# Q1.

This question is about the equilibrium reaction between hydrogen and carbon dioxide.

$$H_2(g) + CO_2(g) \rightleftharpoons H_2O(g) + CO(g) \qquad \Delta H^{\ominus} = +40 \text{ kJ mol}^{-1}$$

What effect would the following changes have on the rate of reaction and the yield of carbon monoxide?

(a) **Increase** in temperature.

**(1)**

| | Rate | Yield of CO |
|---|---|---|
| ☒ **A** | increase | increase |
| ☒ **B** | increase | decrease |
| ☒ **C** | increase | no change |
| ☒ **D** | no change | decrease |

(b) **Increase** in pressure.

**(1)**

| | Rate | Yield of CO |
|---|---|---|
| ☒ **A** | increase | increase |
| ☒ **B** | increase | decrease |
| ☒ **C** | increase | no change |
| ☒ **D** | no change | no change |

# Q2.

(a) Ozone, $O_3$, is formed when oxygen is exposed to ultraviolet (UV) radiation or to an electric discharge. Ozone is a blue gas whereas oxygen is colourless. When the two gases are mixed, an equilibrium is established as shown in the following equation.

$$3O_2(g) \rightleftharpoons 2O_3(g) \qquad \Delta H = +143 \text{ kJ mol}^{-1}$$

(i) When the temperature of the pale blue equilibrium mixture is increased at constant volume, the colour darkens. Explain this observation in terms of the changes to the equilibrium.

**(2)**

(ii) State and explain what you would **see** if the pressure of the system at equilibrium were increased.

**(2)**

(iii) A small amount of oxygen gas containing the isotope $^{18}O$ is added to the equilibrium mixture. After a few hours, ozone containing $^{18}O$ is detected. Given that the equilibrium position is **not** affected, explain this observation.

**(1)**

## Q3.

Ammonia is used in the manufacture of nitric acid.

The equation for one step in this manufacturing process is:

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta_r H = -900 \text{ kJ mol}^{-1}$$

Write the expression for the equilibrium constant, $K_c$, for this reaction.

**(1)**

# Q4.

Ethene reacts with steam to form ethanol in a reversible reaction.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \quad \Delta H = -45 \text{ kJ mol}^{-1}$$

At 300 °C and a pressure of 65 atm, the equilibrium yield of ethanol is 5%.

(i) State the effect, if any, on the yield of ethanol when the temperature is **increased**.

**(1)**

.....

.....

(ii) State the effect, if any, on the yield of ethanol when the pressure is **decreased**.

**(1)**

.....

.....

(iii) What is the expression for the equilibrium constant, $K_c$, for this reaction?

**(1)**

☒ **A** $\dfrac{[C_2H_4(g)]+[H_2O(g)]}{[C_2H_5OH(g)]}$

☒ **B** $\dfrac{[C_2H_4(g)][H_2O(g)]}{[C_2H_5OH(g)]}$

☒ **C** $\dfrac{[C_2H_5OH(g)]}{[C_2H_4(g)]+[H_2O(g)]}$

☒ **D** $\dfrac{[C_2H_5OH(g)]}{[C_2H_4(g)][H_2O(g)]}$

# Q5.

One of the stages in the production of sulfuric acid from sulfide ores involves the oxidation of sulfur dioxide to sulfur trioxide. The equation for the reaction is

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta_r H = -197 \text{ kJ mol}^{-1}$$

The conditions used in one industrial process are: 420 °C and a pressure of 1.7 atm together with a vanadium(V) oxide catalyst.

It is proposed to change the conditions to 600 °C and 10 atm pressure, while still using the same catalyst.

*(a) Evaluate the feasibility of each of these changes in terms of their effect on the rate, yield and economics of the reaction.

**(6)**

(c) (i) Write the expression for the equilibrium constant $K_c$ for this reaction.

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

**(1)**

(ii) What are the units, if any, of the equilibrium constant, $K_c$?

**(1)**

☒ **A** mol $dm^{-3}$

☒ **B** $dm^3$ $mol^{-1}$

☒ **C** no units

☒ **D** $mol^2$ $dm^{-6}$

## Q1.

| Correct Answer | Reject | Mark |
|---|---|---|
| A | | **(1)** |

| Correct Answer | Reject | Mark |
|---|---|---|
| C | | **(1)** |

# Q2.

| Question Number | Acceptable Answers | Reject | Mark |
|---|---|---|---|
| **(a)(i)** | More $O_3$ is formed/equilibrium shifts to the right **(1)**<br><br>Because<br>(increase in temperature) favours **endothermic** reaction<br>ALLOW<br>(Forward) reaction is **endothermic**<br><br>ALLOW<br>ΔH is positive for endothermic **(1)**<br><br>IGNORE references to rate and pressure change | equilibrium shifts to the left<br>(scores zero overall) | **2** |

| Question Number | Acceptable Answers | Reject | Mark |
|---|---|---|---|
| **(a)(ii)** | The mixture becomes darker<br>ALLOW: more blue/bluer **(1)**<br><br>(Increase in pressure) favours side with fewer moles/molecules (of gas)<br>(so equilibrium shifts to the right) **(1)**<br><br>IGNORE references to rate<br><br>Marks are stand alone | Just 'more ozone'<br>Blue gas formed<br>Mixture becomes blue<br><br>Atoms/particles | **2** |

| Question Number | Acceptable Answers | Reject | Mark |
|---|---|---|---|
| **(a)(iii)** | The equilibrium is dynamic<br>OR<br>Forward & reverse reactions still occurring<br>OR<br>$O_3$ continues to be formed from $O_2$ at the same rate as $O_3$ decomposes<br>OR<br>$O_3$ continues to be formed from $O_2$ with no nett change in composition | | **1** |

# Q3.

| | | | |
|---|---|---|---|
| **(c)** | $K_c = \frac{[NO(g)]^4[H_2O(g)]^6}{[NH_3(g)]^4[O_2(g)]^5}$ (1) | State symbols not essential | **1** |

# Q4.

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **(c)(i)** | • (yield) decreases / lower yield | Allow less ethanol is produced<br><br>Ignore equilibrium shifts to the left but do not allow equilibrium shifts to the right<br><br>Ignore any reference to Le Chatelier's principle<br><br>Do not allow high temperature favours the exothermic direction | **(1)** |

| Question Number | Acceptable Answers | Additional Guidance | Mark |
|---|---|---|---|
| **(c)(ii)** | • (yield) decreases / lower yield | Allow less ethanol is produced<br><br>Ignore equilibrium shifts to the left but do not allow equilibrium shifts to the right<br><br>Ignore any reference to Le Chatelier's principle<br><br>Ignore fewer collisions | **(1)** |

| Question Number | Answer | Mark |
|---|---|---|
| **(c)(iii)** | **D** $\left(\frac{[C_2H_5OH(g)]}{[C_2H_4(g)][H_2O(g)]}\right)$ | **(1)** |

# Q5.

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>* (a)</td>
<td>This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.<br>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.<br>The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
The following table shows how the marks should be awarded for structure and lines of reasoning.
<table>
<tr><th></th><th>Number of marks awarded for structure and sustained lines of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout.</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning.</td><td>1</td></tr>
<tr><td>Answer has no linkages between points and is unstructured.</td><td>0</td></tr>
</table>
</td>
<td>Guidance on how the mark scheme should be applied:<br><br>The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points that is partially structured with some linkages and lines of reasoning, scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).<br><br>If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).<br><br>In general it would be expected that 5 or 6 indicative points would get 2 reasoning marks, and 3 or 4 indicative points would get 1 mark for reasoning, and 0, 1 or 2 indicative points would score zero marks for reasoning.<br><br>If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s).<br>Comment: Look for the indicative marking points first, then consider the mark for the structure of the answer and sustained line of reasoning.</td>
<td>(6)</td>
</tr>
</table>

| | | | |
|---|---|---|---|
| * (a) | **Indicative content:**<br><br>• IP1 increase in temperature will increase rate<br><br>• IP2 (but) increase in temperature will decrease yield/move the equilibrium to the LHS/ produce less $SO_3$ **because** it is an exothermic reaction (in the forward direction)<br><br>• IP3 increase in temperature increases **energy** costs<br><br>• IP4 increase in pressure has no effect on rate (because all the active sites are already occupied on a heterogeneous catalyst).<br>**OR**<br>increase in pressure will increase rate (of reaction)<br><br>• IP5 increase in pressure will move position of eqm to RHS/increase yield **because** there are less moles/molecules (of gas) on the RHS<br><br>• IP6 but increased pressure increases (construction and running) costs/reduces economic viability | Decreased yield with no reference to exothermic reaction does not get IP2.<br><br>Allow increases yield of reactants/$SO_2$ **and** $O_2$ (with reference to exothermic reaction)<br><br>Increased yield with no reference to number of moles does not get IP5.<br><br>Award one mark for IP2 and IP5 if correct references to yield in both but reasons not given<br><br>Allow IP3 and IP6 if increased costs of higher temperature and pressure are mentioned together **provided** that the temperature costs are linked to energy costs. Otherwise only IP6 can be awarded.<br><br>Ignore any reference to catalyst | |

| Question Number | Acceptable Answer | Additional Guidance | Mark |
|---|---|---|---|
| (c)(i) | $(K_c = ) \dfrac{[SO_3]^2}{[O_2][SO_2]^2}$ | Do not award just $K$ or $K_p$.<br>must be square brackets<br>do not accept partial pressures<br>ignore units or lack of units<br>ignore state symbols<br>Allow x sign in the denominator but not + | (1) |

| Question Number | Answer | Mark |
|---|---|---|
| (c)(ii) | **(c)(ii). The only correct answer is B**<br><br>***A*** *is not correct because it refers to the inverted expression for* $K_c$<br><br>***C*** *is not correct because units do not cancel for concentration$^2$/concentration$^3$*<br><br>***D*** *is not correct because it refers to concentration$^3$/concentration or similar ratio of powers* | (1) |