Mark schemes

1   (a)   M1   (q = mcΔT = 100 × 4.18 × 38(.0))
               = 15 884 / 15 880 / 15 900 / 16 000 (J)
               (OR 15.884 / 15.88 / 15.9 / 16 (kJ))

                 Award full marks for correct answer

                 Mark is for value not expression (at least 2sf); penalise incorrect
                 units here only if M1 is the only potential scoring point in M1-M3

                 1

          M2   Moles (methanol = 1.65 / 32.0) = 0.0516 or 0.052

                 At least 2sf

                 1

          M3   Heat change per moles = M1/M2
               (15 884 / 0.0516 / 1000 = 308 (kJ mol^{-1}))
               (allow 305 to 310)

                 At least 2sf; answer must be in kJ mol^{-1}

                 1

          M4   Answer = −308 (kJ mol^{-1}) (allow −305 to −310)

                 This mark is for – sign (mark independently)

                 1

   (b)   Heating up copper / calorimeter / container / thermometer /
heat capacity of copper / calorimeter / thermometer not taken into account
OR
Evaporation of alcohol/methanol
OR
Experiment not done under standard conditions

                 Not human errors (e.g. misreading scales)

                 Not impure methanol

                 Allow evaporation of water

                 1

   (c)   (100 × 0.5 / 38 =) 1.3 or 1.32 or 1.316% (minimum 2 sf)

                 Allow correct answer to at least 2sf;

                 Allow 1.31 or 1.315%

                 1

   (d)   Idea that heat loss is more significant issue OR
Idea that temperature <u>change/rise</u> is (significantly / much)
bigger than uncertainty

                 One of these two ideas only and each one must involve a
                 comparison

                 1

(e)   M1   Mass of ethanol = 500 × 0.789 (= 394.5 or 395 (g))

1

M2   Moles of ethanol = M1 / 46.0 (= 8.576 or 8.58)

1

M3   Heat released = M2 × 1371 = 11800 (kJ) must be 3 sf

1

Correct answer to 3sf scores 3; correct value to 2sf or more than 3sf scores 2

Answers that are a factor of 10^x out score 2 if given to 3sf or 1 if given to a different number of sf

M3 ignore units, but penalise incorrect units

M3 ignore sign

M2 and M3 – allow consequential marking

[10]

2   B

[1]

3   (a)   The <u>enthalpy / heat energy change</u> when <u>1 mol</u> (of a substance)

If enthalpy of formation definition given CE=O

NOT *just 'energy'*

ALLOW *alternatives for substance e.g. molecule/compound /element*

1

Is <u>burned/reacts completely in oxygen</u>

ALLOW *reacts in excess oxygen*

1

With all reactants and products in their <u>standard states</u>
OR
With all reactants and products in their normal states at 298K/given temp & 100kPa

ALLOW *'everything' for 'reactants and products'*

Penalise incorrect conditions if given

ALLOW *'normal states under standard conditions'*

1

(b) $\Delta H = \Sigma\Delta H_C(\text{reactants}) - \Sigma\Delta H_C \text{ (products)}$
OR
Correctly and fully balanced cycle

Correct answer scores 3

1

$\Delta H = [3(-394) + 4(-286)] - (-2010)$
OR
$\Delta H = -2326 + 2010$

M2 also scores M1

1

$\Delta H = -316 \text{ (kJ mol}^{-1})$
+316 scores 1 mark only

> ***IGNORE** units*
>
> *Check for AE in working – can award M3 as ecf (error carried forward) from M2 if M2 not given due to AE*

1

(c) $\Delta H/-1893 = \Sigma B(\text{reactants}) - \Sigma B(\text{products})$
OR
$\Delta H/-1893 = \Sigma\text{Bonds broken} - \Sigma\text{Bonds formed}$
OR
$\Delta H/-1893 = 2B(C\text{-}C) + 7B(C\text{-}H) + B(C\text{-}O) + B(O\text{-}H) + 4\frac{1}{2} B(O=O) - 6B(C=O) - 8B(O\text{-}H)$

Correct answer scores 3

1

$-1893 = 2B(C\text{-}C) + 7(412) + 360 + 463 + 4\frac{1}{2}(496) - 6(805) - 8(463)$
OR
$-1893 = 2B(C\text{-}C) +5939 - 8534$
OR
$-1893 = 2B(C\text{-}C) -2595$
OR
$2B(C\text{-}C) = 702$

> *M2 also scores M1*
>
> *May see no 463 in bonds broken and 7x463 in made (gives 5476 – 8071)*

1

$B(C\text{-}C) = (+)351(\text{kJ mol}^{-1})$

> *If **NOT** 351 check for AE. This would lose M2, but could gain M1 and M3*
>
> *(+)234 scores 1 (due to 3(C-C))*
>
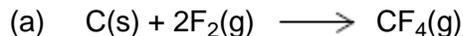> ***NOT** M3 from incorrect M2 unless incorrect M2 is due to AE*
>
> ***IGNORE** units*
>
> *If no other mark awarded then*
>
> ***ALLOW** 1 if 5939 or 5476 or 8534 or 8071 seen*

1

[9]

4 (a) $C(s) + 2F_2(g) \longrightarrow CF_4(g)$

State symbols essential

1

(b)   Around carbon there are 4 bonding pairs of electrons (and no lone pairs)

1

Therefore, these repel equally and spread as far apart as possible

1

(c) $\Delta H = \Sigma\ \Delta_f H$ products $- \Sigma\ \Delta_f H$ reactants or a correct cycle

1

Hence = $(2 \times -680) + (6 \times -269) - (x) = -2889$

1

x = 2889 − 1360 − 1614 = −85 (kJ mol^{-1})

1

Score 1 mark only for +85 (kJ mol^{-1})

(d)   Bonds broken = $4(C-H) + 4(F-F) = 4 \times 412 + 4 \times F-F$

Bonds formed = $4(C-F) + 4(H-F) = 4 \times 484 + 4 \times 562$
      Both required

1

$-1904 = [4 \times 412 + 4(F-F)] - [4 \times 484 + 4 \times 562]$

$4(F-F) = -1904 - 4 \times 412 + [4 \times 484 + 4 \times 562] = 632$

1

F−F = 632 / 4 = 158 (kJ mol^{-1})

1

The student is correct because the F–F bond energy is much less than the C–H or other covalent bonds, therefore the F–F bond is weak / easily broken
      Relevant comment comparing to other bonds
      (Low activation energy needed to break the F–F bond)

1
[10]

5   (a) $C_6H_{11}OH + 8\frac{1}{2}O_2 \longrightarrow 6CO_2 + 6H_2O$

1

(b)   Temperature rise = 20.1

$q = 50.0 \times 4.18 \times 20.1 = 4201$ (J)

1

Mass of alcohol burned = 0.54 g and M_r alcohol = 100.0

∴ mol of alcohol = n = 0.54 / 100 = 0.0054

1

Heat change per mole = q / 1000n **OR** q / n

= 778 kJ mol^{-1} **OR** 778 000 J mol^{-1}

1

$\Delta H = -778$ kJ mol^{-1} **OR** $-778\ 000$ J mol^{-1}

> *M4 is for answer with negative sign for exothermic reaction*
> *Units are tied to the final answer and must match*

1

(c)   Less negative than the reference

1

Heat loss **OR** incomplete combustion **OR** evaporation of alcohol **OR** heat transferred to beaker not taken into account

1

(d)   Water has a known density (of 1.0 g cm^{-3})

1

Therefore, a volume of 50.0 cm^3 could be measured out

1

[9]

6   (a)   Bonds broken = 2(C=O) + 3(H–H) = 2 × 743 + 3 × H–H

Bonds formed = 3(C–H) +(C–O) + 3(O–H) = 3 × 412 + 360 + 3 × 463

> *Both required*

1

$-49 = [2 \times 743 + 3 \times (H–H)] − [3 \times 412 + 360 + 3 \times 463]$

$3(H–H) = -49 − 2 \times 743 + [3 \times 412 + 360 + 3 \times 463] = 1450$

> *Both required*

1

H–H = 483 (kJ mol^{-1})

> *Allow 483.3(3)*

1

(b)   Mean bond enthalpies are not the same as the actual bond enthalpies in CO_2 (and / or methanol and / or water)

1

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

1

(d)   4 mol of gas form 2 mol

1

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

1

This increases the yield of methanol

1

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

> *Allow catalyst poisoned*

1

7 (f) Stage 1: moles of components in the equilibrium mixture
Extended response question

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Initial moles	1.0	3.0	0	0
Eqm moles	(1–0.86) = 0.14	(3–3×0.86) = 0.42	0.86	0.86

1

Stage 2: Partial pressure calculations

Total moles of gas = 2.28

Partial pressures = mol fraction × p_{total}

1

p_{CO2} = mol fraction × p_{total} = 0.14 × 500 / 2.28 = 30.7 kPa

p_{H2} = mol fraction × p_{total} = 0.42 × 500 / 2.28 = 92.1 kPa
M3 is for partial pressures of both reactants
Alternative M3 =
$pp_{CO2} = 0.0614 \times 500$
$pp_{H2} = 0.1842 \times 500$

1

p_{CH3OH} = mol fraction × p_{total} = 0.86 × 500 / 2.28 = 188.6 kPa

p_{H2O} = mol fraction × p_{total} = 0.86 × 500 / 2.28 = 188.6 kPa
M4 is for partial pressures of both products
Alternative M4 =
$pp_{CH3OH} = 0.3772 \times 500$
$pp_{H2O} = 0.3772 \times 500$

1

Stage 3: Equilibrium constant calculation
$K_p = p_{CH3OH} \times p_{H2O} / p_{CO2} \times (p_{H2})^3$

1

Hence K_p = 188.6 × 188.6 / 30.7 × (92.1)³ = 1.483 × 10⁻³ = 1.5 × 10⁻³
Answer must be to 2 significant figures

1

Units = <u>kPa⁻²</u>

1

[16]

7 (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

1

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 × 4.18 × 5.4 = 1128.6 J

Max 2 if 14.6 °C used as ΔT

1

Moles of KCl = 5.00 / 74.6 = 0.0670

1

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

1

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

Answer must be given to this precision

1

(c) $\Delta H_{solution}$ = $\Delta H_{lattice}$ + ΔH(hydration of calcium ions) + 2 × ΔH(hydration of chloride ions)

$\Delta H_{lattice}$ = $\Delta H_{solution}$ – ΔH(hydration of calcium ions) –2 ×ΔH(hydration of chloride ions)

1

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

1

(d)   Magnesium ion is smaller than the calcium ion

1

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

1

[12]

8   (a)   (i) $2C_6H_{12}O_6 \longrightarrow 3CH_3COCH_3 + 3CO_2 + 3H_2O$

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) $CH_3CH(OH)CH_3$ + [O] $\longrightarrow$ CH_3COCH_3 + H_2O

Any <u>correct</u> 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 <u>correct answer</u>

*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^{-1})

OR <u>− 1114.6 to − 1120</u> (kJ mol^{-1})

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 <u>must be either kJ or kJ mol</u>$^{-1}$ in this case*

3

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

       M2   is <u>burned / combusts / reacts</u> <u>completely</u> in <u>oxygen</u>
               OR
               <u>burned / combusted / reacted in excess oxygen</u>

       M3   with (all) <u>reactants and products</u> / (all) <u>substances in standard /</u>
                <u>specified states</u>

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

               *For **M3***

               Ignore reference to 1 atmosphere

3

(e) **M1**

Σ B **(reactants)** − Σ B **(products)** = ΔH
OR
Sum of bonds broken − Sum of bonds formed = ΔH
OR
2B(C−C) + B(C=O) + 6B(C−H) + 4B(O=O) (LHS)

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

M2 (also scores **M1**)
2(348)+805+6(412)+4(496) [LHS = **5957**]

(696)   (2472) (1984)

− 6(805) − 6(463) [RHS = (−) **7608**] = ΔH

   (4830)   (2778)

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

M3
ΔH= **− 1651** (kJ mol^{-1})

Candidates may use a cycle and gain full marks.

> *Correct answer gains full marks*
>
> *Credit 1 mark for (+) 1651 (kJ mol^{-1})*
>
> *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$_2$, 3CO$_2$ and 3H$_2$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*

3

(f) **For the two marks M1 and M2, <u>any two</u> from**
- <u>heat</u> loss or not all <u>heat</u> transferred to the apparatus or <u>heat</u> 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 <u>do not refer to specific compounds</u> OR MBE <u>values vary with different compounds / molecules</u> OR are average / mean values taken <u>from a range of compounds / molecules</u>

> *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]

9 (a) **M1 (could be scored by a correct mathematical expression)**
M1 $\underline{\Delta H = \Sigma \Delta H_f}$ **(products)** $-$ $\Sigma \Delta H_f$ **(reactants)**
OR a <u>correct cycle of balanced equations</u>

M2   = 5(−635) − (−1560)

  = − 3175 + 1560

  (This also scores M1)

M3   = **− 1615** (kJ mol⁻¹)
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⁻¹)*
>
> *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 <u>and</u> 5CaO OR a clear statement of **M1** which could be in words and scores <u>only **M1**</u>*

M4   **Type of reaction is**
  • reduction
  • redox
  • (or accept) <u>V_2O_5 / it / V(V)</u> has been <u>reduced</u>
     *In **M4** not "vanadium / V is reduced"*

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

> <u>Calcium is produced / extracted by electrolysis</u>
> *OR* <u>calcium</u> is <u>expensive to extract</u>
> *OR* <u>calcium extraction uses electricity</u>
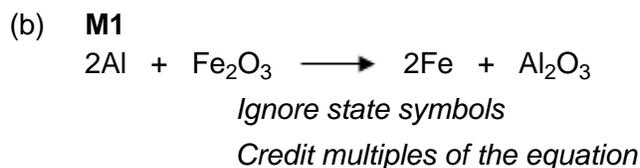> *OR* <u>calcium extraction uses large amount of energy</u>
> *OR* <u>calcium</u> is a (very) <u>reactive metal</u> / <u>reacts with water or air</u>
> *OR* <u>calcium needs to be extracted / does not occur native</u>
>
> **QoL**
>
> *Accept calcium is expensive "to produce" but not "to source, to get, to obtain, to buy" etc.*
>
> *In **M5** it is neither enough to say that calcium is "expensive" nor that calcium "must be purified"*

5

(b) **M1**

2Al + Fe$_2$O$_3$ ⟶ 2Fe + Al$_2$O$_3$

> *Ignore state symbols*
>
> *Credit multiples of the equation*

M2
(Change in oxidation state) <u>**0** to (+)**3**</u>
OR
(changed by) <u>**+3**</u>

> *In **M2** if an explanation is given it must be correct and unambiguous*

2

(c) **M1**

VCl$_2$ + H$_2$ ⟶ V + 2HCl

> *In **M1** credit multiples of the equation*
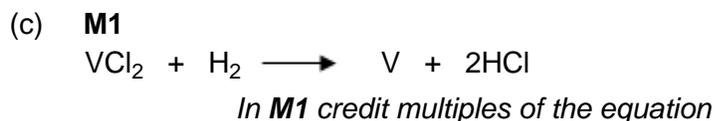
M2 and **M3**
Two hazards in either order
- <u>HCl / hydrogen chloride / hydrochloric acid is acidic / corrosive / toxic / poisonous</u>
- Explosion risk <u>with hydrogen</u> (gas) OR <u>H$_2$ is flammable</u>

> *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 <u>only</u>*

M4
The only other product / the HCl is easily / readily <u>removed / lost / separated because it is a gas</u> *OR* <u>will escape</u> (or this idea strongly implied) <u>as a gas</u>
OR vanadium / it is the <u>only solid product</u> (and is easily separated)
OR vanadium / it is a <u>solid and the other product / HCl is a gas</u>

> *In **M4** it is not enough to state simply that HCl is a gas, since this is in the question.*

4

[11]

10 | 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

1

[2]

11 (a) The enthalpy (change) to break <u>1 mol</u> of H—O / bonds

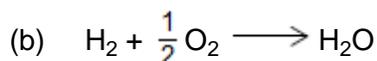*Allow heat energy*

1

Averaged over a range of compounds / molecules

Penalise energy but mark on

ignore states

CE = 0 for ionic bonds

1

(b) $H_2 + \frac{1}{2}O_2 \longrightarrow H_2O$

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

1

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

1

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

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
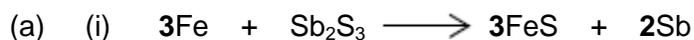
Do not allow similar

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

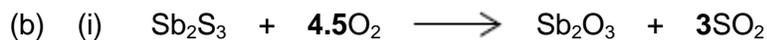*Do not allow mean bond enthalpies are not accurate*

1

[7]

12 (a) (i) $3Fe + Sb_2S_3 \longrightarrow 3FeS + 2Sb$

Or multiples.

Ignore state symbols.

1

(ii) $Fe \longrightarrow Fe^{2+} + 2e^-$
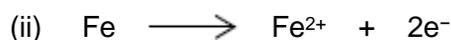
Ignore charge on the electron unless incorrect.

Or multiples.

Credit the electrons being subtracted on the LHS.

Ignore state symbols.

1

(b) (i) Sb_2S_3 + **4.5**O_2 $\longrightarrow$ Sb_2O_3 + **3**SO_2

Or multiples.

Ignore state symbols.

1

(ii) SO_3 or sulfur trioxide / sulfur (VI) oxide

Credit also the following ONLY.

H_2SO_4 or sulfuric acid.

OR

Gypsum / $CaSO_4$ or plaster of Paris.

1

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

Correct answer gains full marks.

M1 $\underline{\Delta H_r = \Sigma \Delta H_f(\textbf{products}) - \Sigma \Delta H_f(\textbf{reactants})}$

OR a <u>correct cycle of balanced equations / correct numbers of moles</u>

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

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

$= 40 - 1182 + 705 + 333$

$= -1142 - (-1038)$

(This also scores M1)

M3 $= \underline{\textbf{-104}}$ (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_2 OR a clear statement of **M1** which could be in words and scores **only M1**.*

3

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

     OR

     <u>Standard state</u> (for Sb) <u>is solid / (s)</u>

     OR

     <u>(Sb) liquid is not its standard state</u>
          Credit a correct definition of standard state as an alternative to the words 'standard state'.
          QoL

1

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

1

(d)   Low-grade ore extraction / it

- uses (cheap) <u>scrap / waste</u> <u>iron / steel</u>

- is a single-step process

     uses / requires <u>less / low(er) energy</u>
          Ignore references to temperature / heat or labour or technology.

1
     [10]