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

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]

M2.(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]

M3.(a) (i) reduction **OR** reduced **OR** redox ***OR*** reduction–oxidation

Not "oxidation" alone

1

(ii) Fe^{3+} + **3**e^- $\longrightarrow$ Fe

Ignore state symbols

Do not penalise absence of charge on electron

Credit $Fe^{3+} \longrightarrow Fe - 3e^-$

Credit multiples

1

(b) (i) **Because (one of the following)**

CO is not the only product ***OR***

Reference to "incomplete combustion to form CO" does not answer the question

(Some) complete combustion (also)occurs ***OR***

CO_2 is (also) formed

Further oxidation occurs

1

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

1

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

For M1, credit correct reference to molecule/s or atom/s

M2 is <u>burned completely</u> / <u>undergoes complete combustion</u> in (excess) <u>oxygen</u>

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

For M3

Ignore reference to 1 atmosphere

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

3

(c) **M1 (could be scored by a correct mathematical expression which <u>must</u> have <u>all</u> ΔH symbols and the $\sum$)**

Correct answer gains full marks

Credit 1 mark ONLY for –1 (kJ mol^{-1})

M1 $\Delta H_r = \sum \Delta H_f$ (**products**) – $\sum \Delta H_f$ (**reactants**)

Credit 1 mark ONLY for – 27 (kJ mol^{-1}) i.e. assuming value for Fe(l) = 0

OR <u>correct cycle of balanced equations with 2Fe, 3C and 3O_2</u>

M2 ΔH_r = 2(+14) + 3(– 394) – (– 822) – 3(–111)

= 28 –1182 + 822 + 333

(This also scores M1)

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

(Award 1 mark ONLY for – 1)

(Award 1 mark ONLY for – 27)

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 2Fe, 3C and $3O_2$ OR a clear statement of M1 which could be in words and scores <u>only M1</u>*

3

(d) (i) $C(s) + O_2(g) \quad CO_2(g)$

State symbols essential

Possible to include C(s, graphite)

1

(ii) These two enthalpy changes are for <u>the same reaction / same equation / same reactants and products</u>

Penalise reference to CO_2 being produced by a different route

OR

They <u>both make one mole of carbon dioxide only from carbon and oxygen</u> (or this idea clearly implied)

"both form CO_2" is not sufficient (since other products might occur e.g.CO)

OR

The <u>same number and same type of bonds are broken and formed</u>

1

[12]

M4.(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

ΔH = ½ 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]

M5. (a) (i) **M1 (could be scored by a correct mathematical expression which must have all ΔH symbols and the $\sum$ or SUM)**

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

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

M2 ΔH_r = – 201 + (– 242) – (– 394)
ΔH_r = – 201 – 242 + 394
ΔH_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 <u>only **M1**</u>*

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

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

M3: Can only score M3 if <u>M2 is correct</u>

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

*For **M3**, <u>not</u> simply "to oppose the change"*

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

(There must be a <u>specific</u> reference to the change that is opposed)

3

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

M2 The (forward) reaction / to the right is <u>endothermic</u> OR <u>takes in/ absorbs heat</u>

OR

The reverse reaction / to the left is <u>exothermic</u> OR <u>gives out / releases heat</u>

*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 <u>if M2 is correct</u>

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

*For **M3**, <u>not</u> simply "to oppose the change"*

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

*to <u>absorb the heat</u> **OR***

*to <u>cool the reaction</u> **OR***

to <u>lower the temperature</u>

(There must be a <u>specific</u> reference to the change that is opposed)

3

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

OR

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

OR

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

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

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** $q = m\ c\ \Delta T$

Award full marks for correct answer

Ignore the case for each letter

OR $q = 140 \times 4.18 \times 7.5$

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

M3 Using 0.0110 mol
therefore ΔH = **– 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 $\Delta T = 280.5$; score $q = m\ c\ \Delta T$ 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]