10^{-4} \text{ mol} \quad (1)$$

$$m(\text{C}_3\text{H}_6\text{O}_3) = nM$$

$$= 6.912 \times 10^{-4} \times (3 \times 12.01 + 6 \times 1.008 + 3 \times 16)$$

$$= 0.06226 \text{ g} \quad (1)$$

$$[\text{C}_3\text{H}_6\text{O}_3] = \frac{m}{V}$$

$$= \frac{0.06226}{0.025}$$

$$= 2.49 \text{ g L}^{-1} \quad (1)$$

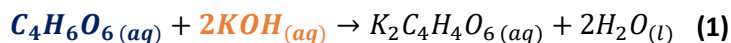
$\therefore$  Glenda **will** drink the milk because it is above his  $4 - 5 \text{ L}^{-1}$  threshold (1).

**Point to note:** In this question we should have told you that lactic acid is monoprotic. There is no expectation for you to be able to figure that out, unless you have studied organic chemistry and can identify it as having one carboxylic acid group.

4.111

[10 marks]

(a)



$$n(\text{KOH}) = cV$$

$$= 0.002 \times 0.01990$$

$$= 3.98 \times 10^{-5} \text{ mol} \quad (1)$$

$$n(\text{C}_4\text{H}_6\text{O}_6)_{\text{dilute}} = n(\text{KOH}) \times \frac{1}{2}$$

$$= 3.98 \times 10^{-5} \times \frac{1}{2}$$

$$= 1.99 \times 10^{-5} \text{ mol} \quad (1)$$

$$\begin{aligned}
 [C_4H_6O_6]_{dilute} &= \frac{n}{V} \\
 &= \frac{1.99 \times 10^{-5}}{0.025} \\
 &= 7.96 \times 10^{-4} \text{ mol L}^{-1} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 [C_4H_6O_6]_{original} &= [C_4H_6O_6]_{dilute} \times \text{Dilution Factor} \\
 &= 7.96 \times 10^{-4} \times \frac{500}{10} \\
 &= 0.0398 \text{ mol L}^{-1} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 [C_4H_6O_6]_{in \text{ g L}^{-1}} &= [C_4H_6O_6] \times m \\
 &= 0.0398 \times (4 \times 12.01 + 6 \times 1.008 + 6 \times 16) \\
 &= 5.97 \text{ g L}^{-1} \quad (1)
 \end{aligned}$$

∴ The this wine is **suitable** to drink because it is between 4 – 6g L<sup>-1</sup> threshold (1).

(b)

$$\begin{aligned}
 m(C_4H_6O_6) &= cV \\
 &= 5.97 \times 0.01 \\
 &= 0.0597 \text{ g} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(\text{Wine}) &= cV \\
 &= 0.97 \times 10 \\
 &= 9.7 \text{ g} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{Percentage by Mass} &= \frac{m(C_4H_6O_6)}{m(\text{Wine})} \times 100 \\
 &= \frac{0.0597}{9.7} \times 100 \\
 &= 0.62\% \quad (1)
 \end{aligned}$$

**Point to note:** It is important to notice that the 0.97 g mL<sup>-1</sup> is in millilitres not litres.

4.121

[10 marks]

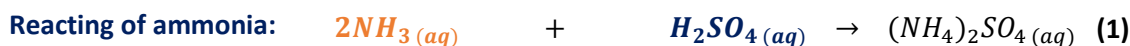


$n_{excess} = \text{unknown}$

$$\begin{aligned}
 c &= 0.0532 \text{ mol L}^{-1} \\
 V &= 30.21 \text{ mL}
 \end{aligned}$$

$$\begin{aligned}
 n(NaOH) &= cV \\
 &= 0.0532 \times 0.03021 \\
 &= 1.607 \times 10^{-3} \text{ mol} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(H_2SO_4)_{in \text{ excess}} &= n(NaOH) \times \frac{1}{2} \\
 &= 1.607 \times 10^{-3} \times \frac{1}{2} \\
 &= 8.035 \times 10^{-4} \text{ mol} \quad (1)
 \end{aligned}$$



$n(NH_3) = \text{unknown}$

$$\begin{aligned}
 n_{initially \text{ reacted}} &= \text{unknown} \\
 n_{total} &= 0.1 \times 0.05 = 5 \times 10^{-3} \text{ mol}
 \end{aligned}$$

$$\begin{aligned}
 n(H_2SO_4)_{initially \text{ reacted}} &= n(H_2SO_4)_{total} - n(H_2SO_4)_{in \text{ excess}} \\
 &= 5 \times 10^{-3} - 8.035 \times 10^{-4} \\
 &= 4.197 \times 10^{-4} \text{ mol} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(\text{NH}_3) &= n(\text{H}_2\text{SO}_4) \times 2 \\
 &= 4.197 \times 10^{-4} \times 2 \\
 &= \mathbf{8.394 \times 10^{-4} \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(\text{N}) &= n(\text{NH}_3) \\
 &= \mathbf{8.394 \times 10^{-4} \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(\text{N}) &= nM \\
 &= 8.394 \times 10^{-4} \times 14.01 \\
 &= \mathbf{0.01176 \text{ g}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 m(\text{Protein}) &= m(\text{N}) \times \text{Conversion factor} \\
 &= 0.01176 \times 5.70 \\
 &= \mathbf{0.06703 \text{ g}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \text{Percentage by Mass} &= \frac{m(\text{Protein})}{m(\text{Hair})} \times 100 \\
 &= \frac{0.06703}{1.43} \times 100 \\
 &= \mathbf{4.69\%} \quad (1)
 \end{aligned}$$

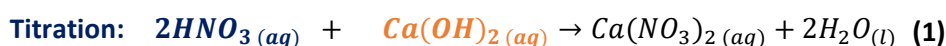
∴ Dylan has really weak hair!

4.122

[11 marks]

Trial	1	2	3	4	5
Final Reading (mL)	16.50	32.30	48.05	15.90	31.65
Initial Reading (mL)	0.00	16.50	32.30	0.00	15.90
Titre (mL)	<b>16.50</b>	<b>15.80</b>	<b>15.75</b>	<b>15.90</b>	<b>15.75</b>

(1)



$n_{\text{excess}} = \text{unknown}$

$c = 0.853 \text{ mol L}^{-1}$   
 $V = 15.77 \text{ mL}$

$$\begin{aligned}
 V(\text{Ca}(\text{OH})_2) &= \frac{15.80 + 15.75 + 15.75}{3} \\
 &= \mathbf{15.77 \text{ mL}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 n(\text{Ca}(\text{OH})_2) &= cV \\
 &= 0.134 \times 0.01577 \\
 &= \mathbf{2.113 \times 10^{-3} \text{ mol}}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{HNO}_3)_{\text{aliquot}} &= n(\text{Ca}(\text{OH})_2) \times 2 \\
 &= 2.113 \times 10^{-3} \times 2 \\
 &= \mathbf{4.226 \times 10^{-3} \text{ mol}} \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 \therefore n(\text{HNO}_3)_{\text{in excess}} &= n(\text{HNO}_3)_{\text{aliquot}} \times \frac{125}{25} \\
 &= \mathbf{0.02113 \text{ mol}} \quad (1)
 \end{aligned}$$



$$n(\text{Ba}(\text{OH})_2) = \text{unknown}$$

$$n_{\text{initially reacted}} = \text{unknown}$$

$$n_{\text{total}} = 0.853 \times 0.125 = 0.1066 \text{ mol}$$

$$n(\text{HNO}_3)_{\text{initially reacted}} = n(\text{HNO}_3)_{\text{total}} - n(\text{HNO}_3)_{\text{in excess}}$$

$$= 0.1066 - 0.02113$$

$$= \mathbf{0.08547 \text{ mol}} \quad (1)$$

$$n(\text{Ba}(\text{OH})_2) = n(\text{HNO}_3) \times \frac{1}{2}$$

$$= 0.08547 \times \frac{1}{2}$$

$$= \mathbf{0.04274 \text{ mol}} \quad (1)$$

$$M(\text{Ba}(\text{OH})_2 \cdot x\text{H}_2\text{O}) = \frac{m}{n}$$

$$= \frac{10.40}{0.04274}$$

$$= \mathbf{243.33 \text{ g}} \quad (1)$$

$$M(x\text{H}_2\text{O}) = M - M(\text{Ba}(\text{OH})_2)$$

$$= 243.33 - (137.3 + 32 + 2.016)$$

$$= \mathbf{72.01 \text{ g}} \quad (1)$$

$$x = \frac{M(x\text{H}_2\text{O})}{M(\text{H}_2\text{O})}$$

$$= \frac{72.01}{16+2.016}$$

$$= \mathbf{4} \quad (1)$$

∴ The administrators won't be alarmed because it's not  $x = 3$  (1).

---

# Chapter 5

---

## Redox Answers

---

Problem Set 8 Progressive Answers – Redox .....	1
Problem Set 8 Repetitive Answers – Redox .....	8
Problem Set 9 Progressive Answers – Electrochemistry .....	14
Problem Set 9 Repetitive Answers – Electrochemistry .....	29



# Problem Set 8 – Redox Progressive Questions

## Concept 1

### Oxidation and Reduction – Progressive Questions Answers

#### Oxidation Numbers: Q1, Q2, Q3, Q4, Q5

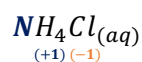
1.

[9 marks]

Student	Substance	Student's Oxidation Number Guess	Actual Oxidation Number	Progresses to next stage (✓ or X)
Luke	$Al_{(s)}$	0	0	✓ (1)
Peter	$O_{2(g)}$	0	0	✓ (1)
Janet	$Cd_{(aq)}^{2+}$	<u>Unsure</u>	+2	✓ (1)
Sarah	$F_{(aq)}^-$	-1	-1	✓ (1)
Alexa	$MnO_{4(aq)}^-$	<u>Unsure</u>	+7	✓ (1)
Dylan	$HClO_{(aq)}$	<u>Unsure</u>	+1	✓ (1)
Jamie	$H_2O_{2(aq)}$	-1	-1	✓ (1)
Rupert	$H_2C_2O_{4(aq)}$	+3	+3	✓ (1)
Tyler	$K_2Cr_2O_{7(aq)}$	+6	+6	✓ (1)
Rabea	$S_2O_{3(aq)}^{2-}$	+2	+2	✓ (1)
Tom	$MgH_{2(s)}$	<u>Unsure</u>	-1	✓ (1)

2.

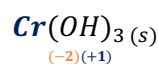
[8 marks]



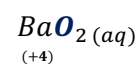
$$N = -3 \quad (1)$$



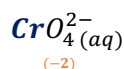
$$O = +2 \quad (1)$$



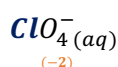
$$Cr = +3 \quad (1)$$



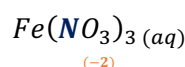
$$O = -2 \quad (1)$$



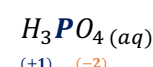
$$Cr = +6 \quad (1)$$



$$Cl = +7 \quad (1)$$



$$N = +5 \quad (1)$$

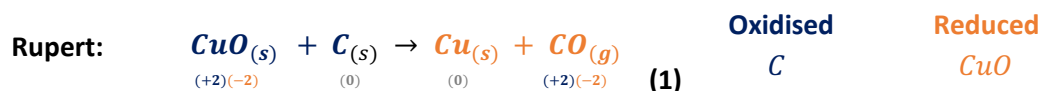


$$P = +5 \quad (1)$$

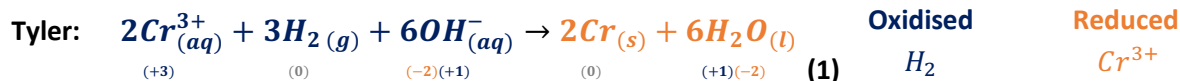
**Points to note:** For  $OF_2$ , the fluorine is more electronegative than oxygen which is why oxygen has an oxidation number of +2 not -2. Additionally, when you have known ions such as  $OH^-$  or  $NO_3^-$  you can assume they have these overall charges within the molecule.

3.

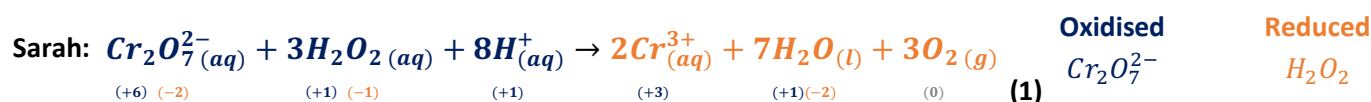
[6 marks]



∴ Rupert is **correct** because C is **oxidised** as its oxidation number has **increased**, and Cu is **reduced** as its oxidation number has **decreased**. ∴ Rupert will progress to the next stage. (1)



∴ Tyler is **correct** because H<sub>2</sub> is **oxidised** as its oxidation number has **increased**, and Cr<sup>3+</sup> is **reduced** as its oxidation number has **decreased**. ∴ Tyler will progress to the next stage. (1)



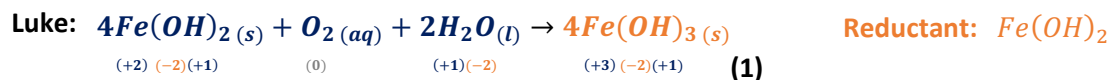
∴ Sarah is **incorrect** because H<sub>2</sub>O<sub>2</sub> is actually **oxidised** as its oxidation number has **increased**, and Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> is **reduced** as its oxidation number has **decreased**. ∴ Sarah will be eliminated. (1)

**Point to note:** For Sarah, it is important to remember that oxygen has an oxidation number of +1 in peroxides.

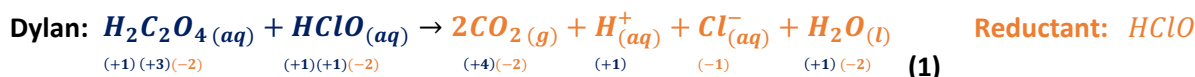
Marking Criteria	Marks Allocated
• Correctly determines oxidation numbers for each reaction	1 – 3
• States whether student is right or wrong	1 – 3
<b>Total</b>	<b>6</b>

4.

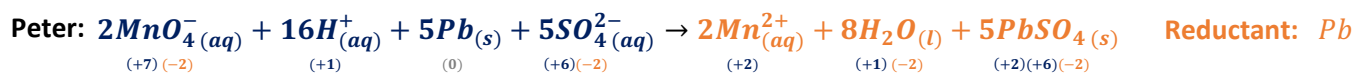
[6 marks]



∴ Luke is **correct** because Fe(OH)<sub>2</sub> is oxidised and is therefore the **reductant**. (1)



∴ Dylan is **incorrect** because H<sub>2</sub>C<sub>2</sub>O<sub>4</sub> is oxidised and is therefore the **reductant**, not HClO. (1)

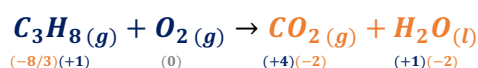


∴ Luke is **correct** because Pb is oxidised and is therefore the **reductant**. (1)

Marking Criteria	Marks Allocated
• Correctly determines oxidation numbers for each reaction	1 – 3
• States whether student is right or wrong	1 – 3
<b>Total</b>	<b>6</b>

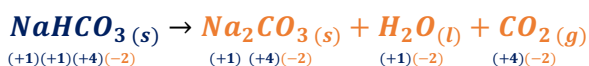
5.

[5 marks]

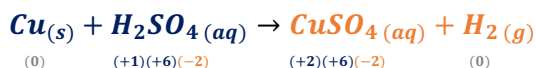


(Yes) or No

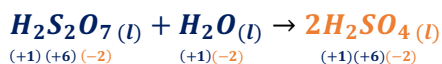




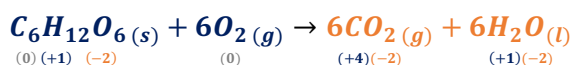
Yes or  No



Yes or No



Yes or  No



Yes or No

**Points to Note:** A reaction is only a redox reaction if there is a change in oxidation numbers. For part (a), C in  $\text{C}_3\text{H}_8$  has an oxidation number of  $-8/3$ . This is not theoretically possible, but this just represents the average oxidation number amongst the C atoms.

Marking Criteria	Marks Allocated
• Correctly circles 'Yes' or 'No'	1 – 5
<b>Total</b>	<b>5</b>

### Half Equations and Overall Equations: Q6, Q7, Q8, Q9

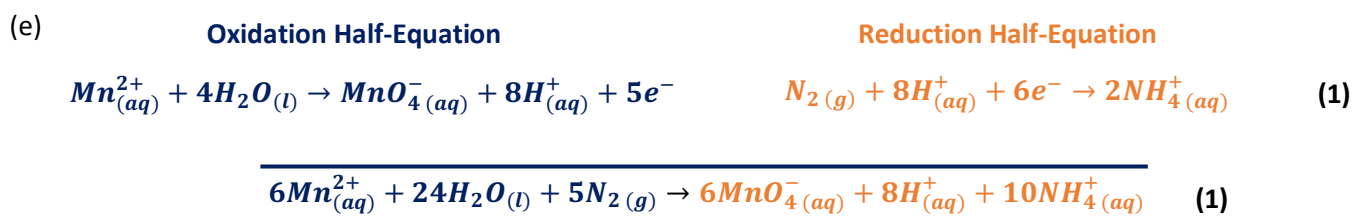
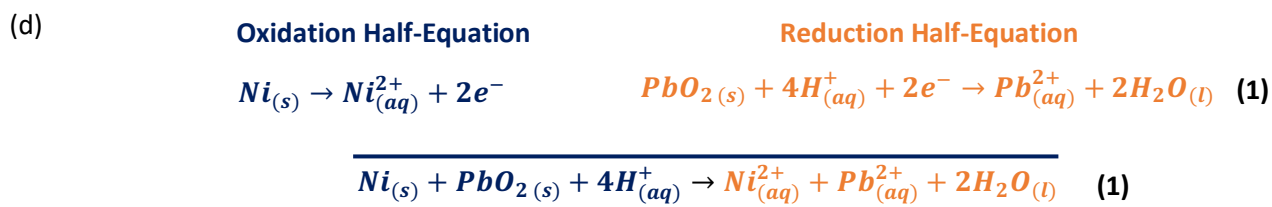
6. [7 marks]

- (a)  $\text{Ag}(s) \rightarrow \text{Ag}_{(aq)}^{2+} + 2e^-$  (1)
- (b)  $\text{Cl}_2(g) + 2e^- \rightarrow 2\text{Cl}_{(aq)}^-$  (1)
- (c)  $\text{MnO}_4^-(aq) + 8\text{H}^+(aq) + 5e^- \rightarrow \text{Mn}_{(aq)}^{2+} + 4\text{H}_2\text{O}(l)$  (1)
- (d)  $\text{Cl}_2(g) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{HClO}_{(aq)} + 2\text{H}_{(aq)}^+ + 2e^-$  (1)
- (e)  $\text{H}_2\text{O}_2(aq) + 2\text{H}_{(aq)}^+ + 2e^- \rightarrow 2\text{H}_2\text{O}(l)$  (1)
- (f)  $2\text{Cr}_{(aq)}^{3+} + 7\text{H}_2\text{O}(l) \rightarrow \text{Cr}_2\text{O}_7^{2-}(aq) + 14\text{H}_{(aq)}^+ + 6e^-$  (1)
- (g)  $\text{N}_2\text{O}_4(aq) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{NO}_3^-(aq) + 4\text{H}_{(aq)}^+ + 2e^-$  (1)

Marking Criteria	Marks Allocated
• Writes the correct half equation	1 – 7
<b>Total</b>	<b>7</b>

7. [14 marks]

- (a)
- |  |   |
|--|---|
| <b>Oxidation Half-Equation</b>   | <b>Reduction Half-Equation</b>                                      |
| $\text{H}_2(g) \rightarrow 2\text{H}_{(aq)}^+ + 2e^-$  | $\text{Fe}_{(aq)}^{3+} + e^- \rightarrow \text{Fe}_{(aq)}^{2+}$ (1) |
| $\text{H}_2(g) + 2\text{Fe}_{(aq)}^{3+} \rightarrow 2\text{H}_{(aq)}^+ + 2\text{Fe}_{(aq)}^{2+}$ (1) |   |
- (b)
- |  |   |
|--|---|
| <b>Oxidation Half-Equation</b>   | <b>Reduction Half-Equation</b>  |
| $\text{Cr}(s) \rightarrow \text{Cr}_{(aq)}^{3+} + 3e^-$  | $\text{H}_2\text{O}_2(aq) + 2\text{H}_{(aq)}^+ + 2e^- \rightarrow 2\text{H}_2\text{O}(l)$ (1) |
| $2\text{Cr}(s) + 3\text{H}_2\text{O}_2(aq) + 6\text{H}_{(aq)}^+ \rightarrow 2\text{Cr}_{(aq)}^{3+} + 6\text{H}_2\text{O}(l)$ (1) |   |
- (c)
- |   |   |
|---|---|
| <b>Oxidation Half-Equation</b>  | <b>Reduction Half-Equation</b>                            |
| $2\text{S}_2\text{O}_3^{2-}(aq) \rightarrow \text{S}_4\text{O}_6^{2-}(aq) + 2e^-$                                   | $\text{I}_2(s) + 2e^- \rightarrow 2\text{I}_{(aq)}^-$ (1) |
| $2\text{S}_2\text{O}_3^{2-}(aq) + \text{I}_2(s) \rightarrow \text{S}_4\text{O}_6^{2-}(aq) + 2\text{I}_{(aq)}^-$ (1) |   |



Marking Criteria	Marks Allocated
• Correctly writes both half-equations	1 – 5
• Balances half-equations to get overall equation	1 – 5
<b>Total</b>	<b>10</b>
<b>Note:</b> Give follow through marks for balancing if half-equations are incorrect	

8. [10 marks]

Scenario	Jamie and Alexa's Equation	Correct or Incorrect?
Chlorine gas is bubbled through a solution of <b>potassium iodide</b>	$Cl_{2(g)} + 2I_{(aq)}^- \rightarrow I_{2(s)} + 2Cl_{(aq)}^-$	Correct (2)
Zinc metal is dissolved in a solution of <b>hydrochloric acid</b>	$2Cl_{(aq)}^- + Zn_{(s)} \rightarrow Zn_{(aq)}^{2+} + Cl_{2(g)}$	Incorrect (2)
Acidified <b>potassium permanganate</b> solution is added to <b>solid iron</b>	$MnO_{4(aq)}^- + 8H_{(aq)}^+ + 2Fe_{(s)} \rightarrow Mn_{(aq)}^{2+} + 8H_2O_{(l)} + 2Fe_{(aq)}^{2+}$	Incorrect (2)
Acidified <b>perchloric acid (HClO)</b> is added to a <b>sodium fluoride</b> solution	$2F_{(aq)}^- + 2HClO_{(aq)} + 2H_{(aq)}^+ \rightarrow F_{2(g)} + Cl_{2(g)} + 2H_2O_{(l)}$	Incorrect (2)
<b>Sulfur dioxide</b> is bubbled through an <b>acidified dichromate (Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup>) solution</b> , producing <b>sulfate ions</b>	$2SO_{2(g)} + Cr_2O_{7(aq)}^{2-} + 6H_{(aq)}^+ \rightarrow 2Cr_{(aq)}^{3+} + 3H_2O_{(l)} + 2SO_{4(aq)}^{2-}$	Incorrect (2)

**Point to note:** For each of these scenarios, write out the half-equations and then the overall balanced equation to determine if they are correct. The workings below are as follows:

- (a) Half-equations:  $2I_{(aq)}^- \rightarrow I_{2(s)} + 2e^-$  and  $Cl_{2(g)} + 2e^- \rightarrow 2Cl_{(aq)}^-$   
 Overall equation:  $2I_{(aq)}^- + Cl_{2(g)} \rightarrow I_{2(s)} + 2Cl_{(aq)}^-$  ∴ the equation is **correct**.
- (b) In this scenario, hydrogen ions will actually oxidise to form hydrogen gas ( $E^0 = 0V$ ) in preference to the chlorine ions ( $-1.36V$ ). Therefore, the equation is **incorrect**.
- (c) Half-equations:  $Fe_{(s)} \rightarrow Fe_{(aq)}^{2+} + 2e^-$  and  $MnO_{4(aq)}^- + 8H_{(aq)}^+ + 5e^- \rightarrow Mn_{(aq)}^{2+} + 4H_2O_{(l)}$   
 Overall equation:  $5Fe_{(s)} + 2MnO_{4(aq)}^- + 16H_{(aq)}^+ \rightarrow 5Fe_{(aq)}^{2+} + 2Mn_{(aq)}^{2+} + 8H_2O_{(l)}$   
 ∴ the equation is **incorrect**
- (d) In this scenario, no reaction will occur because it is not spontaneous. The overall  $E^0$  is  $1.49 - 2.89 = -1.4V$
- (e) Half-equations:  $SO_{2(g)} + 2H_2O_{(l)} \rightarrow SO_{4(aq)}^{2-} + 4H_{(aq)}^+ + 2e^-$  and  $Cr_2O_{7(aq)}^{2-} + 14H_{(aq)}^+ + 6e^- \rightarrow 2Cr_{(aq)}^{3+} + 7H_2O_{(l)}$   
 Overall equation:  $3SO_{2(g)} + Cr_2O_{7(aq)}^{2-} + 2H_{(aq)}^+ \rightarrow 3SO_{4(aq)}^{2-} + 2Cr_{(aq)}^{3+} + H_2O_{(l)}$   
 ∴ the equation is **incorrect**

Reaction and Observation	True	False
Reactants: A solid piece of <b>chromium</b> and a solution of <b>copper sulfate</b> Observation: A <b>silver metal</b> is added to a <b>colourless solution</b> , to produce a <b>green solution</b> and a <b>blue metal</b> .		✓ (1)
<b>Explanation (For the box you ticked):</b> The <b>copper sulfate</b> solution is <b>blue</b> , not colourless, and <b>copper</b> is a <b>salmon pink</b> coloured metal, not blue. (1)		
Reactants: <b>Chlorine gas</b> is bubbled through a solution of <b>hydrogen peroxide</b> Observation: A <b>greenish-yellow gas</b> is bubbled through a <b>colourless solution</b> , to produce a <b>colourless solution</b> .		✓ (1)
<b>Explanation (For the box you ticked):</b> <b>Hydrogen peroxide</b> will be <b>oxidised</b> , and will therefore <b>produce oxygen gas</b> (so a colourless, odourless gas will be produced). (1)		
Reactants: A <b>strip of silver</b> added to a solution of <b>bromine water</b> Observation: A <b>solid silver strip</b> is added to a <b>red solution</b> , to produce a <b>colourless solution</b> .		✓ (1)
<b>Explanation (For the box you ticked):</b> <b>Silver bromide</b> will form as a precipitate, so a <b>white precipitate</b> will be <b>formed</b> . (1)		
Reactants: A solution of <b>oxalic acid (<math>H_2C_2O_4</math>)</b> is added to a solution of <b>iron (III) nitrate</b> Observation: A <b>colourless solution</b> is added to a <b>colourless solution</b> , to produce a <b>colourless solution</b> and a <b>colourless, pungent gas</b> .		✓ (1)
<b>Explanation (For the box you ticked):</b> <b>Iron (III) nitrate</b> is a <b>pale brown colour</b> , and <b>carbon dioxide</b> will be produced which is <b>odourless</b> , not pungent. (1)		

Marking Criteria	Marks Allocated
• Selects correct true/false box	1 – 4
• Provides adequate explanation of <b>all</b> the issues with the observation	1 – 4
<b>Total</b>	<b>8</b>

## Reaction Tendency: Q10, Q11, Q12

10.

[8 marks]

Student	Reactants	Student's Guess (Yes or No)	Progresses to next stage (✓ or X)
Rupert	Copper nitrate and gold	No	✓ (1)
	Potassium permanganate and sodium fluoride	No	X (1)
Luke	Chlorine gas and sodium fluoride solution	Yes	✓ (1)
	Fluorine gas and hydrogen peroxide solution	Yes	✓ (1)
Tyler	Copper metal and tin (II) carbonate solution	No	✓ (1)
	Solid manganese and aluminium sulfate solution	Yes	✓ (1)
Peter	Oxalic acid and zinc nitrate solution	Yes	X (1)
	Sodium dichromate solution and magnesium chloride	No	X (1)

The  $E_0$  values for each of the reactions are as follows:

(a)  $E^0 = -0.34 - 1.50 = -1.84V$  (1)

(b)  $E^0 = -1.23 + 1.51 = +0.28V$  (1)

Note: Water will be oxidised ( $2H_2O \rightarrow O_2(g) + 4H^+_{(aq)} + 4e^-$   $E_0 = -1.23V$ )

(c)  $E^0 = -1.23 + 1.36 = +0.13V$  (1)

Note: Water will be oxidised ( $2H_2O \rightarrow O_2(g) + 4H^+_{(aq)} + 4e^-$   $E_0 = -1.23V$ )

(d)  $E^0 = 2.89 - 0.70 = +2.19V$  (1)

(e)  $E^0 = -0.34 - 0.14 = -0.48V$  (1)

(f)  $E^0 = 1.18 - 0.83 = +0.35V$  (1)

Note: Water will be reduced ( $2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-_{(aq)}$   $E_0 = -0.83V$ )

(g)  $E^0 = 0.43 - 0.76 = -0.33V$  (1)

(h)  $E^0 = -1.23 + 1.36 = 0.13V$  (1)

Note: Water will be oxidised ( $2H_2O \rightarrow O_2(g) + 4H^+_{(aq)} + 4e^-$   $E_0 = -1.23V$ )

∴ We can conclude that **Peter** will be eliminated!

Marking Criteria	Marks Allocated
• Determines correct $E_0$ value and if the student's guess is correct	1 – 8
<b>Total</b>	<b>8</b>

11.

[4 marks]

Increasing oxidant strength:  $F^-_{(aq)}$   $Mg(s)$   $Zn(s)$   $H_2O(l)$   $Fe^{3+}_{(aq)}$   $Cr_2O_7^{2-}_{(aq)}$  (2)

Increasing reductant strength:  $MnO_4^-_{(aq)}$   $Cl_2(g)$   $H_2O(l)$   $Br_2(l)$   $Cu(s)$   $H^+_{(aq)}$  (2)

Marking Criteria	Marks Allocated
• Corrected order only has one mistake	1 – 2
• Corrected order has no mistakes	3 – 4
<b>Total</b>	<b>4</b>

12.

[8 marks]

Reaction	Rupert's Prediction (Yes or No)	Tyler's Prediction (Yes or No)	Correct Person (Rupert or Tyler)
A piece of <b>steel wool (iron)</b> is added to a solution of <b>bromine water</b>	Yes	No	Rupert (1)
A <b>gold plated earring</b> is added to a solution of <b>perchloric acid (HClO)</b>	No	Yes	Tyler (1)
A <b>tin can</b> is added to a solution of <b>lead nitrate</b>	No	Yes	Tyler (1)
A <b>lead dioxide</b> and <b>sulfate ion solution</b> from a car battery is added to some <b>solid magnesium</b>	Yes	No	Rupert (1)
Some <b>solid aluminium</b> from the fridge door handle is added to a <b>manganese nitrate solution</b>	Yes	No	Rupert (1)
A ' <b>chromium plated</b> ' fork is added to a solution of <b>potassium permanganate</b>	No	Yes	Tyler (1)
<b>Solid copper</b> from a copper pipe is added to some <b>iron(III) sulfate solution</b>	No	Yes	Tyler (1)

∴ Tyler will win!

The  $E_0$  values for each reaction are as follows:

(a)  $E^0 = 0.44 + 1.08 = +1.52V$

(b)  $E^0 = -1.29 + 1.49 = +0.20V$

Note: Water will be oxidised ( $2H_2O \rightarrow O_2(g) + 4H^+_{(aq)} + 4e^-$   $E_0 = -1.23V$ )

(c)  $E^0 = 0.14 - 0.13 = +0.01V$

(d)  $E^0 = 2.36 + 1.69 = +4.05V$

(e)  $E^0 = 1.68 - 1.18 = +0.50V$

(f)  $E^0 = -0.74 + 1.51 = +0.77V$

(g)  $E^0 = 1.68 - 1.18 = +0.50V$

(h)  $E^0 = -0.34 + 0.77 = +0.43$

Marking Criteria	Marks Allocated
• Determines correct $E^0$ value and correct guess	1 – 8
<b>Total</b>	<b>8</b>

# Problem Set 8 – Redox

## Repetitive Questions

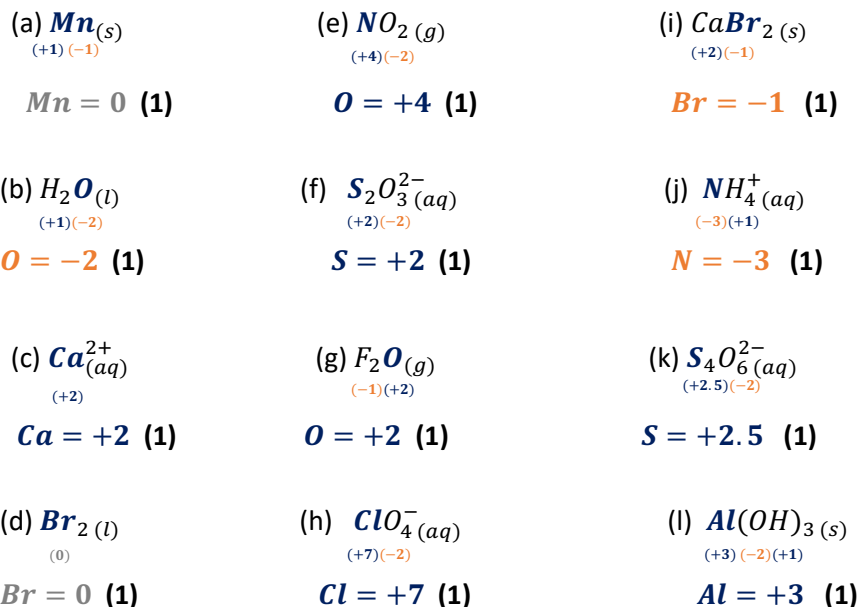
### Concept 1

## Oxidation and Reduction – Progressive Questions Answers

### Oxidation Numbers: 1.1, 1.2, 1.3, 1.5

1.1

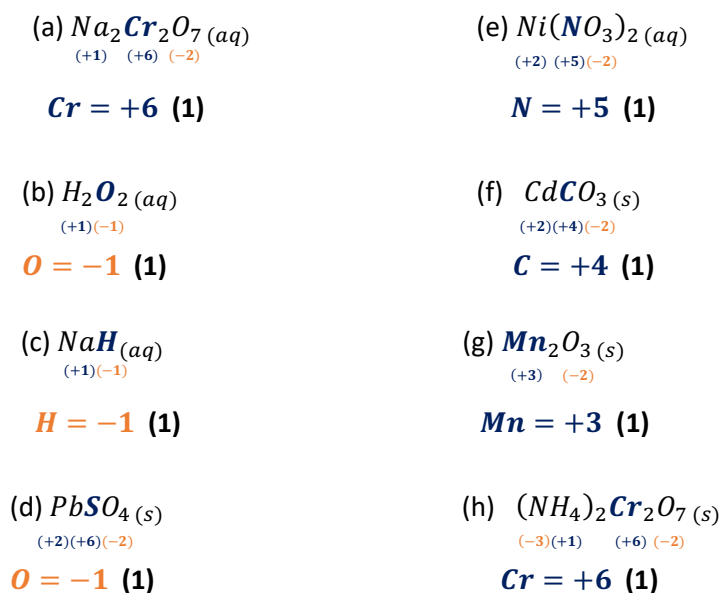
[12 marks]



Marking Criteria	Marks Allocated
• Determines correct oxidation number	1 – 12
<b>Total</b>	<b>12</b>

1.2

[8 marks]

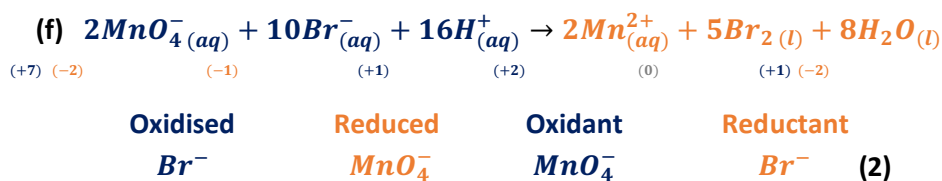
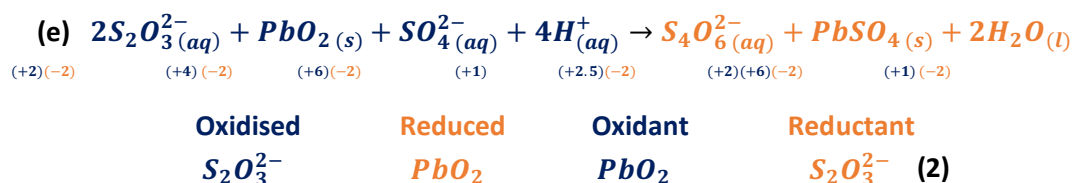
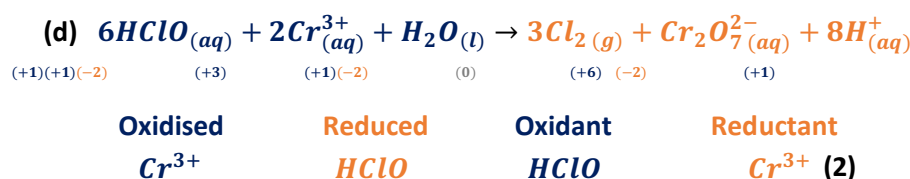
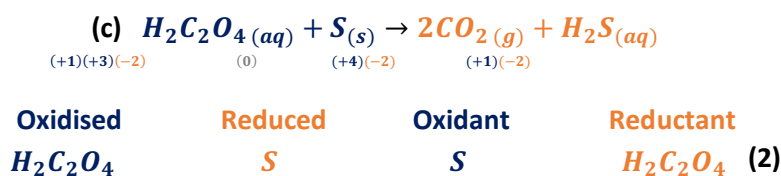
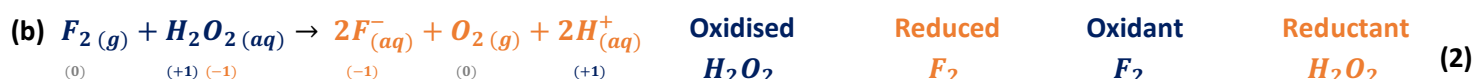


**Points to note:** For ions such as  $NO_3^-$ ,  $NH_4^+$ ,  $Cr_2O_7^{2-}$  etc. you can assume they have these overall charges within the molecule, and you can therefore determine the oxidation numbers of elements such as  $N$  or  $Cr$  by just working within the ion rather than the whole molecule. For part (c),  $NaH$  is a metal hydride so hydrogen has an oxidation number of  $-1$ .

Marking Criteria	Marks Allocated
• Determines correct oxidation number	1 – 8
<b>Total</b>	<b>8</b>

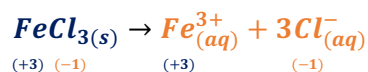
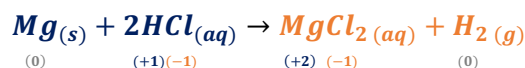
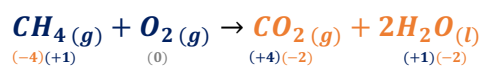
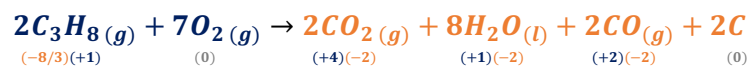
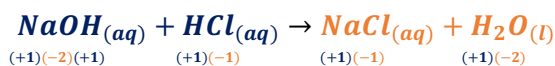
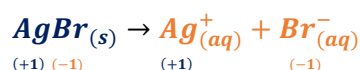
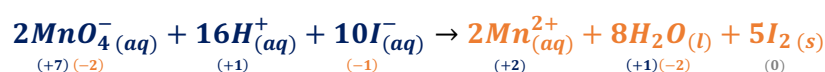
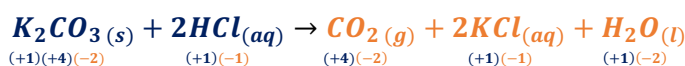
### 1.3

[12 marks]



**Points to note:** For part (e),  $S$  in  $S_4O_6^{2-}$  has an oxidation number of  $+2.5$ . This is not theoretically possible, but this just represents the average oxidation number amongst the  $S$  atoms.

Marking Criteria	Marks Allocated
• Writes correct oxidation numbers	1 – 6
• Determines correct oxidised and reduced species, and correct oxidant/reductant	1 – 6
<b>Total</b>	<b>12</b>

Yes or  No Yes or No Yes or No Yes or NoYes or  NoYes or  No Yes or NoYes or  No

**Points to note:** For part (d), C in  $\text{C}_3\text{H}_8$  has an oxidation number of  $-8/3$ . This is not theoretically possible, but this just represents the average oxidation number amongst the C atoms.

Marking Criteria	Marks Allocated
• Correctly circles 'Yes' or 'No'	1 – 8
<b>Total</b>	<b>8</b>

### Half Equations and Overall Equations: 1.6, 1.7, 1.9

## 1.6

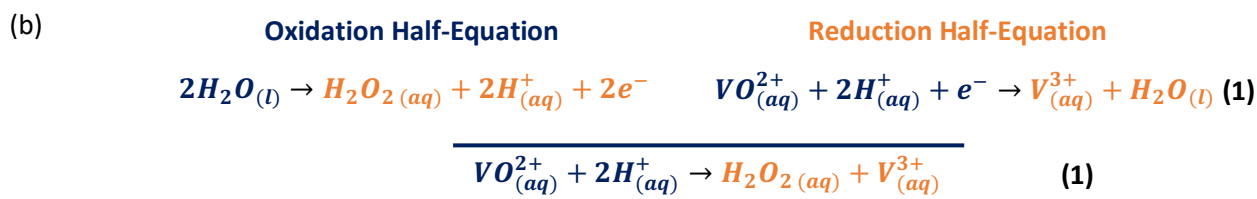
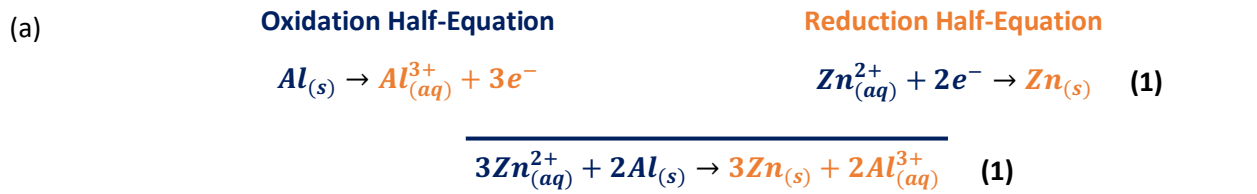
[7 marks]

- (a)  $2\text{CO}_2(g) + 2\text{H}_{(aq)}^+ + 2e^- \rightarrow \text{H}_2\text{C}_2\text{O}_4(aq)$  (1)
- (b)  $2\text{S}_2\text{O}_3^{2-}(aq) \rightarrow \text{S}_4\text{O}_6^{2-}(aq) + 2e^-$  (1)
- (c)  $\text{VO}_2^+(aq) + 2\text{H}_{(aq)}^+ + e^- \rightarrow \text{VO}^{2+}(aq) + \text{H}_2\text{O}(l)$  (1)
- (d)  $\text{CrO}_4^{2-}(aq) + 8\text{H}_{(aq)}^+ + 3e^- \rightarrow \text{Cr}^{3+}(aq) + 4\text{H}_2\text{O}(l)$  (1)
- (e)  $\text{H}_2\text{C}_2\text{O}_4(aq) \rightarrow 2\text{CO}_2(g) + 2\text{H}_{(aq)}^+ + 2e^-$  (1)
- (f)  $\text{Pb}^{2+}(aq) + 2\text{H}_2\text{O}(l) \rightarrow \text{PbO}_2(s) + 4\text{H}_{(aq)}^+ + 2e^-$  (1)
- (g)  $\text{HClO}(aq) + \text{H}_{(aq)}^+ + 2e^- \rightarrow \text{Cl}^-(aq) + \text{H}_2\text{O}(l)$  (1)

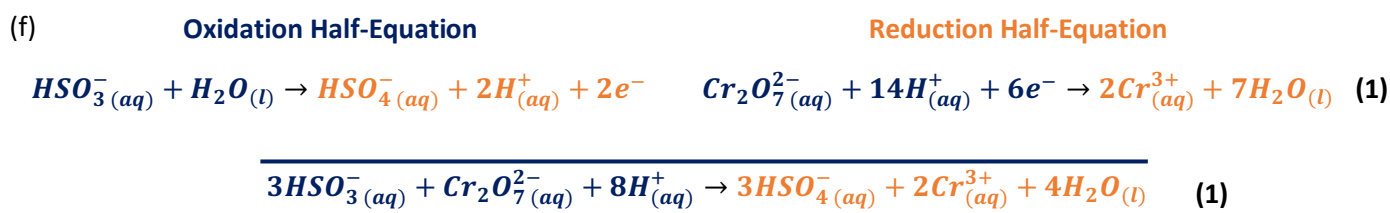
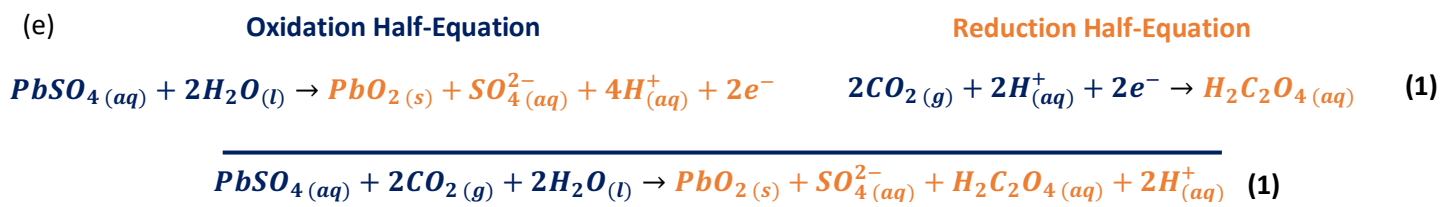
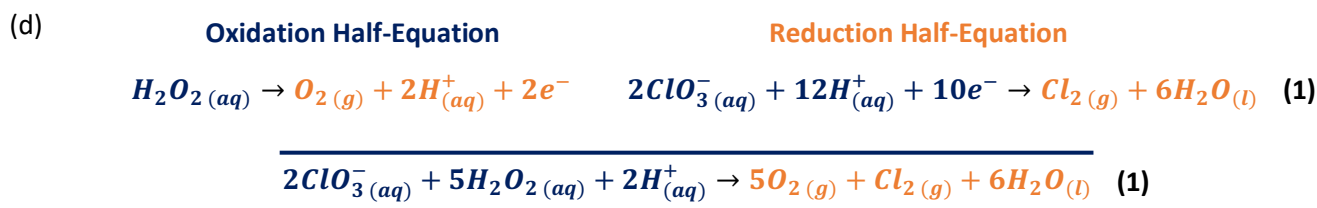
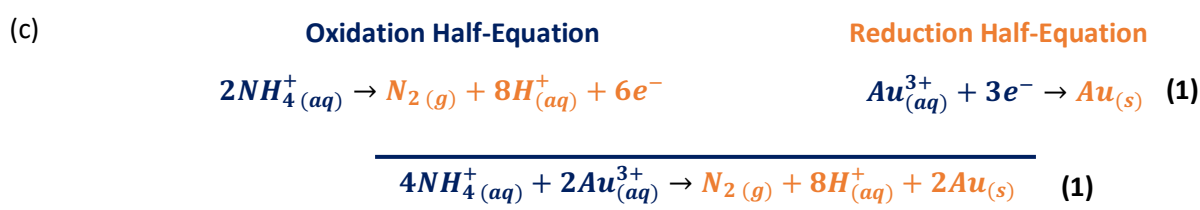
Marking Criteria	Marks Allocated
• Correctly balanced equation	1 – 7
<b>Total</b>	<b>7</b>



1.7



**Point to note:** Part (b) has an error, it should be water that is the specified species, not hydrogen ions, for the oxidation into hydrogen peroxide.



Marking Criteria	Marks Allocated
• Correctly writes both half-equations	1 – 6
• Balances half-equations to get overall equation	1 – 6
<b>Total</b>	<b>12</b>

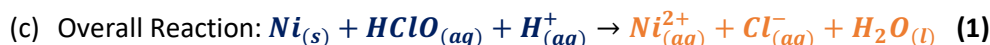


Observation: A **silver metal** is added to a **blue solution**, to produce a **salmon pink solid** and the **blue colour** of the solution **fading** (1).



Observation: A **silver metal** is added to a **colourless solution**, to produce a **green solution** and a **blue metal** (1).

**Point to note:** If you are struggling to find the hydrogen disulfide ( $\text{H}_2\text{S}$ ) oxidation equation on the formula sheet, it is just above the oxidation of hydrogen gas at 0V.

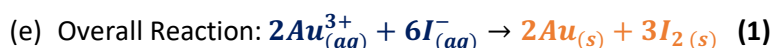


Observation: A **silver metal** is added to a **colourless solution**, to produce a **green solution** (1).

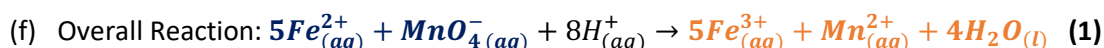
**Point to note:** The other equation that could have been used for perchloric acid is  $2\text{HClO}_{(aq)} + 2\text{H}_{(aq)}^+ + 2e^- \rightarrow \text{Cl}_2(g) + 2\text{H}_2\text{O}_{(l)}$ , we should have specified in the question whether the outcome was chlorine ions or chlorine gas (our mistake!).



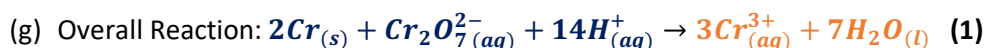
Observation: A **colourless solution** is added to a **red solution**, to produce a **colourless solution** and a **blue metal** (1).



Observation: A **colourless solution** is added to another **colourless solution**, to produce a **purple solid** and a **yellow metal** mixture (1).



Observation: A **pale green solution** is added to a **purple solution**, to produce a **pale pink/pale brown** solution (1).



Observation: A **silver/grey metal** is added to a **orange solution**, to produce a **green solution** (1).



Observation: A **greenish-yellow gas** is bubbled through a **colourless solution**, to produce a **colourless, odourless gas** and a **colourless solution** (1).

**Point to note:** Water will be oxidised in this scenario ( $2\text{H}_2\text{O} \rightarrow \text{O}_2(g) + 4\text{H}_{(aq)}^+ + 4e^-$   $E_0 = -1.23\text{V}$ )



Observation: A **yellow solid** is added to a **colourless solution**, and no reaction will occur from this (1).

Marking Criteria	Marks Allocated
• Writes correct overall equation	1 – 9
• Writes an observation with all key highlighted components	1 – 9
<b>Total</b>	<b>18</b>

## Reaction Tendency: 1.101, 1.111

### 1.101

[16 marks]

(a)  $E^0 = 0.24 - 0.28 = -0.04V$ ,  $\therefore$  the reaction will **not** be spontaneous (1)

(b)  $E^0 = -1.23 + 1.08 = -0.15V$ ,  $\therefore$  the reaction will **not** be spontaneous (1)

Note: Water would be oxidised in this scenario ( $2H_2O \rightarrow O_{2(g)} + 4H^+_{(aq)} + 4e^-$   $E_0 = -1.23V$ ) in preference to the chromium ions, if it were spontaneous.

(c)  $E^0 = -0.4 + 0.54 = +0.14V$ ,  $\therefore$  the reaction **will be** spontaneous (1)

Note: The  $OH^-$  ions are oxidised in this scenario ( $4OH^-_{(aq)} \rightarrow O_{2(g)} + 2H_2O_{(l)} + 4e^-$   $E_0 = -0.40V$ )

(d)  $E^0 = 0.4 + 0 = +0.4V$ ,  $\therefore$  the reaction **will be** spontaneous (1)

Note: The  $H^+$  ions are reduced in this scenario ( $2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)}$   $E_0 = 0V$ )

(e)  $E^0 = -1.23 + 1.63 = +0.4V$ ,  $\therefore$  the reaction **will be** spontaneous (1)

Note: Water is oxidised in this scenario. You could also choose to use the  $E_0$  of the gold ions, depending on the perchloric acid equation you selected.

(f)  $E^0 = -0.54 + 1.76 = +1.22V$ ,  $\therefore$  the reaction **will be** spontaneous (1)

Note: The hydrogen peroxide will be reduced in preference to the iron (III) ions.

(g)  $E^0 = 1.18 - 1.08 = +0.1V$ ,  $\therefore$  the reaction **will be** spontaneous (1)

(h)  $E^0 = -0.34 - 0.13 = -0.47V$ ,  $\therefore$  the reaction will **not** be spontaneous (1)

Note: The hydrogen peroxide will be reduced in preference to the iron (III) ions.

Marking Criteria	Marks Allocated
• Correct $E^0$ value	1 – 8
• Correctly determines whether spontaneous or not	1 – 8
<b>Total</b>	<b>16</b>

### 1.111

[8 marks]

**Point to note:** Multiple errors were made with this question, and it is not possible to solve so please ignore it.

# Problem Set 9 – Electrochemistry

## Progressive Questions

### Concept 1

## Oxidation and Reduction – Progressive Questions Answers

### Galvanic Cells: Q1, Q2, Q3, Q4, Q5

1.

[11 marks]

- (a) In order to **determine** the **voltage** produced by each half reaction, one of the half reactions needed to be assigned a potential energy of **zero (1)**. To do this the hydrogen half-cell was set as the ‘standard’ **(1)**, with a **voltage of zero**. This half-cell could then be used to compare the relative voltages of all other half-reactions **(1)**, and from doing this they were able to create the ‘Standard Reduction Potentials Table’ **(1)**.

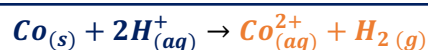
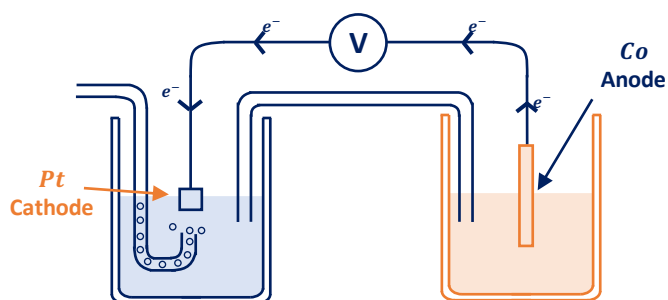
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• To compare half-reactions, one reaction need to be set as a standard. The hydrogen half-cell was selected</li> <li>• The hydrogen half-cell was allocated a potential energy of zero.</li> <li>• This half-cell was used to compare the <b>relative voltages</b> of all other half-reactions</li> <li>• Repeating this process across all half-reactions allowed for the creation of the Standard Reduction Potentials Table</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

- (b) Limitations of the Standard reductions potential table include:

- It only applies to aqueous solutions. **(1)**
- The values of  $E^0$  will change depending on the temperature, pressure, acidity and solution concentration (i.e. the conditions must be at STP). **(1)**
- The values of  $E^0$  do not indicate anything about reaction rate. **(1)**

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• States two limitations</li> </ul>	1 – 2
<b>Total</b>	<b>4</b>

(c)



$$E^0 = 0.28 + 0 = +0.28V$$

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Labels anode, cathode and electron flow correctly</li> </ul>	1 – 3
<ul style="list-style-type: none"> <li>• Correct overall equation and <math>E^0</math> calculation</li> </ul>	1 – 2
<b>Total</b>	<b>5</b>

2.

[6 marks]

Reaction and Observation	True	False
<b>Cell 1 Observation:</b> In the <b>left half-cell</b> the <b>silver electrode</b> will <b>decrease in size</b> over time, and in the <b>right half-cell</b> a <b>colourless, odourless gas</b> will be produced.		✓ (1)
<b>Explanation (For the box you ticked):</b> In the right cell, no colourless gas will be produced. The reduction of $H_2O_2$ produces $H_2O_{(l)}$ so <b>no observations</b> will occur (1).		
<b>Cell 2 Observation:</b> In the <b>left half-cell</b> the <b>solution</b> will become a <b>lighter red colour</b> over time, and in the <b>right half-cell</b> the <b>silver electrode</b> will <b>increase in size</b> over time.		✓ (1)
<b>Explanation (For the box you ticked):</b> In the right cell, the iron anode will <b>decrease in size</b> over time and will oxidise to form pale green $Fe_{(aq)}^{2+}$ ions.		
<b>Cell 3 Observation:</b> In the <b>left half-cell</b> the <b>solution</b> will become a <b>lighter purple and more pale pink colour</b> over time, and in the <b>right half-cell</b> a <b>colourless, odourless gas</b> will be produced.		✓ (1)
<b>Explanation (For the box you ticked):</b> In the right hand cell, the zinc electrode will <b>decrease in size</b> over time. No colourless, odourless gas will be produced (1).		

Marking Criteria	Marks Allocated
• Selects correct True/False box	1 – 4
• Provides adequate explanation of <b>all</b> the issues with the observation	1 – 4
<b>Total</b>	<b>8</b>

3.

[10 marks]

(a) **Anode:**  $Co_{(s)}$       **Cathode:**  $C_{(s)}$       **Voltage:**  $0.28 + 1.36 = +1.64V$       (2)

(b) **Anode:**  $Cr_{(s)}$       **Cathode:**  $Au_{(s)}$       **Voltage:**  $0.74 + 1.50 = +2.24V$       (2)

(c) **Anode:**  $Cu_{(s)}$       **Cathode:**  $Pt_{(s)}$       **Voltage:**  $-0.34 + 1.36 = +1.02V$       (2)

(d) **Anode:**  $Mn_{(s)}$       **Cathode:**  $Pt_{(s)}$       **Voltage:**  $1.18 + 1.76 = +2.94V$       (2)

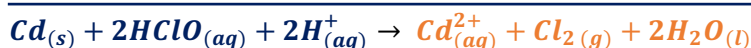
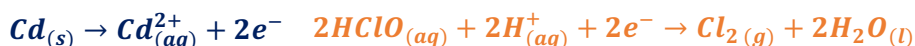
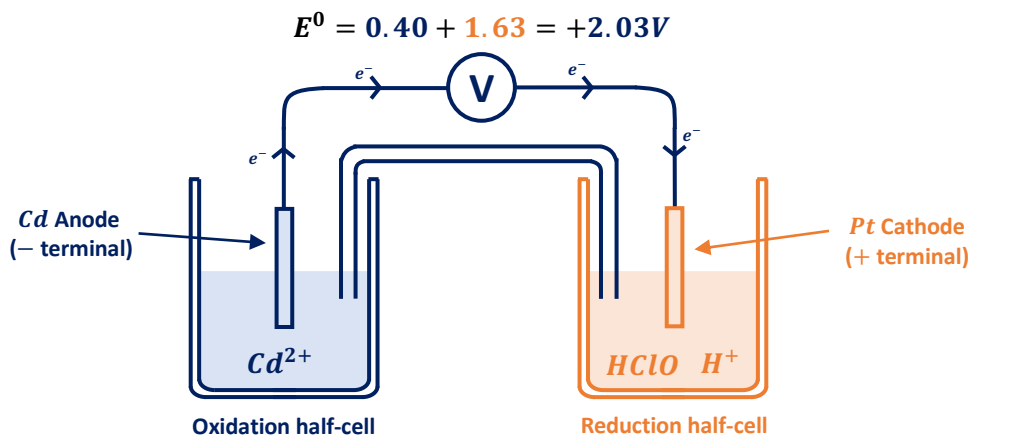
(e) **Anode:**  $Al_{(s)}$       **Cathode:**  $C_{(s)}$       **Voltage:**  $1.68 + 0.77 = +2.45V$       (2)

Marking Criteria	Marks Allocated
• Determines correct anode and cathode	1 – 5
• Determines correct voltage	1 – 5
<b>Total</b>	<b>10</b>

4.

[13 marks]

(a)



**Point to note:** The other equation and voltage for hypochlorous acid could also be used:  $HClO_{(aq)} + H^+_{(aq)} + e^- \rightarrow Cl^-_{(aq)} + H_2O_{(l)}$   $E^0 = 1.49V$ , as the products of the reaction was not specified.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Labels correct anode and cathode</li> <li>Determines correct cell <math>E^0</math></li> <li>Labels correct ions</li> <li>Determines correct overall cell equation</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

(b)

(i) The salt bridge allows for the **controlled flow of ions** across the half-cells but forces the electrons to still flow through an external circuit **(1)**. This **maintains electrical neutrality** and **completes the circuit (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Allows for the controlled flow of ions</li> <li>Maintains electrical neutrality/completes the circuit</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(ii) Overtime the cell **emf** will start to **slowly decrease** over time **(1)**, because the rate of oxidation and reduction will slowly decrease over time **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Emf will slowly decrease over time, as oxidation/reduction rates decrease</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(iii) If the concentration of  $HClO$  was increased, the rate of reduction would increase **(1)** and the cell emf would increase **(2)**.

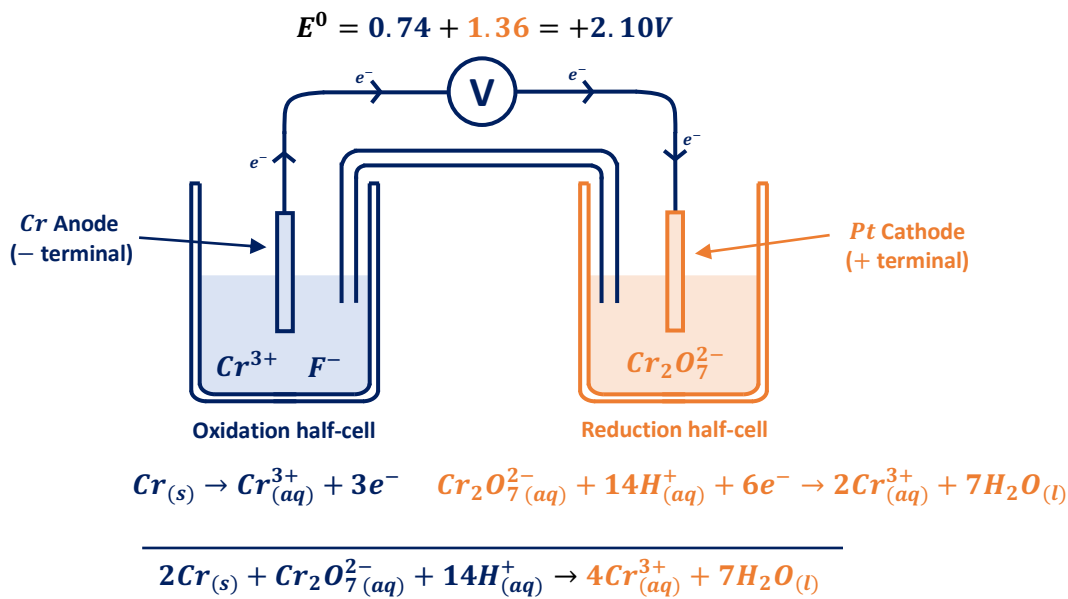
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>The rate of reduction would increase</li> <li>The cell emf would therefore increase</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(iv) In galvanic cells there is not a significant enough charge to pull the ions towards the opposite cell **(1)**. Therefore the  $Cd^{2+}$  ions will move towards the anode **(1)**, and the  $HClO$  and  $H^+$  ions will move towards the cathode **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Galvanic cells do not produce a significant enough charge to pull ions to the opposite electrodes</li> <li><math>Cd^{2+}</math> ions move towards the anode</li> <li><math>HClO</math> and <math>H^+</math> ions move towards the cathode</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

5. [12 marks]

(a)



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Labels correct anode and cathode</li> <li>Determines correct cell <math>E^0</math></li> <li>Labels correct ions</li> <li>Determines correct overall cell equation</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

(b) Peter is very wrong, he has the cells on the wrong sides and has everything mixed up **(1)**. It should be closer to: "In the **left half-cell** the **silver electrode** will **decrease in size** over time and the surrounding solution will become a **darker green** **(1)**, and in the **right half-cell** the **orange solution colour** will fade and become a **green colour** **(1)**."

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>States that Peter is incorrect</li> <li>Gives correct anode observations</li> <li>Gives correct cathode observations</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(c)

Dr Lachlan's Statement	Peter's Prediction (True or False)	Correct Answer (Yes or No)
"If the <b>concentration</b> of <b>potassium dichromate</b> was increased, the <b>voltage produced</b> would be <b>larger</b> "	True	Yes
"The role of the <b>electrolyte</b> is to <b>maintain electrical neutrality</b> and <b>complete the circuit</b> "	True	Yes
"If <b>bromine water</b> was used instead of <b>potassium dichromate</b> , the cell would <b>no longer operate</b> "	False	No
"The temperature of the cells must be at <b>25°C</b> to <b>accurately predict</b> the overall voltage using the <b>Standard Reduction Potential Table</b> "	True	Yes
"As time progresses, the overall cell <b>voltage</b> will <b>slowly increase</b> "	True	Yes

∴ Peter **will not** be allowed to stay at the factory

**Point to note:** The third statement is 'true', the cell would have an overall voltage of +1.92V

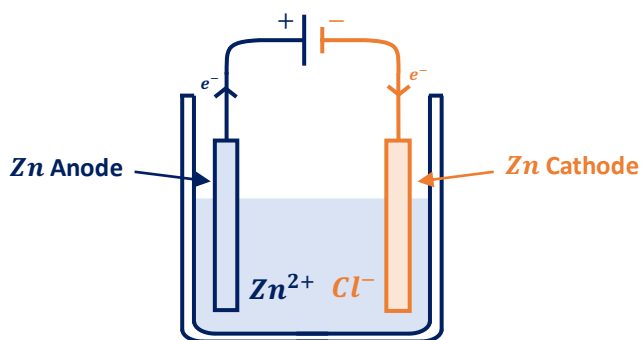
Marking Criteria	Marks Allocated
• Correctly determines if Peter is correct for each statement	1 – 5
<b>Total</b>	<b>5</b>

### Electrolytic Cells: Q6, Q7, Q8, Q9

6.

[9 marks]

(a)



Oxidation half-reaction



Reduction half-reaction



Marking Criteria	Marks Allocated
• Labels correct anode and cathode • Determines correct cell $E^0$ • Labels correct ions • Labels positive and negative electrodes • Determines correct overall cell equation	1 – 5
<b>Total</b>	<b>5</b>



- (b) On the left side the **grey electrode** will **decrease in size** over time (1), and on the **right side** the **grey electrode** will **increase in size** over time (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Gives all correct anode observations</li> <li>Gives all correct cathode observations</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

- (c) The electrodes in an electrolytic cell are dipped into the **same electrolyte solution** (1), meaning they **don't need a salt bridge** to separate them into half-cells (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Operate in the same electrolyte solution/same cell</li> <li>Therefore don't need a salt bridge to be separated</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

7.

[9 marks]

- (a) **Towards anode:**  $Br^-$                       **Towards Cathode:**  $Cr^{3+}$       (1)

**Observations:** On the left side the **surrounding solution** will become a **darker red colour** (1), and on the **right side** the size of the **silver electrode** will **increase** and the **surrounding solution** will become a **lighter green colour** (1).

- (b) **Towards anode:**  $F^-$                       **Towards Cathode:**  $Na^+$       (1)

**Observations:** On the **left side** a **colourless, odourless gas** will be produced (1), and on the **right side** a **colourless, odourless gas** will also be produced (1).

**Point to note:** Water will be both oxidised and reduced in this case, in preference to the sodium and fluorine ions.

- (c) **Towards anode:**  $I^-$                       **Towards Cathode:**  $Pb^{2+}$       (1)

**Observations:** On the left side the size of the **silver electrode** will **decrease over time** (1), and on the **right side** the size of the **silver electrode** will **increase** with a **grey coating** (1).

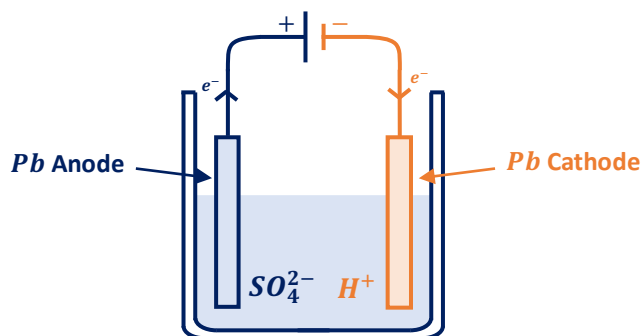
**Point to note:** The lead electrode will be oxidised and the lead ions will be reduced

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Determines correct directions for flow of ions</li> </ul>	1 – 3
<ul style="list-style-type: none"> <li>Gives all correct anode observations</li> </ul>	1 – 3
<ul style="list-style-type: none"> <li>Gives all correct cathode observations</li> </ul>	1 – 3
<b>Total</b>	<b>9</b>

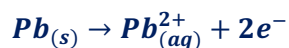
8.

[7 marks]

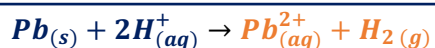
(a)



Oxidation half-reaction



Reduction half-reaction



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Labels correct anode and cathode</li> <li>Labels correct ions</li> <li>Labels positive and negative electrodes</li> <li>Correct half equations</li> <li>Determines correct overall cell equation</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>

(b) Tyler should say that the **no voltage** needs to be applied because the reaction is spontaneous **(1)**, as seen from the calculation  $E^{\circ} = 0.13 + 0 = +0.13\text{V}$  **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>No voltage should be applied, reaction is spontaneous</li> <li>Shows calculation</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

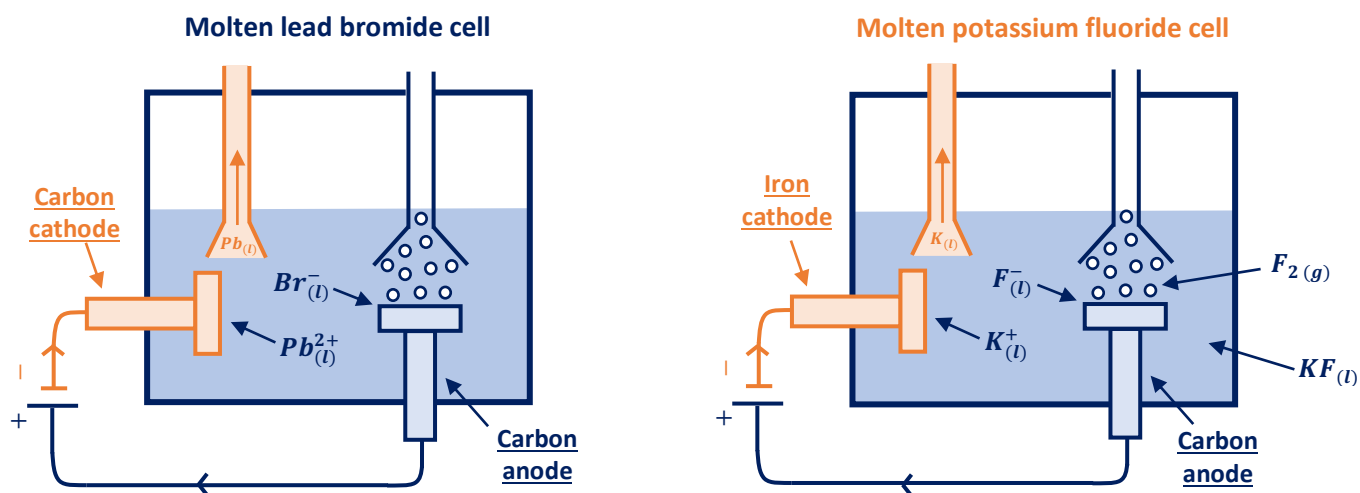
9.

[12 marks]

(a) These are molten cells, meaning that the lead bromide and potassium fluoride are in a **liquid form (1)**, with **no water present. (1)**

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>The molten cells are in a liquid state, not aqueous</li> <li>Water is not present and therefore cannot be oxidised/reduced</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(b)



Marking Criteria	Marks Allocated
• Correctly labelled anode and cathode	1 – 2
• Correct direction of electron flow and correct ion flow	1 – 2
<b>Total</b>	<b>4</b>

(c)

### Molten lead bromide cell

Oxidation Half-Equation



Reduction Half-Equation



$$E^0 = -1.08 - 0.13 = -1.21\text{V} \quad (1)$$

### Molten potassium fluoride cell

Oxidation Half-Equation



Reduction Half-Equation



$$E^0 = -2.89 - 2.94 = -5.83\text{V} \quad (1)$$

Marking Criteria	Marks Allocated
• Correct half equations	1 – 2
• Correct overall equation	1 – 2
• Correct $E^0$ of cell	1 – 2
<b>Total</b>	<b>6</b>

## Concept 2

# Real World Electrochemistry – Progressive Questions Answers

### Primary, Secondary and Fuel Cells: Q1, Q2, Q3, Q4

1. [12 marks]

- (a) **Primary cells** such as the **Leclanché cell** are those cells with a **fixed amount** of each **reactant**, and once used up **cannot be recharged (1)**. Like primary cells, **secondary cells** such as the **lead-acid accumulator** also have a **fixed amount** of each reactant, but once used up they can be **recharged** by applying an external voltage, unlike in primary cells **(1)**. **Fuel cells** such as the **hydrogen fuel cell**, are different because they have their **reactants continually fed into them** and will therefore continually produce electricity for as long as they have fuel fed into them **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Primary cells have fixed amounts of reactants and cannot be recharged</li> <li>• Secondary cells have fixed amount of reactants and can be recharged</li> <li>• Fuel cells have reactants continually fed into them</li> </ul>	1 – 3
<ul style="list-style-type: none"> <li>• One correct example of each cell</li> </ul>	1
<b>Total</b>	<b>4</b>

- (b)
- (i) The Leclanché cell is classified as a primary cell because it has a **fixed amount of reactants** and **cannot be recharged (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• The Leclanché cell has fixed amounts of reactants and cannot be recharged</li> </ul>	1
<b>Total</b>	<b>1</b>

- (ii) **Oxidation Half-Equation**

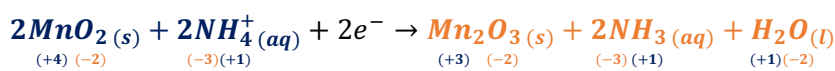
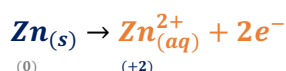


**Reduction Half-Equation**



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Correct half equations</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

- (iii)



Based on the oxidation numbers we can deduce that  $\text{MnO}_{2(s)}$  is the **oxidant (1)**, and  $\text{Zn}_{(s)}$  is the **reductant (1)**.

- (iv) **Advantages** of the Leclanché cell include but are not limited to being: **cheap**, **portable** and **suitable** for powering small devices with a **low required voltage (1)**. **Disadvantages** of the Leclanché cell include but are not limited to: **cannot be recharged**, **need constant replacement**, the zinc casing **slowly dissolves** and can **cause a leak**, and the cell **contains toxic contents (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Gives both advantages and disadvantages</li> <li>States three correct advantages</li> <li>States three correct disadvantages</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

2. [12 marks]

- (a) The lead-acid accumulator is classified as a secondary cell because it has a **fixed amount of reactants** and **can be recharged (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>The lead-acid accumulator has fixed amounts of reactants and can be recharged</li> </ul>	1
<b>Total</b>	<b>1</b>

- (b) **Oxidation Half-Equation**



**Reduction Half-Equation**



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correct half equations</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

- (c)  $E^0 = 0.36 + 1.69 = +2.05V \quad (1)$

- (d) If this was a car battery there would be **six** of these lead-acid accumulators placed in **series** in order to give approximately a **12V battery (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Six lead-acid accumulators placed in series</li> </ul>	1
<b>Total</b>	<b>1</b>

- (e) Increasing the  $H_2SO_4$  concentration will **increase** the **rates of oxidation** and **reduction (1)**, and therefore **increase** the **emf** produced by the lead-acid accumulator **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Increase the rates of oxidation and reduction</li> <li>Increase the cell emf</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

- (f) The oxidation and reduction of  $PbSO_4$  is not a spontaneous process. Therefore the  $PbSO_4$  must be in contact with the electrodes so that the electrons can be pulled from the  $PbSO_4$  or provided for the  $PbSO_4$  in order to allow this process to occur (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Not a spontaneous process, so it needs to be in contact for the electrons to be pulled/provided and allow the process to occur.</li> </ul>	1
<b>Total</b>	<b>1</b>

3. [6 marks]

Question	Jamie, Dylan and Alexa's answer	Correct Answer (Yes or No)
What <b>product(s)</b> is produced from this fuel cell?	$H_2O$	Yes
What is the <b>half-reaction</b> occurring at the <b>anode</b> ?	$H_2(g) + 2OH^-_{(aq)} \rightarrow 2H_2O(l) + 2e^-$	No
What is the <b>half-reaction</b> occurring at the <b>cathode</b> ?	$O_2(g) + 4H^+_{(aq)} + 4e^- \rightarrow 2H_2O(l)$	Yes
What is the <b>overall <math>E^0</math></b> of this fuel cell?	$E^0 = 0.4 + 1.23 = 1.63V$	No
If a <b><math>OH^-</math> electrolyte</b> was used instead of a <b><math>H^+</math> electrolyte</b> , would the <b>voltage</b> be larger?	No	Yes

∴ the trio will **have to come back tomorrow** to try again (1).

**Point to note:** For statement 2, in an **acidic hydrogen fuel cell** the anode half-reaction is:  $H_2(g) \rightarrow 2H^+_{(aq)} + 2e^-$ . For statement 4, the actual  $E^0$  of the cell is:  $E^0 = 0 + 1.23 = +1.23V$ . For statement 5, they are correct because the voltage produced in both the acidic and basic cell is always **+1.23V**.

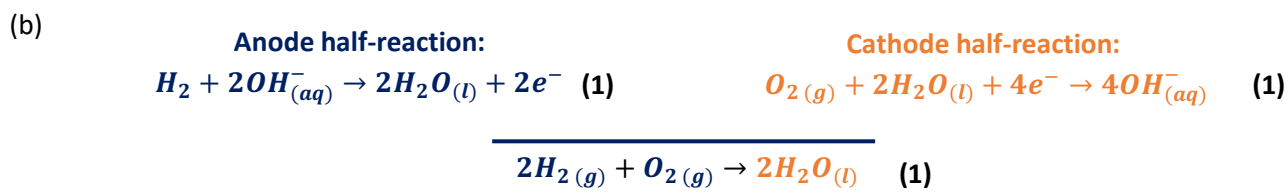
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correctly determines if Jamie, Dylan and Alexa are correct for each statement</li> </ul>	1 – 5
<ul style="list-style-type: none"> <li>States they will have to come back tomorrow</li> </ul>	1
<b>Total</b>	<b>6</b>

4. [10 marks]

- (a) **Advantages** of the hydrogen fuel cell include but are not limited to: the **only by-product is water**, generates electricity **as long as fuel is supplied**, **different fuels** can be used, converts **chemical energy directly to electrical energy**, and **uses  $O_2$  and  $H_2$  gas** as opposed to non-renewable fossil fuels (1).

**Disadvantages** of the hydrogen fuel cell include but are not limited to:  $H_2$  gas is highly **explosive** and  $O_2$  gas is highly **flammable**, fuel cells are **expensive** to produce,  $H_2$  gas is currently sourced from **steam reforming** which uses **fossil fuels** and produces **greenhouse gases**, fuel cells require a **constant supply** of reactants to keep operating, fuel cells need **more development** and **infrastructure** for wide-spread implementation (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>States two advantages and two disadvantages</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>



Marking Criteria	Marks Allocated
• Correct half equations	1 – 2
• Correct overall equation	1
<b>Total</b>	<b>2</b>

(c)  $E^0 = 0.40 + 0.83 = +1.23V$  (1)

(d) Hydrogen gas is **highly explosive** and oxygen gas is **highly flammable** (1), meaning there could be catastrophic damage if it were to crack open and be exposed to an open flame (1).

Marking Criteria	Marks Allocated
• $H_2$ gas is highly explosive and $O_2$ gas is highly flammable	1 – 2
• If exposed to an open flame there would be a large explosion/fire	
<b>Total</b>	<b>2</b>

(e) Increasing the  $OH^-$  concentration will **increase** the **rates of oxidation** and **reduction** (1), and therefore **increase** the **emf** produced by the hydrogen fuel cell (1).

Marking Criteria	Marks Allocated
• Increase the rates of oxidation and reduction	1 – 2
• Increase the emf	
<b>Total</b>	<b>2</b>

### Electrorefining and Electroplating: Q5, Q6

5. [7 marks]

(a) Based on the standard reduction potentials table, the species that would be oxidised are **copper, zinc, nickel, magnesium, tin** and **lead** (2). However the only species that would be reduced is the **copper ions** (2).

Marking Criteria	Marks Allocated
• Copper, zinc, nickel, magnesium, tin and lead will be oxidised	1 – 2
• Copper ions will be reduced	2
<b>Total</b>	<b>4</b>

(b) The anode mud is collected as it contains extremely valuable metals such as gold and silver (1).

Marking Criteria	Marks Allocated
• The anode mud contains metals such as gold and silver, and is therefore extremely valuable	1
<b>Total</b>	<b>1</b>

- (c) As the **copper ions** have the highest reduction potential of **+0.34V (1)**, they will be reduced in preference to the  $Ni^{2+}$  and  $Pb^{2+}$  ions which have  $E^0$  values of **-0.13V** and of **-0.24V** respectively **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Copper ions have the highest reduction potential of +0.34V</li> <li>They will therefore be reduced in preference to the <math>Ni^{2+}</math> and <math>Pb^{2+}</math> ions</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

**6. [8 marks]**

- (a) In this electroplating an external voltage is used to allow this non-spontaneous process to occur. In this process, the **silver anode** will **oxidise** to produce silver ions in the solution:  $Ag_{(s)} \rightarrow Ag_{(aq)}^+ + e^-$  **(1)**. The silver ions in the electrolyte will then reduce onto the key cathode:  $Ag_{(aq)}^+ + e^- \rightarrow Ag_{(s)}$  **(1)**. This process will form a thin coating of silver around the key, giving it a 'silver plated' finish **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>An external voltage is applied to allow this process to occur</li> <li>Silver will oxidise at the anode: <math>Ag_{(s)} \rightarrow Ag_{(aq)}^+ + e^-</math></li> <li>Silver ions will reduce at the cathode: <math>Ag_{(aq)}^+ + e^- \rightarrow Ag_{(s)}</math></li> <li>This will form a thin silver coating around the key</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

- (b) On the **left-side** the **silver electrode** will **decrease in size** over time **(1)**, and on the **right-side** the key will **increase in size** over time from a **silver coating** **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Gives all correct anode observations</li> <li>Gives all correct cathode observations</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

- (c) This process would be **reversed** and over-time the **iron key** would **decrease in size** **(1)**, and the **silver electrode** would become **coated** with more **silver** (as the silver ions will reduce in preference to the  $Fe^{2+}$  ions) **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Process would be reversed</li> <li>Key would decrease in size and silver electrode would increase in size from silver coating</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>



7.

[7 marks]

- (a) Adjustments that Tyler could have made include but are not limited to having: **oxygen and water present, high ion concentrations** in the water, **acidic conditions**, a **higher temperature**, and a **contact with a metal with a higher reduction potential (3)**.

Marking Criteria	Marks Allocated
• Gives three examples	1 – 3
<b>Total</b>	<b>3</b>

(b)

Stage	Description	Equation
1.	<i>Fe</i> is oxidised to form $Fe^{2+}$ ions, and $O_2$ gas is reduced to form $OH^-$ ions	<b>Anode:</b> $Fe_{(s)} \rightarrow Fe_{(aq)}^{2+} + 2e^-$ <b>Cathode:</b> $O_{2(g)} + 2H_2O_{(l)} + 4e^- \rightarrow 4OH_{(aq)}^-$ <b>Overall:</b> $2Fe_{(s)} + O_{2(g)} + 2H_2O_{(l)} \rightarrow 2Fe_{(aq)}^{2+} + 4OH_{(aq)}^-$ (1)
2.	The $Fe^{2+}$ and $OH^-$ ions will precipitate to form $Fe(OH)_2$	$Fe_{(aq)}^{2+} + 2OH_{(aq)}^- \rightarrow Fe(OH)_{2(s)}$ (1)
3.	The $Fe(OH)_2$ will further oxidise to form <b>iron (III) hydroxide (1)</b>	$4Fe(OH)_{2(s)} + O_{2(aq)} + 2H_2O_{(l)} \rightarrow 4Fe(OH)_{3(s)}$
4.	The $Fe(OH)_3$ will <b>lose its water</b> to form <b>hydrated iron (III) oxide (1)</b> .	$Fe(OH)_{3(s)}$ to $Fe_2O_3 \cdot xH_2O_{(s)}$

Marking Criteria	Marks Allocated
• Provides correct equations for stages 1 and 2	1 – 2
• Provides similar explanations to the ones provided for stages 3 and 4	1 – 2
<b>Total</b>	<b>4</b>

8.

[14 marks]

- (a) The **first method** they could use would be to **exclude** oxygen and water by using different materials to **cover the iron surfaces (1)**. This will **prevent oxygen and water** from coming in contact with the iron and therefore prevent corrosion from occurring (1).

The **second method** they could use would be a **sacrificial anode**, where a metal with a **higher oxidation potential** than iron (e.g. *Zn*) is **connected** via an external circuit to the iron object (1). In this 'galvanic cell', the zinc will act as the sacrificial anode and be oxidised in preference to the iron and the electrons will build-up at the iron cathode, preventing it from being oxidised (1).

The **third method** they could use is **cathodic protection**, where an **external voltage** is applied to **build-up electrons** at the iron (1). This will cause the iron to act as a **cathode** and therefore **prevent it** from being oxidised (1).

Marking Criteria	Marks Allocated
• Briefly explains the implementation of each method	1 – 3
• Briefly explains how each method will prevent the oxidation of the iron	1 – 3
<b>Total</b>	<b>6</b>

(b) By coating the structures with paint, they are preventing **oxygen** and **water** from **coming in contact** with the iron structures (**1**), which will **prevent the oxidation** of iron from being able to occur (**1**).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>The paint prevents water and oxygen from coming in contact with the iron</li> <li>This prevents the oxidation from occurring</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(c) The zinc pieces will be **oxidised in preference** to the iron, and therefore the zinc pieces will act as ‘sacrificial anodes’ (**1**). This can be seen in the equations:  $Zn_{(s)} \rightarrow Zn_{(aq)}^{2+} + 2e^-$   $E^0 = 0.76V$  and  $Fe_{(s)} \rightarrow Fe_{(aq)}^{2+} + 2e^-$   $E^0 = 0.44V$ . The **electrons** will then **build-up** at the iron cathode and **prevent** it from being oxidised (**1**).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>The zinc pieces will be oxidised in preference to the iron</li> <li>Relevant equations used</li> <li>The build-up of electrons will prevent the iron from being oxidised</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(d) By applying an external voltage to the iron structures, this will cause **electrons to build-up** at the iron cathode (**1**), which will **prevent** the iron structures from being oxidised (**1**). Additionally by having an inert electrode as the anode, it will **not be oxidised** and will therefore not need to be replaced (**1**).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>The external voltage will build-up electrons in the iron structures</li> <li>This will prevent the iron structures from being oxidised</li> <li>The inert electrode will also not be oxidised, so it doesn’t need replacing</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

# Problem Set 9 – Electrochemistry

## Repetitive Questions

### Concept 1

## Galvanic and Electrolytic Cells – Progressive Questions Answers

### Galvanic Cells: 1.1, 1.2, 1.3, 1.4

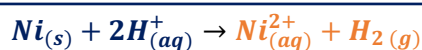
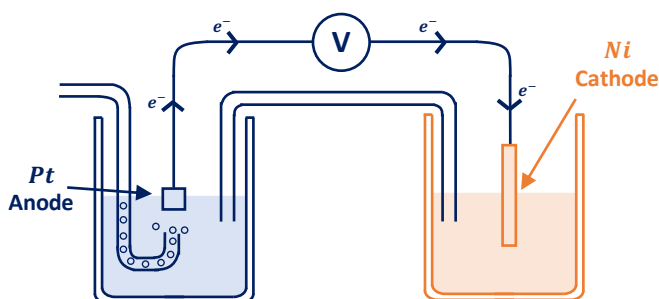
1.1

[10 marks]

- (a) In order to **determine** the **voltage** produced by each half reaction, one of the half reactions needed to be assigned a potential energy of **zero (1)**. The hydrogen half-cell was given this potential energy of zero, and could therefore be used to **compare the relative voltages** of all other half-reactions **(1)**. In terms of the **nickel/nickel nitrate cell**, by pairing it with the hydrogen half-cell they will be able to measure the voltage and determine its  $E^0$  value **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• The hydrogen half-cell was assigned a potential energy of zero.</li> <li>• This half-cell was used to compare the relative voltages of all other half-reactions</li> <li>• When paired with the nickel/nickel nitrate cell, they will be able to measure the voltage and determine its <math>E^0</math> value</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

(b)



$$E^0 = 0.24 + 0 = +0.24V$$

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Labels anode, cathode and electron flow correctly</li> </ul>	1 – 3
<ul style="list-style-type: none"> <li>• Correct overall equation and <math>E^0</math> calculation</li> </ul>	1 – 2
<b>Total</b>	<b>5</b>

(c) **Solid Iodine:**  $E^0 = 0.54 + 0 = +0.54V$  **(1)**

**Gold:**  $E^0 = 0V$  (this redox reaction is non-spontaneous and would not occur) **(1)**

**Lead Sulfate:**  $E^0 = 0V$  (the oxidation/reduction of lead sulfate is non-spontaneous, so it would not occur) **(1)**

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>• Determines correct <math>E^0</math> values</li> </ul>	1 – 3
<b>Total</b>	<b>5</b>

## 1.2

[12 marks]

- (a) In the **left half-cell** a **colourless, odourless gas** will be produced (1), and in the **right half-cell** the **blue solution colour** will **fade** and the size of the **salmon pink electrode** will **increase over time** (1).
- (b) In the **left half-cell** the size of the **silver electrode** will **increase** over time (1), and in the **right half-cell** the **deep green solution colour** will **become darker** and the size of the **silver electrode** will **decrease over time** (1).
- (c) In the **left half-cell** the **greenish-yellow gas** will dissolve into the **colourless solution** (1), and in the same half-cell a **colourless, odourless gas** will be produced. **No observations** will be made in the **right half-cell** (1).
- Point to note:** This is a tricky question. As chlorine gas is reduced in the left half-cell and there are no species that can be oxidised in the right half-cell, the water in the solution of the left half-cell will be oxidised in that half-cell. This is because the electrons would rather directly transfer to the water in the left half-cell, then travel round to the right half-cell and oxidise it there.
- (d) In the **left half-cell** a **greenish-yellow gas** will be produced (1), and in the **right half-cell** the **pale brown/green solution colour** will **become** more of a **pale brown colour** (1).
- (e) In the **left half-cell** a **yellow gas** will dissolve into the **colourless solution** (1), and in the **right half-cell** the size of the **gold electrode** will **increase in size** over time from being coated in a **purple solid** (1).
- (f) In the **left half-cell** the **size** of the **silver electrode** will **increase** over time (1), and in the **right half-cell** the **size** of the **silver electrode** will **decrease** over time (1).

Marking Criteria	Marks Allocated
• Gives all correct anode observations	1 – 6
• Gives all correct cathode observations	1 – 6
<b>Total</b>	<b>12</b>

## 1.3

[10 marks]

- (a) **Anode:**  $Pt_{(s)}$       **Cathode:**  $C_{(s)}$       **Voltage:**  $0 + 1.08 = +1.08V$       (2)
- (b) **Anode:**  $Zn_{(s)}$       **Cathode:**  $Cu_{(s)}$       **Voltage:**  $0.76 + 0.34 = +1.10V$       (2)
- (c) **Anode:**  $Mg_{(s)}$       **Cathode:**  $Mg_{(s)}$       **Voltage:**  $2.36 - 0.83 = +1.53V$       (2)

**Point to note:** In this question water will be reduced, and it will be reduced in the same cell as the magnesium. This is because the electrons would prefer to go directly to the water in the magnesium cell rather than travelling through the external circuit.

- (d) **Anode:**  $Ag_{(s)}$       **Cathode:**  $C_{(s)}$       **Voltage:**  $-0.80 + 1.51 = +0.71V$       (2)
- (e) **Anode:**  $Al_{(s)}$       **Cathode:**  $Pb_{(s)}$       **Voltage:**  $1.68 - 0.13 = +1.55V$       (2)

Marking Criteria	Marks Allocated
• Determines correct anode and cathode	1 – 5
• Determines correct voltage	1 – 5
<b>Total</b>	<b>10</b>

## 1.4

[14 marks]

(a) **Similarities** between galvanic and electrolytic cells include but are not limited to:

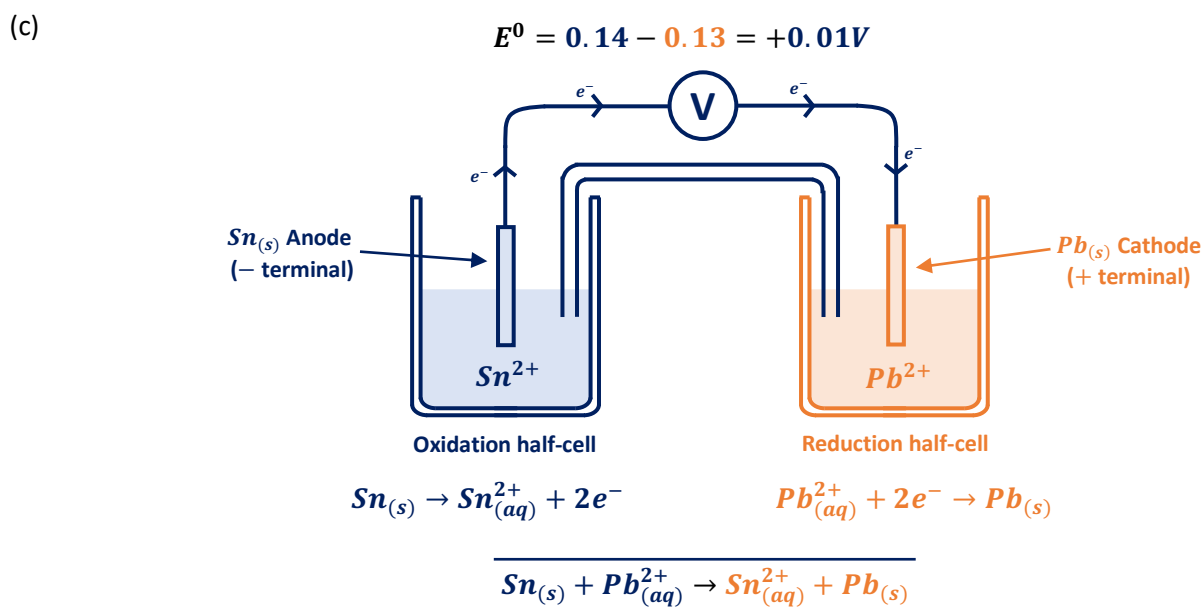
- Both have an **anode** and **cathode**
- Both have an **oxidised** and **reduced** species
- **Oxidation** occurs at the **anode**, **reduction** occurs at the **cathode**
- **Electrons flow** from the **anode** to the **cathode**
- Both have an **electrolyte**
- Both have an **external circuit**
- Both have **electrodes**

Marking Criteria	Marks Allocated
• States four correct similarities	1 – 2
<b>Total</b>	<b>2</b>

(b) **Differences** between galvanic and electrolytic cells include but are not limited to:

- **Galvanic cells** are **spontaneous**, **electrolytic cells** are **non-spontaneous**.
- **Electrolytic cells** are connected to an **external voltage source**.
- **Galvanic cells** have a **negative anode** and a **positive cathode**, **electrolytic cells** have a **positive anode** and a **negative cathode**.
- **Galvanic cells** have **two cells**, **electrolytic cells** only have **one cell**.
- **Galvanic cells** convert **chemical energy** to **electrical energy**, **electrolytic cells** convert **electrical energy** to **chemical energy**.

Marking Criteria	Marks Allocated
• States four correct differences	1 – 2
<b>Total</b>	<b>2</b>



Marking Criteria	Marks Allocated
• Labels correct anode and cathode	1 – 4
• Determines correct cell $E^0$	
• Labels correct ions	
• Determines correct overall cell equation	
<b>Total</b>	<b>4</b>

(d) The salt bridge allows for the **controlled flow of ions** across the half-cells but forces the electrons to still flow through an external circuit **(1)**. This **maintains electrical neutrality** and **completes the circuit (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Allows for the controlled flow of ions</li> <li>Maintains electrical neutrality/completes the circuit</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(e) If the concentration of the lead ions was increased, the **rate of reduction** would **increase (1)**, so the **emf** of the cell would **increase (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Rate of reduction will increase</li> <li>Cell emf will increase</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(f) If a gold electrode was used instead of tin, the **lead electrode** would now become the **anode (1)** and the **gold electrode** would become the **cathode (1)**.

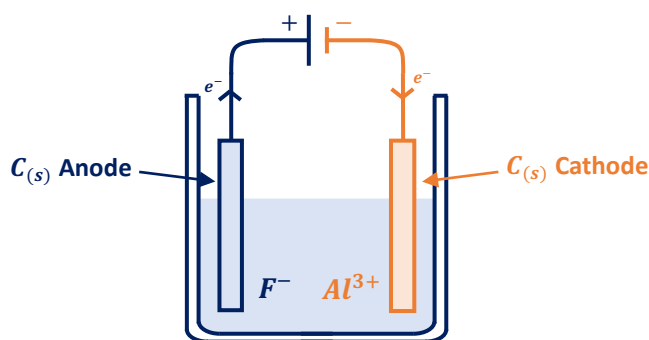
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Lead electrode becomes the anode</li> <li>Gold electrode becomes the cathode</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

### Electrolytic Cells: 1.6, 1.7, 1.9

1.6

[10 marks]

(a)



Oxidation half-reaction

Reduction half-reaction



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Labels correct anode and cathode</li> <li>Labels correct ions</li> <li>Labels positive and negative electrodes</li> <li>Correct half equations</li> <li>Determines correct overall cell equation</li> </ul>	1 – 5
<b>Total</b>	<b>5</b>

- (b) On the **left side** a **colourless, odourless gas** will be produced **(1)**, and on the **right side** a **colourless, odourless gas** will also be produced **(1)**.

**Point to note:** Water will be both oxidised and reduced in this case, in preference to the aluminium and fluorine ions.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correct anode observations</li> <li>Correct cathode observations</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

- (c) The electrodes in an electrolytic cell are dipped into the **same electrolyte solution (1)**, meaning they **don't need** to be separated into half-cells **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Dipped in same electrolyte solution, therefore don't need separate half-cells</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

### 1.7 [12 marks]

- (a) On the **left side** the **salmon pink electrode** will **decrease in size** over time **(1)**, and on the **right side** the size of the **salmon pink electrode** will **increase** becoming coated with a **silver coating (1)**.

- (b) On the **left side** a **colourless, odourless gas** will be produced **(1)**, and on the **right side** a **colourless, odourless gas** will also be produced **(1)**.

**Point to note:** In this scenario, water will be both oxidised and reduced.

- (c) On the **left side** the **grey electrode** will **decrease in size** over time **(1)**, and on the **right side** the size of the **black electrode** will **increase** becoming coated with a **silver coating (1)**.

- (d) On the **left side** a **colourless, odourless gas** will be produced **(1)**, and on the **right side** a **colourless, odourless gas** will also be produced **(1)**.

**Point to note:** In this scenario, water will be both oxidised and reduced.

- (e) On the **left side** the **silver electrode** will **decrease in size** over time **(1)**, and on the **right side** the size of the **silver electrode** will **increase** becoming coated with a **silver coating (1)**.

- (f) On the **left side** the **silver electrode** will **decrease in size** over time **(1)**, and on the **right side** the size of the **silver electrode** will **increase** becoming coated with a **purple solid (1)**.

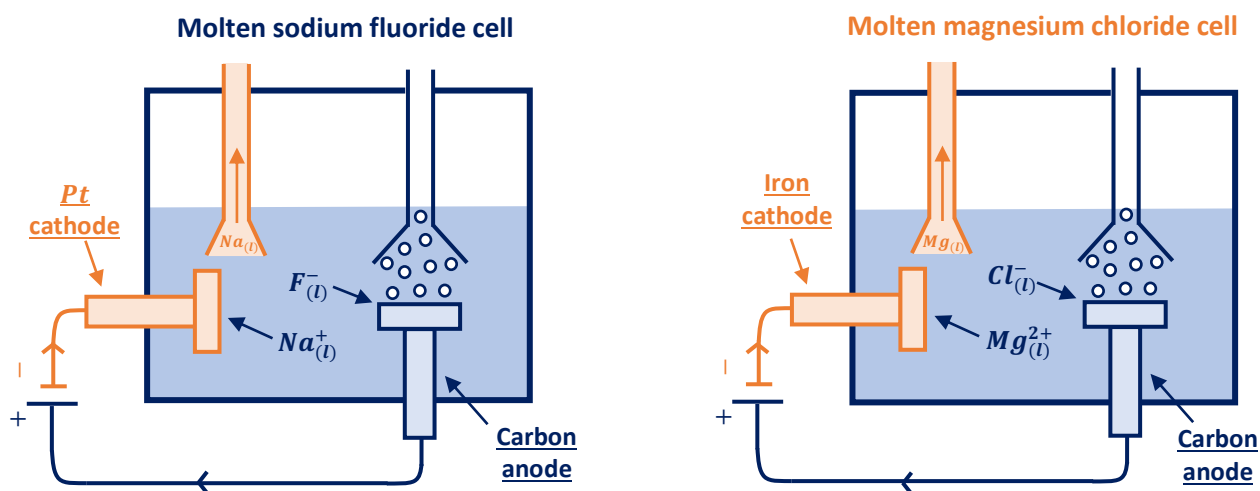
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Gives all correct anode observations</li> </ul>	1 – 6
<ul style="list-style-type: none"> <li>Gives all correct cathode observations</li> </ul>	1 – 6
<b>Total</b>	<b>12</b>

### 1.9 [12 marks]

- (a) These are molten cells, meaning that the sodium fluoride and magnesium chloride are in a **liquid form (1)**, with **no water present. (1)**

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>The molten cells are in a liquid state, not aqueous</li> <li>Water is not present and therefore cannot be oxidised/reduced</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(b)



Marking Criteria	Marks Allocated
• Correctly labelled anode and cathode	1 – 2
• Correct direction of electron flow and direction of ions	1 – 2
<b>Total</b>	<b>4</b>

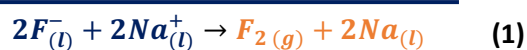
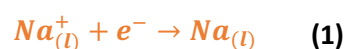
(c)

### Molten sodium fluoride cell

Oxidation Half-Equation



Reduction Half-Equation



$$E^0 = -2.89 - 2.71 = -5.60V \quad (1)$$

### Molten magnesium chloride cell

Oxidation Half-Equation



Reduction Half-Equation



$$E^0 = -1.36 - 2.36 = -3.72V \quad (1)$$

Marking Criteria	Marks Allocated
• Correct half equations	1 – 2
• Correct overall equation	1 – 2
• Correct $E^0$ of cell	1 – 2
<b>Total</b>	<b>6</b>



## Concept 2

# Real World Electrochemistry – Progressive Questions Answers

### Primary, secondary and fuel cells: 2.1, 2.3

#### 2.1

[16 marks]

- (a) **Primary cells** such as the **Leclanché cell (1)** are those cells with a **fixed amount** of each **reactant**, and once used up **cannot be recharged (1)**. Like primary cells, **secondary cells** such as the **lead-acid accumulator (1)** also have a **fixed amount** of each reactant, but once used up they can be **recharged** by applying an external voltage, unlike in primary cells **(1)**. **Fuel cells** such as the **hydrogen fuel cell (1)**, are different because they have their **reactants continually fed into them** and will therefore continually produce electricity for as long as they have fuel fed into them **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>Primary cells have fixed amounts of reactants and cannot be recharged</li><li>Secondary cells have fixed amount of reactants and can be recharged</li><li>Fuel cells have reactants continually fed into them</li></ul>	1 – 3
<ul style="list-style-type: none"><li>One correct example of each cell</li></ul>	1 – 3
<b>Total</b>	<b>6</b>

- (b) **Advantages** of the Leclanché cell include but are not limited to being: **cheap**, **portable** and **suitable** for powering small devices with a **low required voltage (1)**. **Disadvantages** of the Leclanché cell include but are not limited to: **cannot be recharged**, **need constant replacement**, the zinc casing **slowly dissolves** and can **cause a leak**, and the cell **contains toxic contents (1)**.

**Advantages** of the lead-acid accumulator include but are not limited to being: **rechargeable**, last for a **long time**, **relatively cheap**, and it **produce large currents (1)**. **Disadvantages** of the lead-acid accumulator include but are not limited to being: full of **toxic lead** and **corrosive sulfuric acid**, having a **low energy density**, and having a **limited number** of **discharge-recharge cycles (1)**.

**Advantages** of the hydrogen fuel cell include but are not limited to: the **only by-product is water**, generates electricity **as long as fuel is supplied**, **different fuels** can be used, converts **chemical energy directly to electrical energy**, and **uses  $O_2$  and  $H_2$  gas** as opposed to non-renewable fossil fuels **(1)**.

**Disadvantages** of the hydrogen fuel cell include but are not limited to:  $H_2$  gas is highly **explosive** and  $O_2$  gas is highly **flammable**, fuel cells are **expensive** to produce,  $H_2$  gas is currently sourced from **steam reforming** which uses **fossil fuels** and produces **greenhouse gases**, fuel cells require a **constant supply** of reactants to keep operating, fuel cells need **more development** and **infrastructure** for wide-spread implementation **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"><li>States two correct advantages of each cell</li></ul>	1 – 3
<ul style="list-style-type: none"><li>States two correct disadvantages of each cell</li></ul>	1 – 3
<b>Total</b>	<b>6</b>

- (c) In primary cells, they have a **limited amount of reactants** and cannot be recharged **(1)**. Therefore as the reactants are **used up over time**, the **rates of oxidation** and **reduction** will slowly decrease and therefore decrease the emf of the cell over time **(1)**. In secondary cells, they also have a limited amount of reactants, but they can do this at a

**slower rate** because they **can be recharged (1)**. Whilst they can be recharged, the effectiveness of these recharge cycles **slowly starts to decrease** and therefore the maximum emf output of the cell will decrease until the recharging process stops working **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Primary cells have a limited amount of reactants, which will decrease over time.</li> <li>This will decrease the rate of oxidation/reduction and therefore decrease the emf of the cell.</li> <li>Secondary cells do this at a slower rate because they can be recharged.</li> <li>However, the recharge process slowly loses its effectiveness so the maximum emf output keeps decreasing.</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

## 2.2

[11 marks]

(a) In an acidic electrolyte the anode equation is:  $H_{2(g)} \rightarrow 2H_{(aq)}^+ + 2e^-$  and the cathode equation is:  $O_{2(g)} + 4H_{(aq)}^+ + 4e^- \rightarrow 2H_2O_{(l)}$  **(1)**, whereas in a basic electrolyte the anode equation is:  $H_2 + 2OH_{(aq)}^- \rightarrow 2H_2O_{(l)} + 2e^-$  and the cathode equation is:  $O_{2(g)} + 2H_2O_{(l)} + 4e^- \rightarrow 4OH_{(aq)}^-$  **(1)**. The key difference is that in the **acidic electrolyte** the half-reactions involve the  **$H^+$  ion (1)**, whereas in the **basic electrolyte** the half-reactions involve the  **$OH^-$  ion (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>States equations in acidic electrolyte</li> <li>States equations in basic electrolyte</li> <li>Explains the acidic equations involve the <math>H^+</math> ion</li> <li>Explains the basic equations involve the <math>OH^-</math> ion</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

(b) In both the acidic and basic electrolytes the overall reaction equation is:  $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$  **(1)** and the overall voltage produced by both cells is:  $E^0 = 1.23V$  **(1)**. The reason they both have the same equations is because the  **$H^+$  and  $OH^-$  ions end up cancelling each other out** in the half equations **(1)**, and they both have the **same voltage output** because they are the same overall reaction **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Shows same overall equation</li> <li>Shows <math>E^0</math> value of 1.23V</li> <li>Both have the same equations because <math>H^+</math> and <math>OH^-</math> ions cancel each other out</li> <li>Both have same voltage output because they are the same overall reaction</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

(c) The rates of oxidation and reduction would increase, so the emf of the cell would increase **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Emf of the cell would increase</li> </ul>	1
<b>Total</b>	<b>1</b>

(d) The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) was established to:

- Encourage the research and development of the hydrogen fuel-cell on a global scale; and
- To develop codes and standards around their development and use.

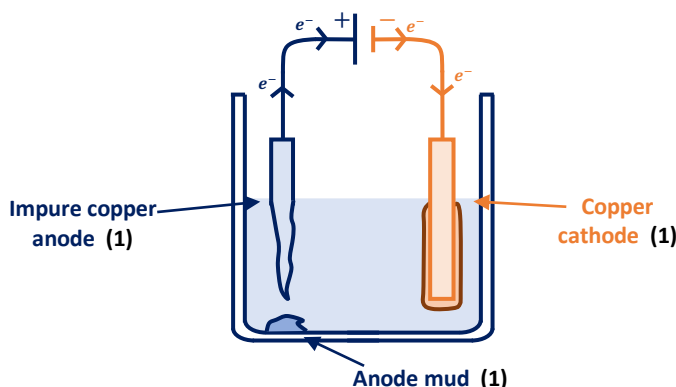
Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Encourage the research and development of the hydrogen fuel-cell on a global scale; and</li> <li>To develop codes and standards around their development and use.</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

## Electrorefining and electroplating: 2.4, 2.5

2.4

[12 marks]

(a)



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Labels anode, cathode and anode mud correctly</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

(b) With an  $E^0$  value of  $-0.34V$ , **copper** will be **oxidised at the anode (1)** along with **tin, lead, chromium, magnesium, manganese** and **cadmium**, as they have  $E^0$  values of: **0.13V, 0.74V, 2.36V, 1.18V** and **0.40V** respectively **(2)**. However, at the cathode only the copper will be oxidised spontaneously, with an  $E^0$  value of: **0.34V (1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Explains copper will be oxidised at the anode</li> <li>Explains tin, lead, chromium, magnesium, manganese and cadmium will also be oxidised at the anode</li> <li>Explains only copper will be reduced at the cathode</li> <li>Uses <math>E^0</math> values to support explanations</li> </ul>	1 – 4
<b>Total</b>	<b>4</b>

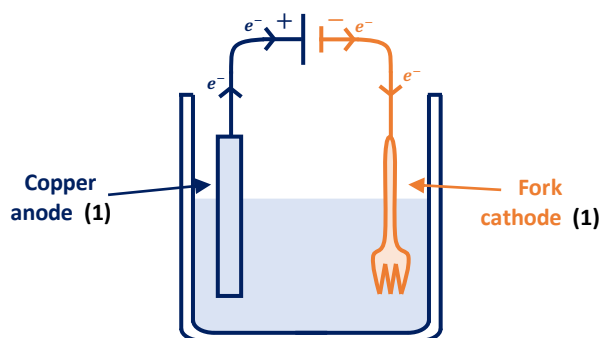
(c) With **gold** and **silver** having  $E^0$  values of  $-1.50V$  and  $-0.80V$  respectively, neither of these valuable metals will oxidise into the solution **(2)**. Therefore Tom should collect this anode mud as it will contain valuable metals such as gold and silver **(1)**.

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Gold and silver will not oxidise in the solution</li> <li>The anode mud contains valuable metals and should therefore be collected</li> <li>Uses <math>E^0</math> values to support explanations</li> </ul>	1 – 3
<b>Total</b>	<b>3</b>

## 2.5

[12 marks]

(a)



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Correct drawing/labelling of copper anode and fork cathode</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(b) Any soluble copper solution such as  $\text{CuNO}_3(\text{aq})$  or  $\text{CuSO}_4(\text{aq})$  (1), with no species that will be oxidised/reduced in preference to the copper

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>A soluble copper solution with no ions that will be oxidised/reduced in preference to copper</li> </ul>	1
<b>Total</b>	<b>1</b>

(c) The anode is made of the metal that will be used to plate the fork (1), the role of the copper anode is to **replace** the ions in the electrolyte solution so that the electrolysis process can continue (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Anode is the metal that will coat the fork</li> <li>Will replace ions in the electrolyte solution as they are plated onto the fork</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(d) On the **left-side** the **salmon pink electrode** will **decrease in size** over time (1), and on the **right-side** the **fork** will **increase in size** over time from a **salmon pink coating** (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Gives all correct anode observations</li> <li>Gives all correct cathode observations</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

(d) This process would be **reversed** and over-time the **silver fork** would **decrease in size** (1), and the **salmon pink electrode** would become **coated** with a **silver metal** (1).

Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Process would be reversed</li> <li>Key would decrease in size and silver electrode would increase in size from silver coating</li> </ul>	1 – 2
<b>Total</b>	<b>2</b>

## Corrosion: 2.7, 2.8

### 2.7

[12 marks]

(a) The process of corrosion occurs in four steps.

In step 1, an exposed part of the **iron** is **oxidised** into  $Fe^{2+}$  ions, and at the same time, but on another part of the surface, the electrons are used to **reduce oxygen** in the presence of **water** to form  $OH^-$  ions, with the overall equation being:  $2Fe_{(s)} + O_{2(aq)} + 2H_2O_{(l)} \rightarrow 2Fe_{(aq)}^{2+} + 4OH_{(aq)}^-$  (1).

In step 2, the  $Fe^{2+}$  and  $OH^-$  ions will react with in the water to form an **iron (II) hydroxide precipitate**:  $Fe_{(aq)}^{2+} + 2OH_{(aq)}^- \rightarrow Fe(OH)_{2(s)}$  (1). In step 3, if in the presence of oxygen, the  $Fe(OH)_2$  will further oxidise to form **iron (III) hydroxide**:  $4Fe(OH)_{2(s)} + O_{2(aq)} + 2H_2O_{(l)} \rightarrow 4Fe(OH)_{3(s)}$  (1).

In step 4, if surrounded by **air**, overtime the  $Fe(OH)_3$  will **lose its water** to form **hydrated iron (III) oxide** ( $Fe_2O_3 \cdot xH_2O$ ), which is **rust**. Once formed as **rust**, this **brown** and **flaky material** will easily **peel away** from the surface, **exposing new iron** to undergo this same process (1).

Marking Criteria	Marks Allocated
• Briefly explains each step in general terms and uses an appropriate equation	1 – 4
<b>Total</b>	<b>4</b>
<b>Note:</b> Can be lenient with wording, so long as equations are correct	

(b) Methods to increase the rate of corrosion include but are not limited to having: **oxygen and water present**, **high ion concentrations** in the water, **acidic conditions**, a **higher temperature**, and a **contact with a metal** with a **higher reduction potential** (3).

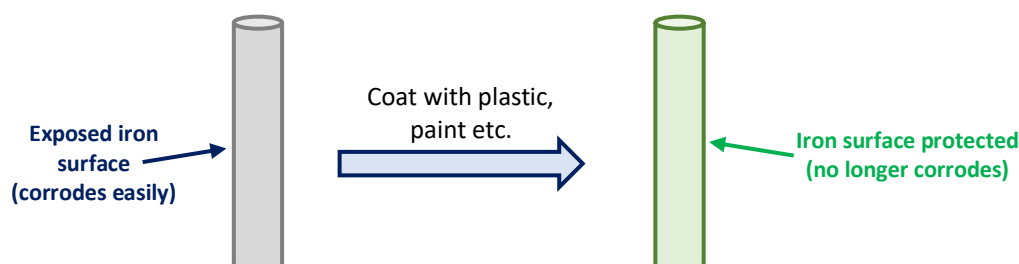
Marking Criteria	Marks Allocated
• Briefly discusses three examples	1 – 3
<b>Total</b>	<b>3</b>

### 2.8

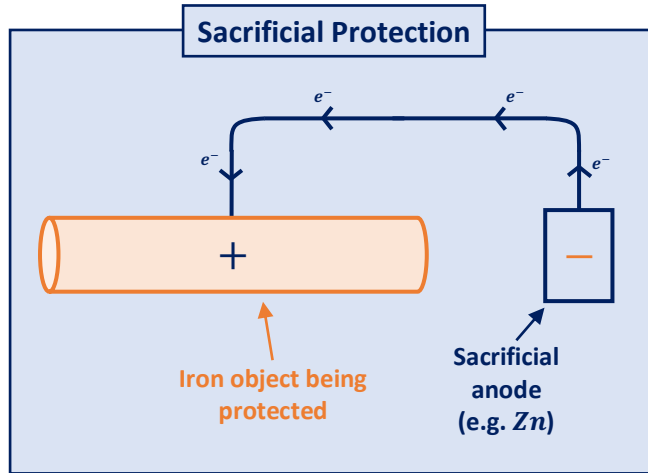
[12 marks]

Can choose two out of the three following methods.

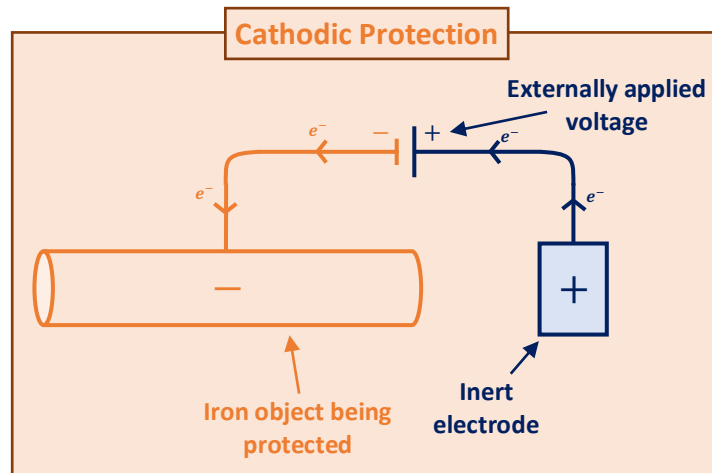
The **first method** that could be used would be to **exclude oxygen and water** by using different materials to **cover the iron surfaces** (1). This will **prevent oxygen and water** from coming in contact with the iron and therefore prevent corrosion from occurring (1). Examples of materials that could be used to coat the iron object include paint, plastic, grease or non-corrosive metals (1), a sample diagram is shown below (1).



The **second method** that could be used would be a **sacrificial anode**, where a metal with a **higher oxidation potential** than iron (e.g.  $Zn$ ) is **connected** via an external circuit to the iron object (**1**). In this 'galvanic cell', the zinc will act as the sacrificial anode and be oxidised in preference to the iron and the electrons will build-up at the iron cathode, preventing it from being oxidised (**1**). Examples of materials that could be used are any metals with a higher oxidation potential than iron and that aren't too reactive, such as zinc or chromium (**1**), a sample diagram is shown below (**1**).



The **third method** they could use is **cathodic protection**, where an **external voltage** is applied to **build-up electrons** at the iron (**1**). This will cause the iron to act as a **cathode** and therefore **prevent it** from being oxidised (**1**). Examples of inert electrodes that could be used in this process include carbon and platinum (**1**), a sample diagram is shown below (**1**).



Marking Criteria	Marks Allocated
<ul style="list-style-type: none"> <li>Provides a general overview of the method</li> <li>Discusses how it prevents the corrosion of iron</li> <li>Provides examples of materials that can be used for each method</li> <li>Provides adequate diagram</li> </ul>	(1 – 4) × 2
<b>Total</b>	<b>8</b>