6 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.

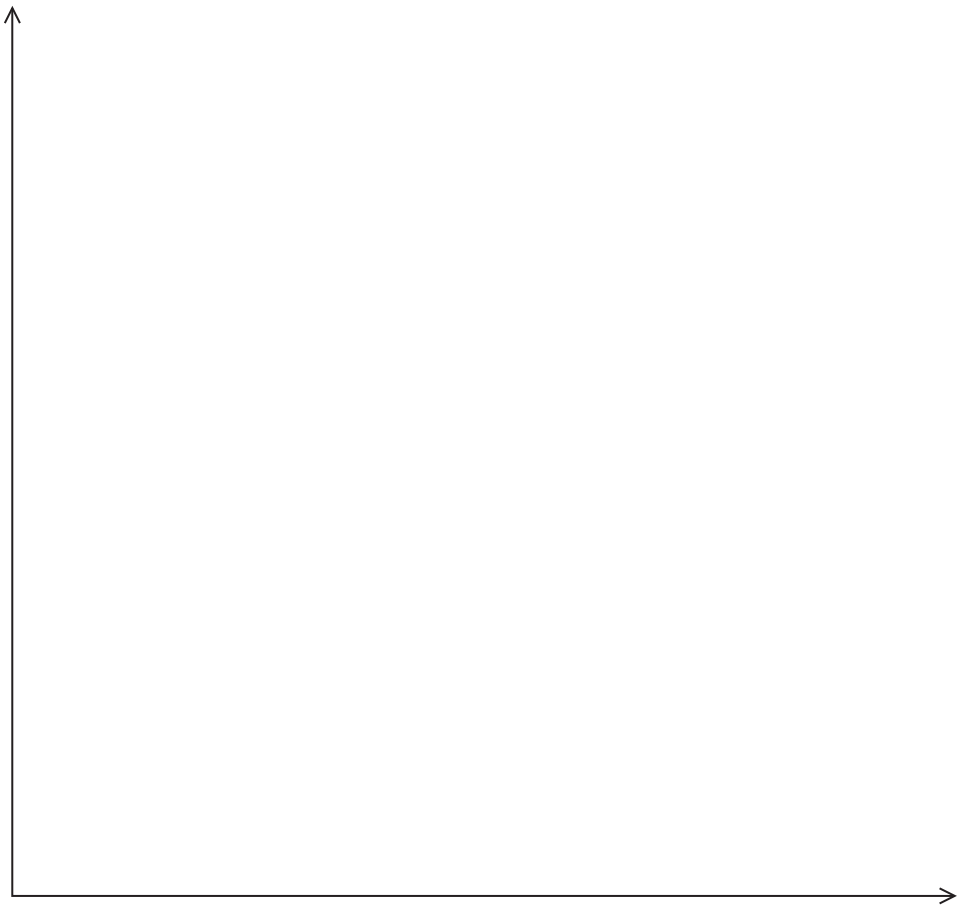
(6)

(b) (i) On the axes provided, sketch the reaction profiles for the uncatalysed and catalysed reaction.

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

Label the uncatalysed reaction, **A**, and the reaction catalysed by vanadium(V) oxide, **B**.

(3)



(ii) On your reaction profile, identify and label both the enthalpy change and the activation energy for the catalysed reaction.

(2)

(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}

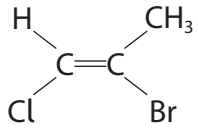
☒ **C** no units

☒ **D** mol^2 dm^{-6}

(Total for Question 6 = 13 marks)

2 Compounds with a carbon–carbon double bond are unsaturated.

(a) What is the name of the compound shown?



(1)

☒ **A** *cis*-2-bromo-1-chloroprop-1-ene

☒ **B** *E*-2-bromo-1-chloroprop-1-ene

☒ **C** *trans*-2-bromo-1-chloroprop-1-ene

☒ **D** *Z*-2-bromo-1-chloroprop-1-ene

(b) Ethene reacts with bromine in the dark.

(i) What is the classification of the mechanism for the reaction between ethene and bromine?

(1)

☒ **A** electrophilic addition

☒ **B** electrophilic substitution

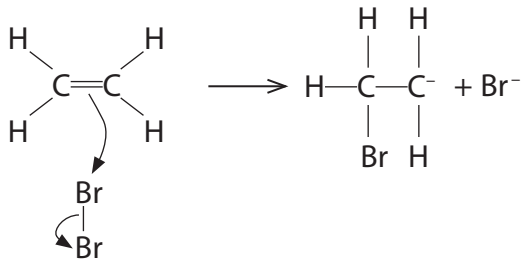
☒ **C** nucleophilic addition

☒ **D** nucleophilic substitution

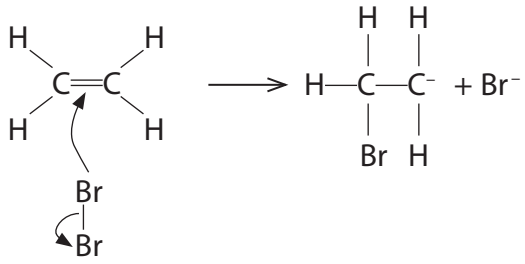
(ii) Which of the following shows the formation of the intermediate in the mechanism for the reaction between ethene and bromine?

(1)

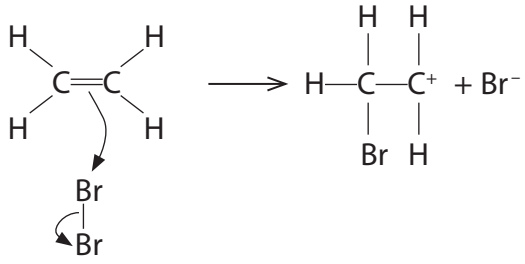
☒ **A**



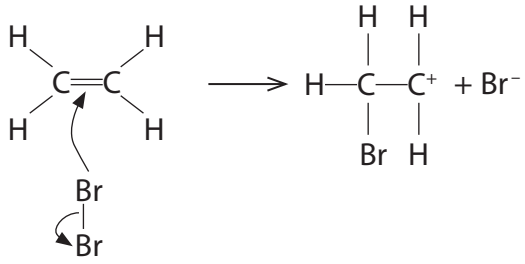
☒ **B**



☒ **C**



☒ **D**



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

(Total for Question 2 = 6 marks)

3 Ammonia is used in the manufacture of nitric acid.

The equation for one step in this manufacturing process is:

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

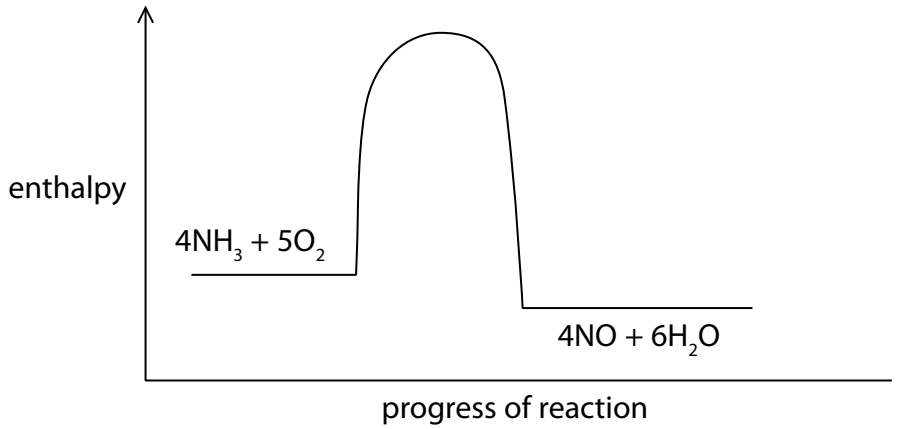
*(a) A manufacturer carries out this reaction at a temperature of 1200 K and a pressure of 10 atm. A scientist proposes that a temperature of 1000 K should be used at the same pressure.

Evaluate the effects of making this change on the rate and yield of this reaction.

(6)

(b) When this reaction is used in industry, the catalyst is an alloy of platinum and rhodium.

The diagram shows the reaction profile for the uncatalysed reaction.



(i) On the diagram, draw the reaction profile for the catalysed reaction.

(1)

(ii) Label the diagram to show

- the enthalpy change, $\Delta_r H$
- the activation energy, E_a

for the catalysed reaction.

(2)

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

(1)

(Total for Question 3 = 10 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>*6(a)</td>
<td>This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.
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</table>
</td>
<td>Guidance on how the mark scheme should be applied:

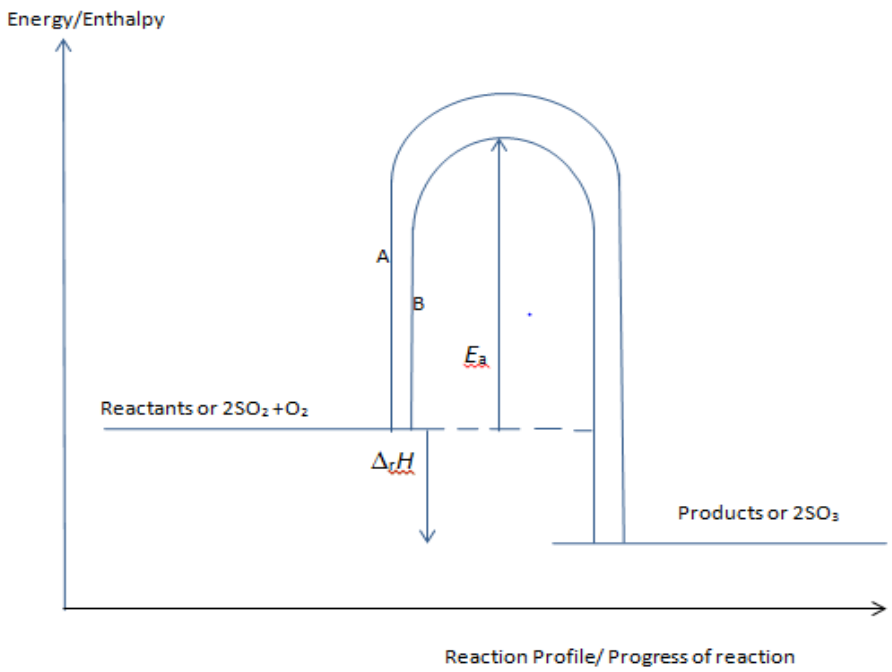
The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points that is partially structured with some linkages and lines of reasoning, scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).

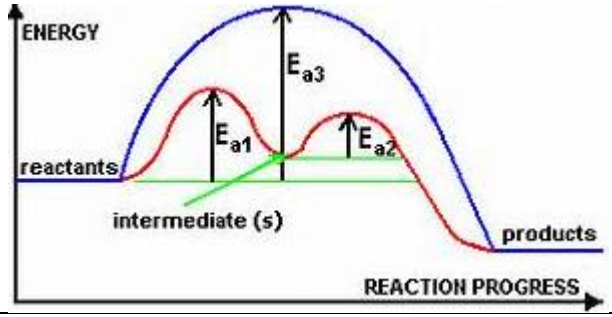
If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

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.

If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s).
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>

***6(a)**	**Indicative content:** • IP1 increase in temperature will increase rate • 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) • IP3 increase in temperature increases **energy** costs • IP4 increase in pressure has no effect on rate (because all the active sites are already occupied on a heterogeneous catalyst). **OR** increase in pressure will increase rate (of reaction) • IP5 increase in pressure will move position of eqm to RHS/increase yield **because** there are less moles/molecules (of gas) on the RHS • IP6 but increased pressure increases (construction and running) costs/reduces economic viability	Decreased yield with no reference to exothermic reaction does not get IP2. Allow increases yield of reactants/SO_2 **and** O_2 (with reference to exothermic reaction) Increased yield with no reference to number of moles does not get IP5. Award one mark for IP2 and IP5 if correct references to yield in both but reasons not given 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. Ignore any reference to catalyst	

Question Number	Acceptable Answer	Additional Guidance	Mark
6(b)(i)	• vertical axis labelled: H/enthalpy/energy/E **(1)** • level of reactants / $2SO_2 + O_2$ above level of products / $2SO_3$ **(1)**	 Do not award ΔH Ignore horizontal axis label Ignore units if given ignore state symbols even if incorrect	**(3)**

	• correct profile for uncatalysed reaction labelled A **and** peak lower for catalysed reaction labelled B **(1)**	allow vertical lines for catalysed and uncatalysed reactions to run together allow double hump profile  	

Question Number	Acceptable Answer	Additional Guidance	Mark
6(b)(ii)	enthalpy change, $\Delta_r H / \Delta H /$ (-)197(kJ mol^{-1}), shown correctly **(1)** activation energy, E_a, shown correctly (upper diagram) **(1)**	Ignore presence/absence of arrowheads Allow a degree of imprecision in the start/finish points of the lines for ΔH and E_a Ea shown on double hump profile - shown in this diagram as Ea_1 Ignore Ea2 if also shown	**(2)**

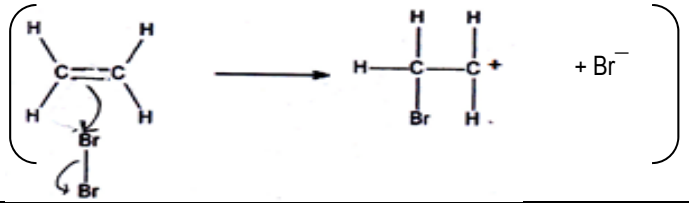
Question Number	Acceptable Answer	Additional Guidance	Mark
6(c)(i)	$(K_c =) \dfrac{[SO_3]^2}{[O_2][SO_2]^2}$	Do not award just K or K_p. must be square brackets do not accept partial pressures ignore units or lack of units ignore state symbols Allow x sign in the denominator but not +	**(1)**

Question Number	Answer	Mark
6(c)(ii)	**6(c)(ii). The only correct answer is B** ***A*** *is not correct because it refers to the inverted expression for* K_c ***C*** *is not correct because units do not cancel for concentration*^{2}*/concentration*^{3} ***D*** *is not correct because it refers to concentration*^{3}*/concentration or similar ratio of powers*	**(1)**

(Total for Question 6 = 13 marks)

Question Number	Answer	Mark
2(a)	**D** (*Z*-2-bromo-1-chloroprop-1-ene)	(1)

Question Number	Answer	Mark
2(b)(i)	**A** (electrophilic addition)	(1)

Question Number	Answer	Mark
2(b)(ii)	**C** 	(1)

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

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

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

(Total for Question 2 = 6 marks)

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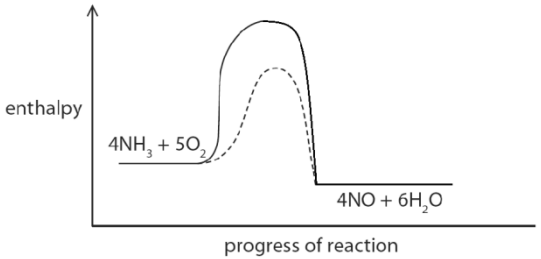
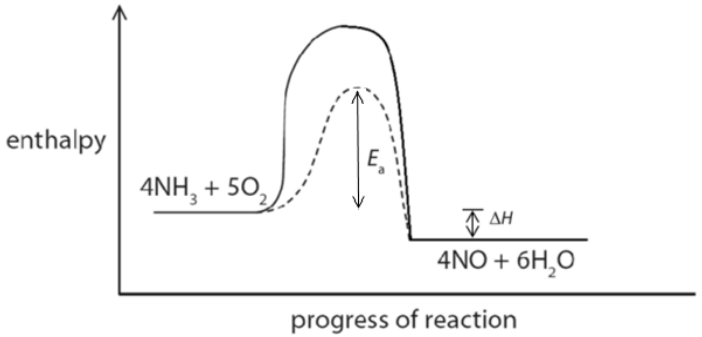
</table>

Indicative content:

• temperature decrease lowers the rate of the reaction
• because there are fewer molecules/particles with $E \geq E_a$
• <u>and</u> therefore there are fewer <u>successful</u> collisions <u>per second</u>
• temperature decrease increases the yield (of the product)
• because the (forward) reaction is exothermic
• lower rate and increased yield are opposing factors and it is not possible to tell which has greater effect on overall yield in a given time.</td><td>Accept slows down the reaction

Accept shifts the position of equilibrium to the right/in forward direction</td><td></td></tr>
</table>

Question Number	Answer	Additional Guidance	Mark
3(b)(i)	 • curve starting at reactants level, ending at products level, and peaking lower than original curve (1)		**1**
3(b)(ii)	 • $\Delta_r H$ shown as the approximately vertical distance between reactants and products (1) • E_a shown as the approximately vertical distance between reactants and peak of drawn curve for catalysed reaction (1)	ecf from candidate's curve	**2**
3(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**

(Total for Question 3 = 10 marks)