

## Mark schemes

1

(a) Bonds broken =  $2(\text{C}=\text{O}) + 3(\text{H}-\text{H}) = 2 \times 743 + 3 \times \text{H}-\text{H}$

Bonds formed =  $3(\text{C}-\text{H}) + (\text{C}-\text{O}) + 3(\text{O}-\text{H}) = 3 \times 412 + 360 + 3 \times 463$

*Both required*

1

$$-49 = [2 \times 743 + 3 \times (\text{H}-\text{H})] - [3 \times 412 + 360 + 3 \times 463]$$

$$3(\text{H}-\text{H}) = -49 - 2 \times 743 + [3 \times 412 + 360 + 3 \times 463] = 1450$$

*Both required*

1

$$\text{H}-\text{H} = 483 \text{ (kJ mol}^{-1}\text{)}$$

*Allow 483.3(3)*

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- (b) Mean bond enthalpies are not the same as the actual bond enthalpies in  $\text{CO}_2$  (and / or methanol and / or water)

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- (c) The carbon dioxide (produced on burning methanol) is used up in this reaction

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- (d) 4 mol of gas form 2 mol

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At high pressure the position of equilibrium moves to the right to lower the pressure / oppose the high pressure

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This increases the yield of methanol

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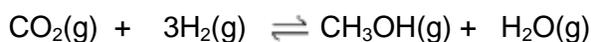
- (e) Impurities (or sulfur compounds) block the active sites

*Allow catalyst poisoned*

1

- (f) Stage 1: moles of components in the equilibrium mixture

*Extended response question*



Initial moles	1.0	3.0	0	0
Eqm moles	$(1-0.86)$ = 0.14	$(3-3 \times 0.86)$ = 0.42	0.86	0.86

1

Stage 2: Partial pressure calculations

Total moles of gas = 2.28

Partial pressures = mol fraction  $\times$   $p_{\text{total}}$

1

$$p_{\text{CO}_2} = \text{mol fraction} \times p_{\text{total}} = 0.14 \times 500 / 2.28 = 30.7 \text{ kPa}$$

$$p_{\text{H}_2} = \text{mol fraction} \times p_{\text{total}} = 0.42 \times 500 / 2.28 = 92.1 \text{ kPa}$$

*M3 is for partial pressures of both reactants*

*Alternative M3 =*

$$pp_{\text{CO}_2} = 0.0614 \times 500$$

$$pp_{\text{H}_2} = 0.1842 \times 500$$

1

$$p_{\text{CH}_3\text{OH}} = \text{mol fraction} \times p_{\text{total}} = 0.86 \times 500 / 2.28 = 188.6 \text{ kPa}$$

$$p_{\text{H}_2\text{O}} = \text{mol fraction} \times p_{\text{total}} = 0.86 \times 500 / 2.28 = 188.6 \text{ kPa}$$

*M4 is for partial pressures of both products*

*Alternative M4 =*

$$pp_{\text{CH}_3\text{OH}} = 0.3772 \times 500$$

$$pp_{\text{H}_2\text{O}} = 0.3772 \times 500$$

1

Stage 3: Equilibrium constant calculation

$$K_p = p_{\text{CH}_3\text{OH}} \times p_{\text{H}_2\text{O}} / p_{\text{CO}_2} \times (p_{\text{H}_2})^3$$

1

$$\text{Hence } K_p = 188.6 \times 188.6 / 30.7 \times (92.1)^3 = 1.483 \times 10^{-3} = 1.5 \times 10^{-3}$$

*Answer must be to 2 significant figures*

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Units = kPa<sup>-2</sup>

1

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2

(a) Start a clock when KCl is added to water

1

Record the temperature every subsequent minute for about 5 minutes

*Allow record the temperature at regular time intervals until some time after all the solid has dissolved for M2*

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Plot a graph of temperature vs time

1

Extrapolate back to time of mixing = 0 and determine the temperature

1

(b) Heat taken in =  $m \times c \times \Delta T = 50 \times 4.18 \times 5.4 = 1128.6 \text{ J}$

*Max 2 if 14.6 °C used as  $\Delta T$*

1

$$\text{Moles of KCl} = 5.00 / 74.6 = 0.0670$$

1

$$\text{Enthalpy change per mole} = +1128.6 / 0.0670 = 16\,839 \text{ J mol}^{-1}$$

1

$$= +16.8 \text{ (kJ mol}^{-1}\text{)}$$

*Answer must be given to this precision*

1

- (c)  $\Delta H_{\text{solution}} = \Delta H_{\text{lattice}} + \Delta H(\text{hydration of calcium ions}) + 2 \times \Delta H(\text{hydration of chloride ions})$

$$\Delta H_{\text{lattice}} = \Delta H_{\text{solution}} - \Delta H(\text{hydration of calcium ions}) - 2 \times \Delta H(\text{hydration of chloride ions})$$

1

$$\Delta H_{\text{lattice}} = -82 - 9 - (-1650 + 2 \times -364) = +2295 \text{ (kJ mol}^{-1}\text{)}$$

1

- (d) Magnesium ion is smaller than the calcium ion

1

Therefore, it attracts the chloride ion more strongly / stronger ionic bonding

1

[12]

3

- (a) (i)  $2\text{C}_6\text{H}_{12}\text{O}_6 \longrightarrow 3\text{CH}_3\text{COCH}_3 + 3\text{CO}_2 + 3\text{H}_2\text{O}$

*Or multiples*

1

- (ii) to speed up the reaction

**OR**

(provide a) catalyst or catalyses the reaction or biological catalyst

**OR**

release / contain / provides an enzyme

*Ignore "fermentation"*

*Ignore "to break down the glucose"*

*Not simply "enzyme" on its own*

1

- (b) (i)  $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3 + [\text{O}] \longrightarrow \text{CH}_3\text{COCH}_3 + \text{H}_2\text{O}$

*Any correct representation for the two organic structures. Brackets not essential.*

*Not "sticks" for the structures in this case*

1

- (ii) Secondary (alcohol) OR 2° (alcohol)

1

(c) **M1**  $q = m c \Delta T$

**OR**  $q = 150 \times 4.18 \times 8.0$

*Award full marks for correct answer*

*In **M1**, do not penalise incorrect cases in the formula*

**M2** = ( $\pm$ ) 5016 (J) **OR** 5.016 (kJ) **OR** 5.02 (kJ)  
(also scores M1)

**M3** This mark is for dividing correctly the number of kJ by the number of moles and arriving at a final answer in the range shown.  
Using 0.00450 mol

therefore  $\Delta H = - \underline{1115}$  (kJ mol<sup>-1</sup>)

**OR**  $- \underline{1114.6}$  to  $- \underline{1120}$  (kJ mol<sup>-1</sup>)

**Range (+)1114.6 to (+)1120 gains 2 marks**

**BUT – 1110 gains 3 marks and +1110 gains 2 marks**

**AND – 1100 gains 3 marks and +1100 gains 2 marks**

*Award full marks for correct answer*

*In **M1**, do not penalise incorrect cases in the formula*

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect;*

**(+)1114.6 to (+)1120 gains 2 marks**

*Penalise **M2** for arithmetic error and mark on*

*If  $\Delta T = 281$ ; score  $q = m c \Delta T$  only*

*If  $c = 4.81$  (leads to 5772) penalise **M2** ONLY and mark on for **M3** =  
– 1283*

*Ignore incorrect units in **M2***

*If units are given in **M3** they must be either kJ or kJ mol<sup>-1</sup> in this case*

3

(d) **M1** The enthalpy change / heat change at constant pressure when  
1 mol of a compound / substance / element

**M2** is burned / combusts / reacts completely in oxygen

**OR**

burned / combusted / reacted in excess oxygen

**M3** with (all) reactants and products / (all) substances in standard /  
specified states

**OR**

(all) reactants and products / (all) substances in normal states under standard  
conditions / 100 kPa / 1 bar and specified T / 298 K

*For **M3***

*Ignore reference to 1 atmosphere*

3

(e) **M1**

$$\underline{\sum B(\text{reactants}) - \sum B(\text{products}) = \Delta H}$$

**OR**

$$\underline{\text{Sum of bonds broken} - \text{Sum of bonds formed} = \Delta H}$$

**OR**

$$2B(\text{C-C}) + B(\text{C=O}) + 6B(\text{C-H}) + 4B(\text{O=O}) \text{ (LHS)}$$

$$- 6B(\text{C=O}) - 6B(\text{O-H}) \text{ (RHS)} = \underline{\Delta H}$$

**M2** (also scores **M1**)

$$2(348) + 805 + 6(412) + 4(496) \text{ [LHS} = \mathbf{5957}]$$

$$(696) \quad (2472) \quad (1984)$$

$$- 6(805) - 6(463) \text{ [RHS} = \mathbf{(-) 7608}] = \Delta H$$

$$(4830) \quad (2778)$$

**OR** using only bonds broken and formed (**5152 - 6803**)

**M3**

$$\Delta H = \underline{-1651} \text{ (kJ mol}^{-1}\text{)}$$

**Candidates may use a cycle and gain full marks.**

*Correct answer gains full marks*

*Credit 1 mark for (+) 1651 (kJ mol<sup>-1</sup>)*

*For other incorrect or incomplete answers, proceed as follows*

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication / addition error; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with 4O<sub>2</sub>, 3CO<sub>2</sub> and 3H<sub>2</sub>O OR a clear statement of **M1** which could be in words and scores **only M1***

*Allow a maximum of one mark if the only scoring point is LHS = 5957 (or 5152) OR RHS = 7608 (or 6803)*

*Award 1 mark for + 1651*

(f) **For the two marks M1 and M2, any two from**

- heat loss or not all heat transferred to the apparatus or heat absorbed by the apparatus or (specific) heat capacity of the apparatus not considered
- incomplete combustion / not completely burned / reaction is not complete
- The idea that the water may end up in the gaseous state (rather than liquid)
- reactants and / or products may not be in standard states.
- MBE data refers to gaseous species but the enthalpy of combustion refers to liquids in their standard states / liquid propanone and liquid water in standard states
- MBE do not refer to specific compounds OR MBE values vary with different compounds / molecules OR are average / mean values taken from a range of compounds / molecules

*Apply the list principle but ignore incomplete reasons that contain correct chemistry*

*Ignore "evaporation"*

*Ignore "faulty equipment"*

*Ignore "human error"*

*Not enough simply to state that "MBE are mean / average values"*

2

[15]

4

(a) **M1 (could be scored by a correct mathematical expression)**

**M1**  $\Delta H = \sum \Delta H_f(\text{products}) - \sum \Delta H_f(\text{reactants})$

**OR** a correct cycle of balanced equations

**M2** =  $5(-635) - (-1560)$

=  $-3175 + 1560$

(This also scores M1)

**M3** = **-1615** (kJ mol<sup>-1</sup>)

Award 1 mark **ONLY** for (+) 1615

*Correct answer to the calculation gains all of **M1**, **M2** and **M3***

*Credit 1 mark for (+) 1615 (kJ mol<sup>-1</sup>)*

*For other incorrect or incomplete answers, proceed as follows*

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with  $V_2O_5$  and  $5CaO$  **OR** a clear statement of **M1** which could be in words and scores **only M1***

**M4** **Type of reaction is**

- reduction
- redox
- (or accept)  $V_2O_5$  / it / V(V) has been reduced  
*In **M4** not "vanadium / V is reduced"*

**M5** **Major reason for expense of extraction – the answer must be about calcium**

Calcium is produced / extracted by electrolysis

**OR** calcium is expensive to extract

**OR** calcium extraction uses electricity

**OR** calcium extraction uses large amount of energy

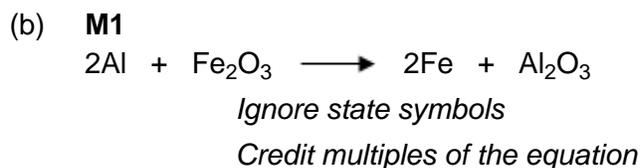
**OR** calcium is a (very) reactive metal / reacts with water or air

**OR** calcium needs to be extracted / does not occur native

**QoL**

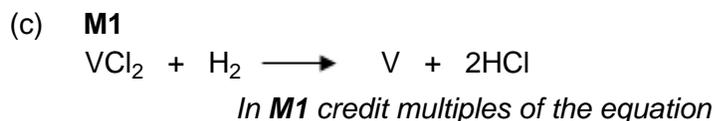
*Accept calcium is expensive "to produce" but not "to source, to get, to obtain, to buy" etc.*

*In **M5** it is neither enough to say that calcium is "expensive" nor that calcium "must be purified"*



**M2**  
 (Change in oxidation state) 0 to (+)3  
**OR**  
 (changed by) +3  
*In M2 if an explanation is given it must be correct and unambiguous*

2



**M2 and M3**  
 Two hazards in either order

- HCl / hydrogen chloride / hydrochloric acid is acidic / corrosive / toxic / poisonous
- Explosion risk with hydrogen (gas) OR H<sub>2</sub> is flammable

*For M2 / M3 there must be reference to hydrogen; it is not enough to refer simply to an explosion risk*  
*For M2 / M3 with HCl hazard, require reference to acid(ic) / corrosive / toxic only*

**M4**  
 The only other product / the HCl is easily / readily removed / lost / separated because it is a gas OR will escape (or this idea strongly implied) as a gas  
**OR** vanadium / it is the only solid product (and is easily separated)  
**OR** vanadium / it is a solid and the other product / HCl is a gas  
*In M4 it is not enough to state simply that HCl is a gas, since this is in the question.*

4  
 [11]

**5** Increase in volume  
*If a volume is quoted it must be less than 300*

1

Smaller increase in T above room temperature  
 Or increased contact between calorimeter and water  
 Or smaller heat loss by evaporation / from the surface

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 [2]

**6**

- (a) The enthalpy (change) to break
- 1 mol
- of H—O / bonds

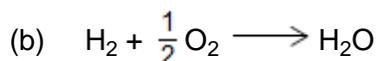
*Allow heat energy*

1

Averaged over a range of compounds / molecules

*Penalise energy but mark on**ignore states**CE = 0 for ionic bonds*

1



$$\Delta H = (\text{H-H}) + \frac{1}{2} (\text{O}=\text{O}) - 2(\text{H-O}) / \text{sum of (bonds broken)} - \text{sum of (bonds formed)}$$

1

$$= 436 + 496 / 2 - 2 \times 464$$

1

$$= -244 \text{ (kJ mol}^{-1}\text{)}$$

*Allow 1 mark only for +244 and -488**Units not essential but penalise incorrect units*

1

- (c) (i) same reaction / same equation / same number / same reactants and same products / same number and type of bonds broken and formed

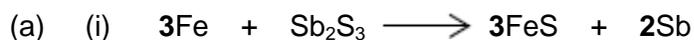
*Do not allow similar*

1

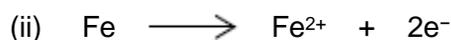
- (ii) There must be a slight difference between the actual bond enthalpy (in water) and mean bond enthalpies for the O—H bond (in other molecules)

*Allow bond enthalpy value for enthalpy of formation may not be under standard conditions.**Allow reference to bond energy rather than bond enthalpy**Do not allow heat loss or experimental error**Do not allow mean bond enthalpies are not accurate*

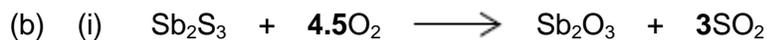
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**[7]****7***Or multiples.**Ignore state symbols.*

1

*Ignore charge on the electron unless incorrect.**Or multiples.**Credit the electrons being subtracted on the LHS.**Ignore state symbols.*

1



Or multiples.

Ignore state symbols.

1

(ii)  $\text{SO}_3$  or sulfur trioxide / sulfur (VI) oxide

Credit also the following ONLY.

$\text{H}_2\text{SO}_4$  or sulfuric acid.

**OR**

Gypsum /  $\text{CaSO}_4$  or plaster of Paris.

1

(c) (i) **M1 (could be scored by a correct mathematical expression)**

Correct answer gains full marks.

**M1**  $\Delta H_r = \Sigma \Delta H_f(\text{products}) - \Sigma \Delta H_f(\text{reactants})$

**OR** a correct cycle of balanced equations / correct numbers of moles

Credit 1 mark for +104 ( $\text{kJ mol}^{-1}$ ).

**M2**  $= 2(+20) + 3(-394) - (-705) - 3(-111)$

$= 40 - 1182 + 705 + 333$

$= -1142 - (-1038)$

(This also scores M1)

**M3**  $= \underline{-104}$  ( $\text{kJ mol}^{-1}$ )

**(Award 1 mark ONLY for + 104)**

For other incorrect or incomplete answers, proceed as follows:

- Check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks.
- If no AE, check for a correct method; this requires either a correct cycle with 3CO, 2Sb and 3CO<sub>2</sub> OR a clear statement of **M1** which could be in words and scores **only M1**.

3

(ii) It / Sb is not in its standard state

**OR**

Standard state (for Sb) is solid / (s)

**OR**

(Sb) liquid is not its standard state

*Credit a correct definition of standard state as an alternative to the words 'standard state'.*

**QoL**

1

(iii) Reduction **OR** reduced **OR** redox

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(d) Low-grade ore extraction / it

- uses (cheap) scrap / waste iron / steel
- is a single-step process

uses / requires less / low(er) energy

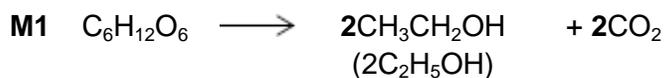
*Ignore references to temperature / heat or labour or technology.*

1

**[10]**

**8**

(a)



*Penalise C<sub>2</sub>H<sub>6</sub>O for ethanol in M1.*

**M2 and M3**

*Mark M2 and M3 independently.*

Any **two** conditions in any order for **M2** and **M3** from

- (enzymes from) yeast or zymase
- 25 °C ≤ T ≤ 42 °C OR 298 K ≤ T ≤ 315 K
- anaerobic / no oxygen / no air OR neutral pH

*A lack of oxygen can mean either without oxygen or not having enough oxygen and does not ensure no oxygen, therefore only credit "lack of oxygen" if it is qualified.*

*Penalise 'bacteria', 'phosphoric acid', 'high pressure' using the list principle.*

**M4** (fractional) distillation or GLC

*Ignore reference to 'aqueous' or 'water' (ie not part of the list principle).*

**M5** Carbon-neutral **in this context** means

There is no net / overall (annual) carbon dioxide / CO<sub>2</sub> emission to the atmosphere

**OR**

There is no change in the total amount / level of carbon dioxide / CO<sub>2</sub> present in the atmosphere

*For M5 – must be about CO<sub>2</sub> and the atmosphere.*

*The idea that the carbon dioxide / CO<sub>2</sub> given out equals the carbon dioxide / CO<sub>2</sub> that was taken in from the atmosphere.*

- (b) **M1**  $q = m c \Delta T$  (this mark for correct mathematical formula)  
*Full marks for **M1**, **M2** and **M3** for the correct answer.*  
*In **M1**, do not penalise incorrect cases in the formula.*

**M2** =  $(75 \times 4.18 \times 5.5)$

1724 (J) **OR** 1.724 (kJ) **OR** 1.72 (kJ) **OR** 1.7 (kJ)

(also scores **M1**)

*Ignore incorrect units in **M2**.*

**M3** Using 0.0024 mol

therefore  $\Delta H = \underline{-718}$  (kJ mol<sup>-1</sup>)

(Accept a range from -708 to -719 but do not penalise more than 3 significant figures)

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect.*  
*Therefore **+718** gains two marks.*

*If units are quoted in **M3** they must be correct.*

*If  $\Delta T = 278.5$ , CE for the calculation and penalise **M2** and **M3**.*

**M4** and **M5** in any order

Any **two** from

- incomplete combustion
- heat loss
- heat capacity of Cu not included
- some ethanol lost by evaporation
- not all of the  $(2.40 \times 10^{-3} \text{ mol})$  ethanol is burned / reaction is incomplete  
*If  $c = 4.81$  (leads to 1984) penalise **M2** ONLY and mark on for **M3** = - 827*

5

- (c) (i) **M1** enthalpy / heat / energy change (at constant pressure) or enthalpy / heat / energy needed in breaking / dissociating (a) covalent bond(s)  
*Ignore bond making.*

**M2** averaged for that type of bond over different / a range of molecules / compounds

*Ignore reference to moles.*

2

(ii) **M1**

$$\underline{\sum B(\text{reactants})} - \underline{\sum B(\text{products})} = \underline{\Delta H}$$

**OR**

$$\underline{\text{Sum of bonds broken}} - \underline{\text{Sum of bonds formed}} = \underline{\Delta H}$$

**OR**

$$B(\text{C-C}) + B(\text{C-O}) + B(\text{O-H}) + 5B(\text{C-H}) + 3B(\text{O=O}) \\ - 4B(\text{C=O}) - 6B(\text{O-H}) = \Delta H = -1279$$

*Correct answer gains full marks.*

*Credit **1 mark for - 496** (kJ mol<sup>-1</sup>)*

*For other incorrect or incomplete answers, proceed as follows*

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**).*

*If no AE, check for a correct method; this requires either a correct cycle with 2CO<sub>2</sub> and 3H<sub>2</sub>O OR a clear statement of **M1** which could be in words and scores only M1.*

**M2** (also scores **M1**)

$$348+360+463+5(412)+ 3B(\text{O=O})$$

$$(3231) \quad (\text{or } 2768 \text{ if O-H cancelled})$$

$$- 4(805) - 6(463) = \Delta H = - 1279$$

$$(5998) \quad (\text{or } 5535 \text{ if O-H cancelled})$$

$$3B(\text{O=O}) = \underline{1488} \text{ (kJ mol}^{-1}\text{)}$$

*Credit a maximum of one mark if the only scoring point is bonds formed adds up to **5998** (or **5535**) OR bonds broken includes the calculated value of **3231** (or **2768**).*

**M3**

$$B(\text{O=O}) = \underline{496} \text{ (kJ mol}^{-1}\text{)}$$

Award 1 mark for -496

**Students may use a cycle and gain full marks**