1

(a) (Q = mcΔT)

= 50 × 4.18 × 27.3

If incorrect (eg mass = 0.22 or 50.22 g) ***CE = 0 / 2***

1

= **5706 J** (accept 5700 and 5710)

Accept 5.7 kJ with correct unit. Ignore sign.

1

(b) M_r of 2-methylpropan-2-ol = 74(.0)

For incorrect M_r, lose M1 but mark on.

1

Moles = mass / M_r

= 0.22 / 74(.0)

= **0.00297 moles**

1

Δ*H* = –5706 / (0.002970 × 1000)

= **–1921 (kJ mol^{-1})**

If 0.22 is used in part (a), answer = –8.45 kJ mol^{-1} scores 3

(Allow –1920, –1919)

If uses the value given (5580 J), answer = –1879 kJ mol^{-1} scores 3

Answer without working scores M3 only.

Do not penalise precision.

Lack of negative sign loses M3

1

(c) Δ*H* = ΣΔH products – ΣΔH reactants
OR a correct cycle

Correct answer with no working scores 1 mark only.

1

Δ*H* = −(−360) + (4 × −393) + (5 × −286)

M2 also implies M1 scored.

1

Δ*H* = **–2642** (kJ mol^{-1}) This answer only.

Allow 1 mark out of 3 for correct value with incorrect sign.

1

(d) (–2422 – part (b)) × 100 / –2422

Ignore negative sign.

Expect answers in region of 20.7

If error carried forward, 0.22 allow 99.7

If 5580 J used earlier, then allow 22.4

1

(e) Reduce the distance between the flame and the beaker / put a sleeve around the flame to protect from drafts / add a lid / use a copper calorimeter rather than a pyrex beaker / use a food calorimeter

Any reference to insulating material around the beaker must be on top.

Accept calibrate the equipment using an alcohol of known enthalpy of combustion.

1

(f) Incomplete combustion

1

[11]

2

(a) (i) M1 c(oncentrated) phosphoric acid / c(onc.) H_3PO_4

OR c(oncentrated) sulfuric acid / c(onc.) H_2SO_4

*In **M1**, the acid must be concentrated.*
Ignore an incorrect attempt at the correct formula that is written in addition to the correct name.

M2 Re-circulate / re-cycle the (unreacted) ethene (and steam) / the reactants ***OR*** pass the gases over the catalyst several / many times

*In **M2**, ignore "remove the ethanol".*
Credit "re-use".

2

(ii) M1
(By Le Chatelier's principle) the equilibrium is driven / shifts / moves to the right / L to R / forwards / in the forward direction

M2 depends on a correct statement of M1
The equilibrium moves / shifts to

- oppose the addition of / increased concentration of / increased moles / increased amount of water / steam
- to decrease the amount of steam / water

Mark M3 independently
M3 Yield of product / conversion increase ***OR*** ethanol increases / goes up / gets more

3

(iii) M1 Poly(ethene) / polyethene / polythene / HDPE / LDPE

M2 At higher pressures
More / higher cost of electrical energy to pump / pumping cost
OR
Cost of higher pressure equipment / valves / gaskets / piping etc.
OR expensive equipment

*Credit all converse arguments for **M2***

2

(b) M1 for balanced equation

M2 for state symbols in a correctly balanced equation

$2C(s / graphite) + 3H_2(g) + \frac{1}{2}O_2(g) \longrightarrow CH_3CH_2OH(l)$
(C_2H_5OH)

Not multiples but credit correct state symbols in a correctly balanced equation.

Penalise C_2H_6O but credit correct state symbols in a correctly balanced equation.

2

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

*If standard enthalpy of formation **CE=0***

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

(ii) M1

Correct answer gains full marks

<u>ΣB(**reactants**) − ΣB(**products**) = *ΔH*</u>

Credit 1 mark for (+) 1279 (kJ mol^{-1})

OR
<u>Sum of bonds broken − Sum of bonds formed = ΔH</u>
OR
B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O) (LHS)
− 4B(C=O) − 6B(O−H) (RHS) = <u>*ΔH*</u>

M2 (also scores **M1**)
348+360+463+5(412)+3(496) [LHS = **4719**]
(2060) (1488)
− 4(805) − 6(463) [RHS = − **5998**] = *ΔH*
(3220) (2778)
OR using only bonds broken and formed (**4256 − 5535**)

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 2C and 6H and 7O OR a clear statement of **M1** which could be in words and scores <u>**only M1**</u>*

M3

ΔH= <u>**− 1279**</u> (kJ mol^{-1})

*Allow a maximum of one mark if the only scoring point is LHS = 4719 **OR** RHS = 5998*

Award 1 mark for +1279

Candidates may use a cycle and gain full marks

3

(d) (i) <u>Reducing agent</u> ***OR*** <u>reductant</u> ***OR*** <u>electron donor</u>
OR to <u>reduce the copper oxide</u>

Not "reduction".

Not "oxidation".

Not "electron pair donor".

1

(ii) CH_3COOH

1

[17]

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

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

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

Credit 1 mark for − 101 (kJ mol^{-1})

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

M2 = − 1669 − 3(− 590)
= − 1669 + 1770
(This also scores M1)

M3 = **+ 101** (kJ mol^{-1})

Award 1 mark ONLY for − 101

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 3Sr <u>and</u> 2Al OR a clear statement of **M1** which could be in words and scores **<u>only M1</u>***

M4 - Using powders
Any **one** from

- To <u>increase collision frequency / collisions in a given time / rate of collisions</u>
- To <u>increase the surface contact</u> / <u>contact between the solids / contact between</u> (exposed) <u>particles</u>

Ignore dividing final answer by 3

*Penalise **M4** for reference to molecules.*

5

M5 Major reason for expense of extraction
Any **one** from

- <u>Aluminium is extracted by electrolysis ***OR*** aluminium extraction uses</u> (large amounts of) <u>electricity</u>
- <u>Reaction / process / It / the mixture requires heat</u>
- <u>It is endothermic</u>

(b) Calcium has a higher melting point than strontium, because

Ignore general Group 2 statements.

Correct reference to size of cations / proximity of electrons

M1 (For Ca) delocalised <u>electrons closer to cations / positive ions / atoms / nucleus</u>
OR <u>cations / positive ions / atoms are smaller</u>
OR <u>cation / positive ion / atom or it has fewer (electron) shells / levels</u>

*Penalise **M1** if either of Ca or Sr is said to have <u>more or less</u> delocalised electrons OR the same nuclear charge.*

Ignore reference to shielding.

Relative strength of metallic bonding

M2 (Ca) has <u>stronger</u> attraction between the <u>cations / positive ions / atoms / nucleus</u> and the <u>delocalised electrons</u>
OR
<u>stronger metallic</u> bonding

(assume argument refers to Ca but credit converse argument for Sr)

***CE= 0** for reference to molecules or Van der Waals forces or intermolecular forces or covalent bonds.*

2

(c) **M1** **2**Mg + O_2 ⟶ **2**MgO

M2 Mg + **2**H_2O ⟶ $Mg(OH)_2$ + H_2

Credit multiples of the equations.

M3 Magnesium hydroxide is used as an antacid / relieve indigestion (heartburn) / neutralise (stomach) acidity / laxative

*Not simply "milk of magnesia" in **M3***

3

[10]

4

(a) Chlor<u>ide</u> (ions) are smaller (than brom<u>ide</u> ions)

Must state or imply ions.

Allow chlor<u>ide</u> has greater charge density (than bromide).

Penalise <u>chlorine ions</u> once only (max 2 / 3).

1

So the force of attraction between chloride ions and water is stronger

This can be implied from M1 and M3 but do not allow intermolecular forces.

1

Chloride <u>ions</u> attract the δ+ on H of water / electron deficient H on water

Allow attraction between ions and polar / dipole water.

*Penalise H^+ (ions) and mention of hydrogen bonding for **M3***

Ignore any reference to electronegativity.

Note: If water not mentioned can score M1 only.

1

(b) $\Delta H_{solution} = \Delta H_L + \Delta H_{hyd}$ K^+ ions + ΔH_{hyd} Br^- ions / = 670 − 322 − 335

Allow $\Delta H_{solution} = \Delta H_L + \Sigma \Delta H_{hyd}$

1

= (+)13 (kJ mol^{-1})

Ignore units even if incorrect.
+13 scores M1 and M2
−13 scores 0
−16 scores M2 only (transcription error).

1

(c) (i) The entropy change is positive / entropy increases

ΔS is negative loses M1 and M3

1

Because 1 mol (solid) → 2 mol (aqueous ions) / no of particles increases

Allow the aqueous ions are more disordered (than the solid).
Mention of atoms / molecules loses M2

1

Therefore $\underline{T\Delta S > \Delta H}$

1

(ii) Amount of KCl = $5/M_r = 5/74.6 = \underline{0.067(0) \text{ mol}}$

If moles of KCl not worked out can score M3, M4 only (answer to M4 likely to be 205.7 K)

1

Heat absorbed = 17.2 × 0.0670 = 1.153 kJ

Process mark for M1 × 17.2

1

Heat absorbed = mass × sp ht × ΔT

$(1.153 \times 1000) = 20 \times 4.18 \times \Delta T$

If calculation uses 25 g not 20, lose M3 only (M4 = 11.04, M5 = 287)

1

$\Delta T = 1.153 \times 1000 / (20 \times 4.18) = 13.8$ K

If 1000 not used, can only score M1, M2, M3
M4 is for a correct ΔT
Note that 311.8 K scores 4 (M1, M2, M3, M4).

1

$T = 298 - 13.8 = 284(.2)$ K

If final temperature is negative, M5 = 0
Allow no units for final temp, penalise wrong units.

1

[13]

5 (a) (i) **M1 (could be scored by a correct mathematical expression which <u>must</u> have <u>all</u> Δ*H* symbols and the ∑ or SUM)**

Correct answer gains full marks

*Credit 1 mark ONLY if **–122** (kJ mol^{-1})*

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

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

M2 $\underline{\Delta H}$ = 3(−394) − 3(−111) − (−971)
(This also scores M1)

M3 = **<u>(+) 122</u>**(kJ mol^{-1})

Award 1 mark ONLY for –122

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 correct method; this requires either a correct cycle of balanced equations OR a clear statement of **M1** which could be in words and scores **<u>M1 only</u>***

3

(ii) By definition

Ignore reference to "standard state"

OR

Because it is an element / elemental

1

(b) (i) $TiO_2 + \mathbf{2}Cl_2 + \mathbf{2}C \longrightarrow TiCl_4 + \mathbf{2}CO$

Allow multiples

OR

$TiO_2 + \mathbf{2}Cl_2 + C \longrightarrow TiCl_4CO_2$

Ignore state symbols

M1 use of Cl_2 <u>and</u> C

M2 a correct balanced equation

2

(ii) $TiCl_4$ + **4**Na ⟶ Ti + **4**NaCl

Allow multiples

OR

$TiCl_4$ + **2**Mg ⟶ Ti + **2**$MgCl_2$

Ignore state symbols

M1 use of Na ***OR*** Mg

M2 a correct balanced equation

2

(c) (i) **4** $FeCr_2O_4$ + **8** Na_2CO_3 + **7**O_2 ⟶ **8**Na_2CrO_4 + 2Fe_2O_3 + 8CO_2

Allow multiples

Ignore state symbols

1

(ii) Cr_2O_3 + **2**Al ⟶ Al_2O_3 + **2**Cr

Allow multiples

Ignore state symbols

1

[10]

6 (a) The <u>enthalpy change / heat (energy) change</u> (at constant pressure) in a reaction is independent of the route / path taken (and depends only on the initial and final states)

Ignore the use of ΔH for enthalpy

1

(b) $\Delta H_{exp} + \Delta H_2 - \Delta H_1 = 0$

Any correct mathematical statement that uses <u>all three terms</u>

OR

$\Delta H_{exp} + \Delta H_2 = \Delta H_1$ ***OR*** $\Delta H_1 = \Delta H_{exp} + \Delta H_2$

OR

$\Delta H_{exp} = \Delta H_1 - \Delta H_2$ ***OR*** $\Delta H_{exp} = \Delta H_1 + (-\Delta H_2)$

1

(c) $\Delta H_{exp} = \Delta H_1 - \Delta H_2$

$\Delta H_{exp} = -156 - 12 =$ ***−168*** *(kJ mol^{-1})*

Ignore units

Award the mark for the correct answer without any working

1

(d) (i) M1 q = m c ΔT OR calculation (25.0 x 4.18 x 14.0)

Award full marks for correct answer

M2 = **1463**J OR **1.46** kJ (This also scores **M1**)

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

M3 must have both the correct value within the range specified **and** the minus sign

*Penalise **M3** ONLY if correct numerical value but sign is incorrect; e.g. **+69.5 to +69.7 gains 2 marks** (ignore +70 after correct answer)*

For 0.0210 mol, therefore

ΔH_1 = **− 69.67** to **− 69.52** (kJ mol^{-1})

OR ΔH_1 = **− 69.7** to **− 69.5** (kJ mol^{-1})

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

Accept answers to 3sf or 4sf in the range − 69.7 to − 69.5

ΔT = 287, score q = m c ΔT only

Ignore -70 after correct answer

*If c = 4.81 (leads to 1684J) penalise **M2** ONLY and mark on for **M3** = − 80.17 (range − 80.0 to − 80.2)*

Ignore incorrect units

3

(ii) The idea of heat loss

NOT impurity

OR

Incomplete reaction (of the copper sulfate)

NOT incompetence

OR

Not all the copper sulfate has dissolved

NOT incomplete combustion

1

(e) Impossible to add / react the <u>exact / precise amount</u> of water

Not just "the reaction is incomplete"

OR

Very difficult to measure the temperature rise <u>of a solid</u>

OR

Difficult to prevent solid dissolving

OR

(Copper sulfate) solution will form

1

[8]

7 (a) $3N_2H_4 \longrightarrow 4NH_3 + N_2$

Or multiples

Ignore state symbols

1

(b) M1 <u>enthalpy / heat (energy)</u> <u>change / required / needed</u> to <u>break</u> / <u>dissociate</u> a <u>covalent bond (or a specified covalent bond)</u>

Ignore bond making

Ignore standard conditions

M2** requires an attempt at **M1

M2 <u>average / mean</u> over <u>different molecules / compounds / substances</u>

2

(c) M1

$\sum$ (bonds broken) − $\sum$ (bonds formed) = ΔH

***M1** could stand alone*

OR

Sum of bonds broken − Sum of bonds formed = ΔH

Award full marks for correct answer

M2 (also scores **M1**)

Ignore units

4(+388) + 163 + 2(146) + 4(463) − 944 − 8(463) = ΔH
OR broken +3859 (2007) formed − 4648 (2796)

M3

ΔH = **− 789** (kJ mol^{-1})

Two marks can score with an arithmetic error in the working

Award 1 mark for + 789

*Credit **one mark only** for calculating either the sum of the bonds broken or the sum of the bonds formed provided this is the only mark that is to be awarded*

Students may use a cycle and gain full marks

3

[6]

8 (a) (Enthalpy change to) break the bond in 1 mol of chlorine (molecules)

Allow (enthalpy change to) convert 1 mol of chlorine molecules into atoms
Do not allow energy or heat instead of enthalpy, allow heat energy

1

To form (2 mol of) gaseous chlorine atoms / free radicals

Can score 2 marks for 'Enthalpy change for the reaction':
$Cl_2(g) \rightarrow 2Cl(g)$

Equation alone gains M2 only

Can only score M2 if 1 mol of chorine molecules used in M1 (otherwise it would be confused with atomisation enthalpy)

Any mention of ions, CE = 0

1

(b) (For atomisation) only 1 mol of chlorine atoms, not 2 mol (as in bond enthalpy) is formed / equation showing ½ mol chlorine giving 1 mol of atoms

Allow breaking of one bond gives two atoms

Allow the idea that atomisation involves formation of 1 mol of atoms not 2 mol

Allow the idea that atomisation of chlorine involves half the amount of molecules of chlorine as does dissociation

Any mention of ions, CE = 0

1

(c) (i) $\frac{1}{2}F_2(g) + \frac{1}{2}Cl_2(g) \rightarrow ClF(g)$

1

(ii) $\Delta H = \frac{1}{2}E(F–F) + \frac{1}{2}E(Cl–Cl) – E(Cl–F)$

Allow correct cycle

1

$E(Cl–F) = \frac{1}{2}E(F–F) + \frac{1}{2}E(Cl–Cl) – \Delta H$

$= 79 + 121 – (–56)$

$= 256$ (kJ mol^{-1})

−256 scores zero

Ignore units even if wrong

1

(iii) $\frac{1}{2}Cl_2 + 3/2\ F_2 \rightarrow ClF_3$

If equation is doubled CE=0 unless correcr answer gained by / 2 at end
This would score M1

1

$\Delta H = \frac{1}{2}E(Cl–Cl) + 3/2\ E(F–F) – 3E(Cl–F)$

$= 121 + 237 – 768$ / (or 3 × value from (c)(ii))

This also scores M1 (note = 358 − 768)

1

$= −410$ (kJ mol^{-1})

If given value of 223 used ans = −311
Allow 1 / 3 for +410 and +311

1

(iv) (Bond enthalpy of) Cl−F bond in ClF is different from that in ClF_3

Allow Cl-F bond (enthalpy) is different in different compounds (QoL)

1

(d) NaCl is ionic / not covalent

1

[11]

9 (a) (i) **M1 (could be scored by a correct mathematical expression which must have all ΔH symbols and the $\sum$ or SUM)**

M1 ΔH_r **=** $\Sigma\Delta H_f$ **(products)** - $\Sigma\Delta H_f$ **(reactants)**

OR a correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$

M2 $\Delta H_r = -201 + (-242) - (-394)$
$\Delta H_r = -201 - 242 + 394$
$\Delta H_r = -443 + 394$
(This also scores M1)

M3 = – **49** (kJ mol^{-1})
(Award 1 mark ONLY for + 49)
Correct answer gains full marks
Credit 1 mark ONLY for + 49 (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 correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$*
  *OR a clear statement of **M1** which could be in words and scores only **M1***

3

(ii) It is an element / elemental
Ignore reference to "standard state"

OR

By definition

1

(b) **M1** (The yield) increases / goes up / gets more

*If M1 is given as "decreases" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank M1*

M2 There are more moles / molecules (of gas) on the left / of reactants
OR fewer moles / molecules (of gas) on the right
/ products
OR there are 4 moles /molecules (of gas) on the left and 2 moles / molecules on the right.
OR (equilibrium) shifts / moves to the side with less moles / molecules

*Ignore "volumes", "particles" "atoms" and "species" for **M2***

M3: Can only score M3 if M2 is correct

The (position of) equilibrium shifts / moves (from left to right) to oppose the increase in pressure

*For **M3**, not simply "to oppose the change"*

*For **M3** credit the equilibrium shifts / moves (to right) to lower / decrease the pressure*

(There must be a specific reference to the change that is opposed)

3

(c) **M1** Yield increases goes up

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

*If M1 is given as "decrease" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank **M1***

Can only score M3 if M2 is correct

M3 The (position of) equilibrium shifts / moves (from left to right) to oppose the increase in temperature **(QoL)**

*For **M3**, not simply "to oppose the change"*

*For **M3**, credit the (position of) equilibrium shifts / moves **(QoL)***

*to absorb the heat **OR***

*to cool the reaction **OR***

to lower the temperature

(There must be a specific reference to the change that is opposed)

3

(d) (i) An activity which has no net / overall (annual) carbon emissions to the atmosphere

OR

An activity which has no net / overall (annual) greenhouse gas emissions to the atmosphere.

OR

There is no change in the total amount / level of carbon dioxide /CO_2 carbon /greenhouse gas present in the atmosphere.

The idea that the carbon /CO_2 given out equals the carbon /CO_2 that was taken in from the atmosphere

1

(ii) $CH_3OH + \mathbf{1}½\ O_2 \longrightarrow CO_2 + \mathbf{2}H_2O$

Ignore state symbols

Accept multiples

1

(iii) $\mathbf{3}H_2 + \mathbf{1}½\ O_2 \longrightarrow \mathbf{3}H_2O$

Ignore state symbols

OR

Accept multiples

$\mathbf{2}H_2 + O_2 \longrightarrow \mathbf{2}H_2O$

Extra species must be crossed through

1

(e) **M1** q = m c ∆T

Award full marks for correct answer

Ignore the case for each letter

OR q = 140 × 4.18 × 7.5

M2 = 4389 (J) OR 4.389 (kJ) OR 4.39 (kJ) OR 4.4 (kJ)(also scores M1)

M3 Using 0.0110 mol

therefore ∆H = **– 399** (kJmol^{-1})

OR **– 400**

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect; +399 **gains 2 marks***

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

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

If ∆T = 280.5; score q = m c ∆T only

*If c = 4.81 (leads to 5050.5) penalise **M2** ONLY and mark on for **M3** = – 459*

+399 or +400 gains 2 marks

Ignore incorrect units

3

[16]