

**Q1.**

The rate of reaction is greater when a catalyst is used, without changing the temperature.

Which statement explains why the rate of reaction is greater with a catalyst?

- A** The collision frequency increases because the catalysed reaction has a lower activation energy.
- B** The collision frequency increases because there is an increase in the average energy of the particles.
- C** The proportion of successful collisions increases because the catalysed reaction has a lower activation energy.
- D** The proportion of successful collisions increases because there is an increase in the average energy of the particles.

**(Total 1 mark)**

**Q2.**

Which statement about catalysts used in reactions at equilibrium, at a constant temperature, is correct?

- A** They are always used in the solid state.
- B** They increase the rate of the forward reaction but decrease the rate of the reverse reaction.
- C** They have no effect on the value of the equilibrium constant.
- D** They make the forward reaction more exothermic.

**(Total 1 mark)**





Equation 1

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Equation 2

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(4)

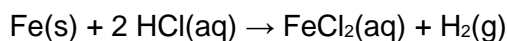
- (c) Give a reason why  $\text{Zn}^{2+}$  ions do **not** catalyse the reaction in part (b).

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(1)

- (d) Iron reacts with dilute hydrochloric acid to form iron(II) chloride and hydrogen.



A 0.998 g sample of pure iron is added to 30.0 cm<sup>3</sup> of 1.00 mol dm<sup>-3</sup> hydrochloric acid.

One of these reagents is in excess and the other reagent limits the amount of hydrogen produced in the reaction.

Calculate the maximum volume, in m<sup>3</sup>, of hydrogen gas produced at 30 °C and 100 kPa.

Give your answer to 3 significant figures.

In your answer you should identify the limiting reagent in the reaction.

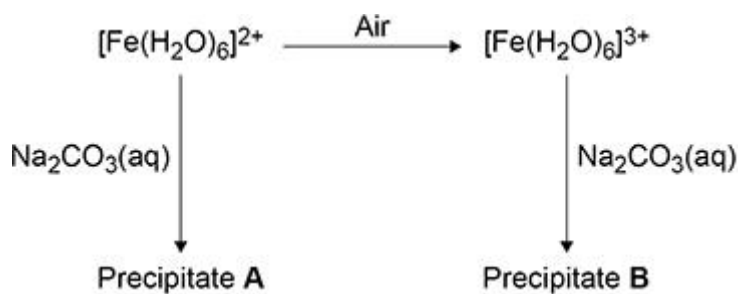
The gas constant,  $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

Volume of hydrogen \_\_\_\_\_ m<sup>3</sup>

(6)



The figure below shows some reactions of iron ions in aqueous solution.



- (e) Identify **A** and state its colour.

Identity \_\_\_\_\_

Colour \_\_\_\_\_

(2)

- (f) Give the formula of **B** and state its colour.

Give an ionic equation for the reaction of  $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$  with aqueous  $\text{Na}_2\text{CO}_3$  to form **B**.

Formula \_\_\_\_\_

Colour \_\_\_\_\_

Ionic equation

\_\_\_\_\_

(3)

- (g) Explain why an aqueous solution containing  $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$  ions has a lower pH than an aqueous solution containing  $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$  ions.

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\_\_\_\_\_

(3)

(Total 25 marks)

**Q4.**

Which statement about the addition of a catalyst to an equilibrium mixture is correct?

- A** The activation energy for the reverse reaction increases.
- B** The equilibrium constant for the forward reaction increases.
- C** The rate of the reverse reaction increases.
- D** The enthalpy change for the forward reaction decreases.

(Total 1 mark)

**Q5.**

Methanol ( $\text{CH}_3\text{OH}$ ) is an important alcohol with many uses.

- (a) Draw a diagram to show how two methanol molecules interact with each other through hydrogen bonding in the liquid phase.

Include all partial charges and all lone pairs of electrons in your diagram.

(3)

- (b) The bond angle around the oxygen atom in methanol is slightly smaller than the regular tetrahedral angle of  $109.5^\circ$

Explain why this bond angle is smaller than  $109.5^\circ$

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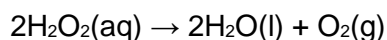
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(1)



**Q6.**

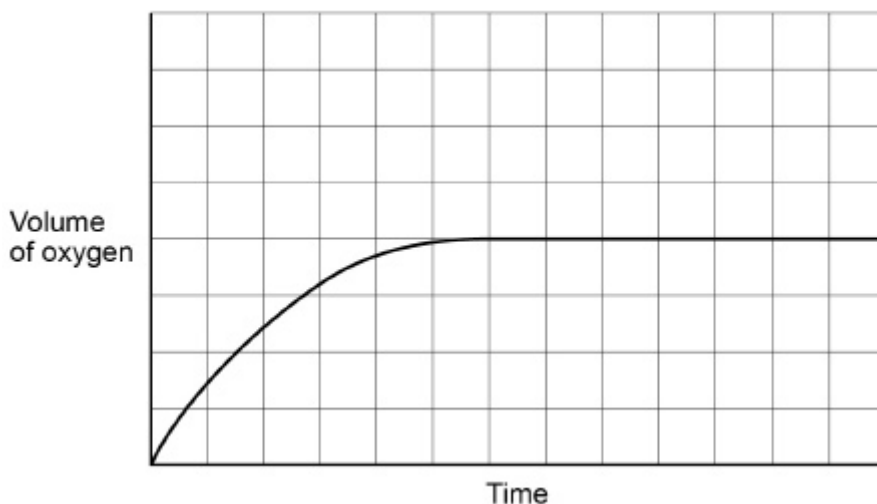
Hydrogen peroxide solution decomposes slowly to form water and oxygen.  
The reaction is much faster in the presence of a manganese(IV) oxide catalyst.



Three experiments, shown in the table, were carried out to investigate how the volume of oxygen produced varied over time under different conditions. The same mass of catalyst was used in each experiment.

Experiment	Concentration of $\text{H}_2\text{O}_2(\text{aq}) / \text{mol dm}^{-3}$	Volume of $\text{H}_2\text{O}_2(\text{aq}) / \text{cm}^3$	Temperature / $^\circ\text{C}$	Catalyst
1	1.0	50	20	lumps
2	1.0	50	20	powder
3	0.5	50	20	lumps

The graph shows how the volume of oxygen collected varied with time in Experiment 1.



- (a) Explain, in general terms, how a catalyst increases the rate of a reaction.

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(2)

- (b) Draw **two** lines on the graph to show how the volume of oxygen collected varied with time in Experiments 2 and 3.  
Label each line with the experiment number.

(2)



- (c) Explain, in terms of collision theory, the effect of increasing the concentration of hydrogen peroxide on the rate of reaction.

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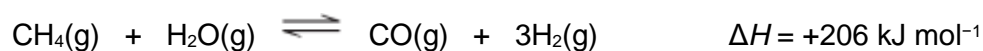
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(2)  
(Total 6 marks)

**Q7.**

Hydrogen is produced in industry from methane and steam in a two-stage process.

- (a) In the first stage, carbon monoxide and hydrogen are formed.  
The equation for this reaction is



- (i) Use Le Chatelier's principle to state whether a high or low temperature should be used to obtain the highest possible equilibrium yield of hydrogen from this first stage.  
Explain your answer.

Temperature \_\_\_\_\_

Explanation \_\_\_\_\_

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(3)



- (ii) Le Chatelier's principle suggests that a high pressure will produce a low yield of hydrogen in this first stage.

Explain, in terms of the behaviour of particles, why a high operating pressure is used in industry.

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(2)

- (iii) A nickel catalyst is used in the first stage.

Explain why the catalyst is more effective when coated onto an unreactive honeycomb.

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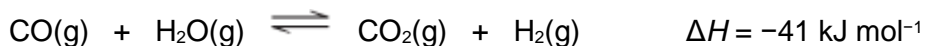
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(2)

- (b) The second stage is carried out in a separate reactor. Carbon monoxide is converted into carbon dioxide and more hydrogen is formed.

The equation for this reaction is



Use Le Chatelier's principle to state the effect, if any, of a **decrease** in the total pressure on the yield of hydrogen in this second stage. Explain your answer.

Effect \_\_\_\_\_

Explanation \_\_\_\_\_

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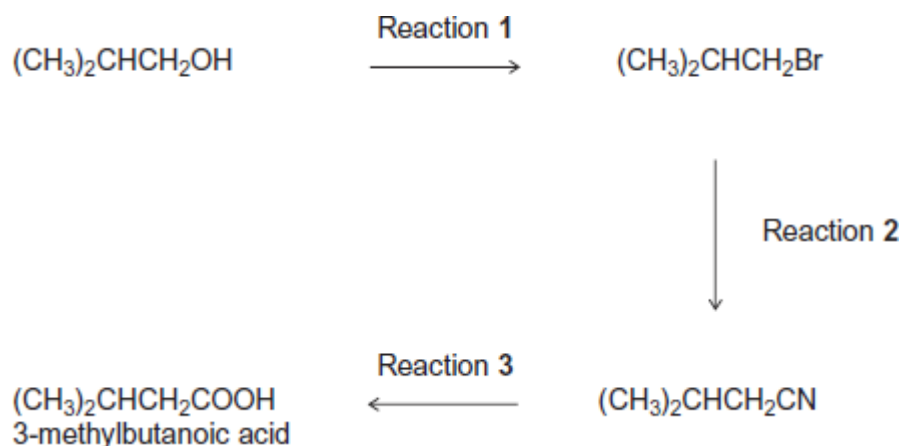
(2)

(Total 9 marks)



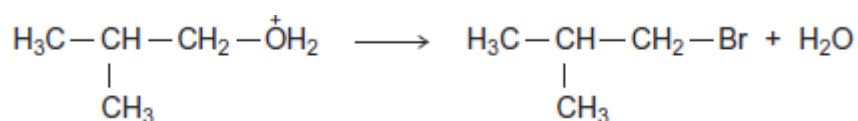
## Q8.

The carboxylic acid 3-methylbutanoic acid is used to make esters for perfumes. The following scheme shows some of the reactions in the manufacture of this carboxylic acid.



- (a) One of the steps in the mechanism for Reaction 1 involves the replacement of the functional group by bromine.
- (i) Use your knowledge of organic reaction mechanisms to complete the mechanism for this step by drawing **two** curly arrows on the following equation.

$\text{BF}_3$ :



(2)

- (ii) Deduce the name of the mechanism in part (i).

Give the IUPAC name of  $(\text{CH}_3)_2\text{CHCH}_2\text{Br}$

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(2)



- (b) Reaction 3 is an acid-catalysed reaction in which water is used to break chemical bonds when the CN functional group is converted into the COOH functional group. Infrared spectroscopy can be used to distinguish between the compounds in this reaction.

Deduce the name of the type of reaction that occurs in Reaction 3.

Identify **one** bond in  $(\text{CH}_3)_2\text{CHCH}_2\text{CN}$  and a **different** bond in  $(\text{CH}_3)_2\text{CHCH}_2\text{COOH}$  that can be used with infrared spectroscopy to distinguish between each compound.

For each of these bonds, give the range of wavenumbers at which the bond absorbs. Use **Table A** on the Data Sheet when answering this question.

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(3)

- (c) When 3-methylbutanoic acid reacts with ethanol in the presence of an acid catalyst, an equilibrium is established. The organic product is a pleasant-smelling ester.



The carboxylic acid is very expensive and ethanol is inexpensive. In the manufacture of this ester, the mole ratio of carboxylic acid to ethanol used is 1 to 10 rather than 1 to 1.

- (i) Use Le Chatelier's principle to explain why a 1 to 10 mole ratio is used. In your explanation, you should **not** refer to cost.

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(3)

- (ii) Explain how a catalyst increases the rate of a reaction.

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(2)

(Total 12 marks)



## Mark schemes

**Q1.**

C

*The proportion of successful collisions increases because the catalysed reaction has a lower activation energy.*

[1]

**Q2.**

C

*They have no effect on the value of the equilibrium constant.*

[1]

**Q3.**

(a)

This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.	
<b>Level 3</b> <b>5-6</b> <b>marks</b>	All stages are covered and the description of each stage is generally correct and virtually complete. Answer is communicated coherently and shows a logical progression from stage 1 to stage 2 and stage 3.
<b>Level 2</b> <b>3-4</b> <b>marks</b>	All stages are covered but the description of each stage may be incomplete or may contain inaccuracies <b>OR</b> two stages are covered and the explanations are generally correct and virtually complete. Answer is mainly coherent and shows progression from stage 1 to stage 2 and/or stage 3.
<b>Level 1</b> <b>1-2</b> <b>marks</b>	Two stages are covered but the description of each stage may be incomplete or may contain inaccuracies, <b>OR</b> only one stage is covered but the explanation is generally correct and virtually complete. Answer includes isolated statements and these are presented in a logical order.
<b>Level 0</b>	<b>0 marks</b> Insufficient correct chemistry to gain a mark.

Stage 1

1a Heterogeneous means in a different phase/state from reactants

1b Catalyst speeds up reaction and is left unchanged **OR** lowers the activation energy for the reaction

Stage 2

2a Hydrogen and nitrogen/reactants adsorb onto the surface/ active sites of the iron

2b Bonds weaken/reaction takes place



2c Products desorb/leave from the surface (of the iron)	
Stage 3	
3a Large surface area (of iron) by using powder or small pellets or support medium/mesh	
3b Catalyst poisoned / sulfur poisons or binds to the catalyst	
3c Active sites blocked	
Ignore references to temperature and pressure	6
(b) Two negative ions repel	1
So activation energy is high	1
$2 \text{Fe}^{2+} + \text{S}_2\text{O}_8^{2-} \rightarrow 2 \text{SO}_4^{2-} + 2 \text{Fe}^{3+}$	1
$2 \text{Fe}^{3+} + 2 \text{I}^- \rightarrow 2 \text{Fe}^{2+} + \text{I}_2$	
<i>Ignore any state symbols given</i>	
<i>Allow multiples for both equations</i>	
<i>Allow equations in either order</i>	1
(c) (Zn ions) have only one oxidation state	
Or	
Zn <sup>2+</sup> is the only ion	
<i>Allow doesn't have variable oxidation state</i>	
<i>Allow cannot be oxidised to Zn<sup>3+</sup></i>	
<i>Ignore has a full d shell</i>	1
(d) M1 Amount of Fe = $0.998 \div 55.8 = 0.0179 \text{ mol}$	1
M2 Amount of HCl = 0.0300 mol	1
M3 HCl is the limiting reagent	1
M4 Amount of H <sub>2</sub> produced = 0.0150 mol	
$M4 = M2 \div 2$	1
M5 T = 303 K P = 100 000 Pa	1
M6 $V \left( = \frac{0.0150 \times 8.31 \times 303}{100\,000} \right) = 3.78 \times 10^{-4} \text{ (m}^3\text{)}$	
$M6 \left( = \frac{M4 \times 8.31 \times 303}{100\,000} \right) \text{ (m}^3\text{)}$	1



(e)  $\text{FeCO}_3$  or iron(II) carbonate 1

Green

*Allow white*

1

(f)  $\text{Fe}(\text{H}_2\text{O})_3(\text{OH})_3$  1  
*Ignore square brackets if added*

brown

1



*Accept multiples*

1

(g) M1  $\text{Fe}^{3+}$  is smaller (than  $\text{Fe}^{2+}$ ) **OR**  $\text{Fe}^{3+}$  has a greater charge **OR**  $\text{Fe}^{3+}$  has a greater charge density **OR**  $\text{Fe}^{3+}$  has a greater charge to size ratio 1  
*Penalise  $\text{Fe}(\text{H}_2\text{O})_6^{3+}$  ions once in M1 or M2*

M2  $\text{Fe}^{3+}$  ions are more polarising **OR**  $\text{Fe}^{3+}$  ions polarise water molecules more 1

M3 So more O-H bonds (in the water ligands) break **OR** more  $\text{H}^+$  ions released **OR** weaken O-H bonds in ligands more (in the  $\text{Fe}^{3+}$  solution)

*Do not allow  $\text{Fe}^{3+}$  releases  $3\text{H}^+$  ions*

1

[25]

Q4.

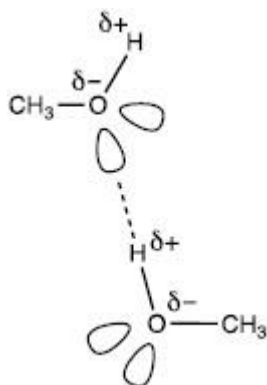
C

*The rate of the reverse reaction increases.*

[1]

Q5.

(a)



**M1** on at least one O atom two lone pairs and  
 on at least one OH  $\delta^+$  on H and  $\delta^-$  on O



1

**M2** dotted line shown between lone pair on one molecule and the correct H on another

1

**M3** O...H-O in straight line

1

*Accept pair of dots or crosses for lone pair in place of orbital shape (orbital shape may or may not include two electrons)*

*Ignore any partial charges on C-H or C-O bonds*

*For straight line in **M3**, allow a deviation of up to 15°*

*If a different molecule containing hydrogen bonding due to O-H bond drawn (e.g. ethanol, water) or an incorrect attempt at the structure of methanol, then maximum of 2 marks (i.e. only penalise if would score all three marks otherwise)*

(b) Idea that lone pairs have greater repulsion than bonding pairs

*There must be a comparison between the repulsion of a lone pair and bonding pair*

*Allow covalent bond = bonding pair*

1

(c)

This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.	
<b>Level 3</b> <b>5-6 marks</b>	<b>All stages are covered and the explanation of each stage is generally correct and virtually complete.</b> (6 v 5) Answer is well structured, with no repetition or irrelevant points, and covers all aspects of the question. Accurate and clear expression of ideas with no errors in use of technical terms.
<b>Level 2</b> <b>3-4 marks</b>	<b>All stages are covered but stage(s) may be incomplete or may contain inaccuracies OR two stages are covered and are generally correct and virtually complete</b> (4 v 3) Answer has some structure and covers most aspects of the question. Ideas are expressed with reasonable clarity with, perhaps, some repetition or some irrelevant points. If any, only minor errors in use of technical terms.
<b>Level 1</b> <b>1-2 marks</b>	<b>Two stages are covered but stage(s) may be incomplete or may contain inaccuracies OR only one stage is covered but is generally correct and virtually complete</b> (2 v 1) Answer includes statements which are presented in a logical order and/or linked.



<b>0 marks</b>	Insufficient correct chemistry to gain a mark.
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**Stage 1**

Describes the effect of catalyst use

1a use of a catalyst has no impact on equilibrium yield

1b use of a catalyst gives faster rate

1c use of catalyst lowers costs

**Stage 2**

Describes the effect of pressure

2a higher pressure gives a higher equilibrium yield

2b higher pressure gives a faster rate

2c the higher the pressure, the greater the cost

**Stage 3**

Describes the effect of temperature

3a lower temperature gives a higher equilibrium yield

3b higher temperature gives a faster rate

3c the higher the temperature, the greater the cost

Note that converse statements are fine (e.g. 1a higher temperature gives a lower equilibrium yield)

6

**[10]****Q6.**

- (a) **M1** provides a different route / mechanism / pathway  
*Ignore reference to (frequency of) collisions, surface area or active sites* 1
- M2** with lower activation energy  
*Penalise reference to increasing energy of particles ( $CE = 0$ )*  
*Allow  $E_a / E_{act}$  or definition of activation energy in **M2*** 1
- (b) **M1** line 2 = steeper than original and finishes at same height 1
- M2** line 3 = less steep than original and finishes at half the height  
*If two correct lines are drawn but neither labelled, then allow 1 mark.*  
*If two correct lines are drawn and only one is labelled, then allow 2 marks.*  
*If only one correct line is drawn and neither are labelled, then 0 marks.*  
*If two correct lines are drawn but line 2 is labelled 1 and line 3 is labelled 2, then allow 1 mark*  
*Allow some unevenness in drawing of lines in terms of height it levels off at, with up to a quarter of a box of unevenness*  
*At the start, lines must separate from the original before the first vertical line.*  
*In terms of the origin, lines must start within one half of a square of*



*the origin.*

*For each line ignore the time at which the line becomes horizontal – it is the fact it is more or less steep than the original line that matters (along with the height at which it finishes)*

1

- (c) **M1** more particles/molecules/reactants/H<sub>2</sub>O<sub>2</sub>/moles in given/same volume/space OR particles/molecules/reactants/H<sub>2</sub>O<sub>2</sub>/moles closer together

*Penalise reference to changing the activation energy (CE = 0)*

*For **M1** do not allow area*

1

- M2** successful collisions are more frequent

*For **M2***

*successful collisions – allow reference to collisions with sufficient energy or collisions with the activation energy or effective collisions*

*more frequent – allow reference to per unit time, per second (but ignore reference to rate of collisions, ignore chance of collisions, ignore likelihood of collisions)*

1

[6]

### Q7.

- (a) (i) **M1**  
High (temperature) OR Increase (the temperature)

*If **M1** is incorrect **CE = 0** for the clip*

*If **M1** is blank, mark on and seek to **credit the correct information in the text***

**M2**

The (forward) reaction / to the right is endothermic or takes in / absorbs heat  
**OR**

The reverse reaction / to the left is exothermic or gives out / releases heat

**M3 depends on correct M2 and must refer to temperature / heat**

***M3** depends on a correct statement for **M2***

At high temperature, the (position of ) equilibrium shifts / moves left to right to oppose the increase in temperature

*For **M3**, the position of equilibrium shifts / moves*

*to absorb heat OR*

*to lower the temperature OR*

*to cool down the reaction*

3

- (ii) **M1**  
The reaction gets to equilibrium faster / in less time  
**OR**

Produces a small yield faster / in less time

**OR**

Increases the rate (of reaction / of attainment of equilibrium)



Mark independently

**M2**

High pressure leads to **one** of the following

- more particles / molecules in a given volume
- particles / they are closer together
- higher concentration of particles / molecules

**AND**

- more collisions in a given time / increased collision frequency

Penalise **M2** for reference to increased energy of the particles

2

(iii) **M1** Increase in / more / large(r) / big(ger) surface area / surface sites

Mark independently

For **M1** accept "Éan increase in surface"

**M2** increase in / more successful / productive / effective collisions (in a given time) (on the surface of the catalyst / with the nickel)

For **M2** not simply "more collisions"

Ignore "the chance or likelihood" of collisions

2

(b) **M1**

No effect / None

If **M1** is incorrect **CE = 0** for the clip

If **M1** is blank, mark on and seek to **credit the correct information in the text**

**M2 requires a correct M1**

Equal / same number / amount of moles / molecules / particles on either side of the equation

**OR**

2 moles / molecules / particles on the left and 2 moles / molecules / particles on the right

**M2** depends on a correct statement for **M1**

In **M2** not "atoms"

2

[9]

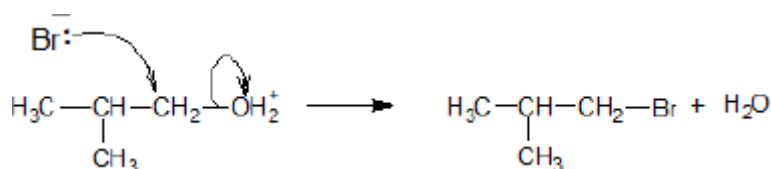
**Q8.**

(a) (i) **M1** double-headed curly arrow from the lone pair of the bromide ion to the C atom of the CH<sub>2</sub>

Penalise additional arrows.

**M2** double-headed arrow from the bond to the O atom

As follows



2

(ii) **M1** nucleophilic substitution**M1** both words needed (allow phonetic spelling).**M2** 1-bromo(-2-)methylpropane**M2** Require correct spelling in the name but ignore any hyphens or commas.

2

(b) **M1** hydrolysisFor **M1** give credit for 'hydration' on this occasion only.**M2** C≡N with absorption range 2220–2260 (cm<sup>-1</sup>)Credit 1 mark from **M2** and **M3** for identifying C≡N **and** either O–H(acids) **or** C=O **or** C–O without reference to wavenumbers or with incorrect wavenumbers.**M3** O–H(acids) with absorption range 2500–3000 (cm<sup>-1</sup>)**OR**C=O with absorption range 1680–1750 (cm<sup>-1</sup>)**OR**C–O with absorption range 1000–1300 (cm<sup>-1</sup>)Apply the list principle to **M3**

3

(c) (i) **M1** Yield / product **OR** ester increases / goes up / gets more**M2** (By Le Chatelier's principle) the position of equilibrium is driven / shifts / moves to the right / L to R / in the forward direction / to the product(s)**M3** – requires a correct statement in **M2**

(The position of equilibrium moves)

to oppose the increased concentration of ethanolto oppose the increased moles of ethanolto lower the concentration of ethanolto oppose the change and decrease the ethanolIf no reference to **M1**, marks **M2** and **M3** can still score BUT if **M1** is incorrect CE=0If there is reference to 'pressure' award **M1** ONLY.

3



(ii) **M1**

Catalysts provide an alternative route / pathway / mechanism

**OR**

surface adsorption / surface reaction occurs

*For **M1**, not simply 'provides a surface' as the only statement.*

***M1** may be scored by reference to a specific example.*

**M2**

that has a lower / reduced activation energy

**OR**

lowers / reduces the activation energy

*Penalise **M2** for reference to an increase in the energy of the molecules.*

*For **M2**, the student may use a definition of activation energy without referring to the term.*

*Reference to an increase in successful collisions in unit time alone is not sufficient for **M2** since it does not explain why this has occurred.*

2

[12]