Q17.

This question is about the extraction of metals.

(a) Manganese can be extracted from Mn_2O_3 by reduction with carbon monoxide at high temperature.

(i) Use the standard enthalpy of formation data from the table and the equation for the extraction of manganese to calculate a value for the standard enthalpy change of this extraction.

	$Mn_2O_3(s)$	$CO(g)$	$Mn(s)$	$CO_2(g)$
$\Delta H_f^{\ominus}$/ kJ mol^{-1}	−971	−111	0	−394

$$Mn_2O_3(s) + 3CO(g) \longrightarrow 2Mn(s) + 3CO_2(g)$$

(3)

(ii) State why the value for the standard enthalpy of formation of Mn(s) is zero.

(1)

(b) Titanium is extracted in industry from titanium(IV) oxide in a two-stage process.

(i) Write an equation for the first stage of this extraction in which titanium(IV) oxide is converted into titanium(IV) chloride.

(2)

(ii) Write an equation for the second stage of this extraction in which titanium(IV) chloride is converted into titanium.

(2)

(c) Chromium is extracted in industry from chromite ($FeCr_2O_4$).

(i) In the first stage of this extraction, the $FeCr_2O_4$ is converted into Na_2CrO_4 Balance the equation for this reaction.

$$.....FeCr_2O_4 + ...Na_2CO_3 + ...O_2 \longrightarrow .....Na_2CrO_4 + 2Fe_2O_3 + 8CO_2$$

(1)

(ii) In the final stage, chromium is extracted from Cr_2O_3 by reduction with aluminium.

Write an equation for this reaction.

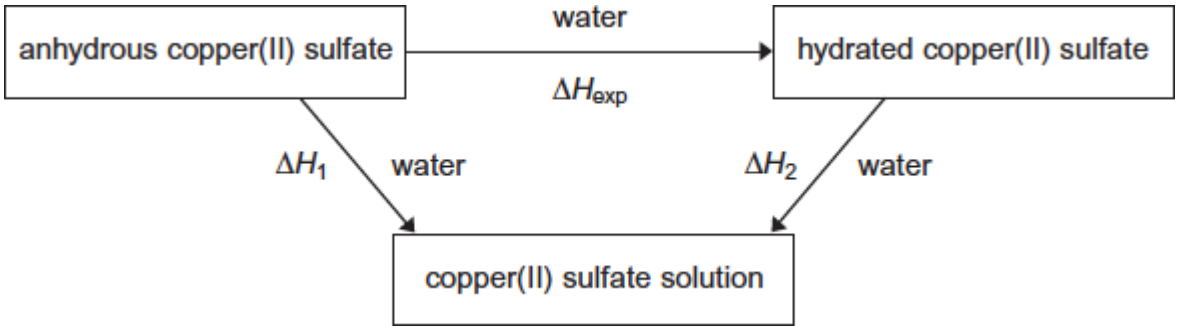
_____

(1)

(Total 10 marks)

Q18.

A student used Hess's Law to determine a value for the enthalpy change that occurs when anhydrous copper(II) sulfate is hydrated. This enthalpy change was labelled ΔH_{exp} by the student in a scheme of reactions.



(a) State Hess's Law.

_____

_____

_____

_____

(1)

(b) Write a mathematical expression to show how ΔH_{exp}, ΔH_1 and ΔH_2 are related to each other by Hess's Law.

_____

(1)

(c) Use the mathematical expression that you have written in part (b), and the data book values for the two enthalpy changes ΔH_1 and ΔH_2 shown, to calculate a value for ΔH_{exp}

$\Delta H_1 = -156$ kJ mol^{-1}
$\Delta H_2 = +12$ kJ mol^{-1}

_____

_____

_____

_____

(1)

(d) The student added 0.0210 mol of pure anhydrous copper(II) sulfate to 25.0 cm^3 of deionised water in an open polystyrene cup. An exothermic reaction occurred and the temperature of the water increased by 14.0 °C.

(i) Use these data to calculate the enthalpy change, in kJ mol^{-1}, for this reaction of copper(II) sulfate. This is the student value for ΔH_1

In this experiment, you should assume that all of the heat released is used to raise the temperature of the 25.0 g of water. The specific heat capacity of water is 4.18 J K^{-1} g^{-1}.

(3)

(ii) Suggest **one** reason why the student value for ΔH_1 calculated in part (d)(i) is less accurate than the data book value given in part (c).

(1)

(e) Suggest **one** reason why the value for ΔH_{exp} **cannot** be measured directly.

(1)

(Total 8 marks)

Q19.

Methanol (CH_3OH) is an important fuel that can be synthesised from carbon dioxide.

(a) The table shows some standard enthalpies of formation.

	$CO_2(g)$	$H_2(g)$	$CH_3OH(g)$	$H_2O(g)$
$\Delta H_f^{\ominus}$/kJ mol^{-1}	– 394	0	– 201	– 242

(i) Use these standard enthalpies of formation to calculate a value for the standard enthalpy change of this synthesis.

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

(3)

(ii) State why the standard enthalpy of formation for hydrogen gas is zero.

(1)

(b) State and explain what happens to the yield of methanol when the total pressure is increased in this synthesis.

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

Effect on yield _____

Explanation _____

(3)

(c) The hydrogen required for this synthesis is formed from methane and steam in a reversible reaction. The equation for this reaction is shown below.

$$CH_4(g) + H_2O(g) \rightleftharpoons C0(g) + 3H_2(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

State and explain what happens to the yield of hydrogen in this reaction when the temperature is increased.

Effect on yield _____

Explanation _____

_____

_____

_____

_____

_____

(3)

(d) The methanol produced by this synthesis has been described as a carbon-neutral fuel.

(i) State the meaning of the term *carbon-neutral*.

_____

_____

_____

_____

(1)

(ii) Write an equation for the complete combustion of methanol.

_____

(1)

(iii) The equation for the synthesis of methanol is shown below.

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

Use this equation and your answer to part (d)(ii) to deduce an equation to represent the overall chemical change that occurs when methanol behaves as a carbon-neutral fuel.

Equation _____

(1)

(e) A student carried out an experiment to determine the enthalpy change when a sample of methanol was burned.

The student found that the temperature of 140 g of water increased by 7.5 °C when 0.011 mol of methanol was burned in air and the heat produced was used to warm the water.

Use the student's results to calculate a value, in kJ mol^{-1}, for the enthalpy change when one mole of methanol was burned.
(The specific heat capacity of water is 4.18 J K^{-1} g^{-1}).

_____

_____

_____

_____

_____

_____

_____

_____

(3)

(Total 16 marks)

Q20.

(a) Iron is extracted from iron(III) oxide using carbon at a high temperature.

(i) State the type of reaction that iron(III) oxide undergoes in this extraction.

_____

(1)

(ii) Write a half-equation for the reaction of the iron(III) ions in this extraction.

_____

(1)

(b) At a high temperature, carbon undergoes combustion when it reacts with oxygen.

(i) Suggest why it is **not** possible to measure the enthalpy change directly for the following combustion reaction.

$$C(s,graphite) + \frac{1}{2}O_2(g) \longrightarrow CO(g)$$

_____

_____

(1)

(ii) State Hess's Law.

_____

_____

_____

(1)

(iii) State the meaning of the term *standard enthalpy of combustion.*

_____

_____

_____

_____

(3)

(c) Use the standard enthalpies of formation in the table below and the equation to calculate a value for the standard enthalpy change for the extraction of iron using carbon monoxide.

	$Fe_2O_3(s)$	$CO(g)$	$Fe(l)$	$CO_2(g)$
ΔH_f/ kJ mol^{-1}	- 822	- 111	+14	- 394

$$Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(l) + 3CO_2(g)$$

_____

_____

_____

_____

_____

_____

(3)

(d) (i) Write an equation for the reaction that represents the standard enthalpy of formation of carbon dioxide.

_____

(1)

(ii) State why the value quoted in part (c) for the standard enthalpy of formation of $CO_2(g)$ is the same as the value for the standard enthalpy of combustion of carbon.

_____

_____

(1)

(Total 12 marks)

Q21.

This question is about the extraction of titanium from titanium(IV) oxide by a two-stage process.
The first stage in the process produces titanium(IV) chloride. In the second stage, titanium(IV) chloride is converted into titanium.
The enthalpy change for the second stage can be determined using Hess's Law.

(a) Give **one** reason why titanium is **not** extracted directly from titanium(IV) oxide using carbon.

_____

_____

(1)

(b) Give the meaning of the term *enthalpy change*.

_____

_____

_____

(1)

(c) State Hess's Law.

_____

_____

_____

_____

(1)

(d) Define the term *standard enthalpy of formation*.

_____

_____

_____

_____

_____

_____

(3)

(e) The following standard enthalpy of formation data refer to the second stage in the extraction of titanium.

	$TiCl_4(g)$	Na(l)	NaCl(s)	Ti(s)
$\Delta H_f^\ominus$/ kJ mol^{-1}	–720	+3	–411	0

(i) State why the value for the standard enthalpy of formation of Na(l) is **not** zero.

_____

_____

(1)

(ii) Use data from the table to calculate a value for the standard enthalpy change of the following reaction.

$$TiCl_4(g) + 4Na(l) \longrightarrow 4NaCl(s) + Ti(s)$$

_____

_____

_____

_____

_____

_____

_____

(3)

(iii) State the role of sodium in this reaction.

_____

(1)

(Total 11 marks)

Q22.

Hess's Law is used to calculate the enthalpy change in reactions for which it is difficult to determine a value experimentally.

(a) State the meaning of the term *enthalpy change*.

_____

(1)

(b) State Hess's Law.

_____

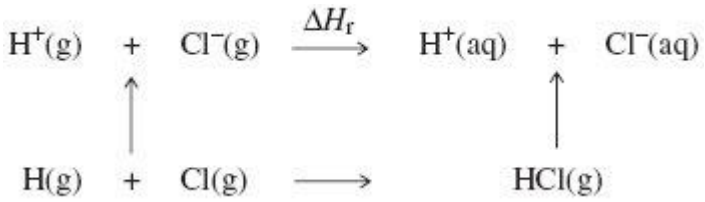
_____

_____

(1)

(c) Consider the following table of data and the scheme of reactions.

Reaction	Enthalpy change / kJ mol^{-1}
$HCl(g) \rightarrow H^+(aq) + Cl^-(aq)$	–75
$H(g) + Cl(g) \rightarrow HCl(g)$	–432
$H(g) + Cl(g) \rightarrow H^+(g) + Cl^-(g)$	+963



Use the data in the table, the scheme of reactions and Hess's Law to calculate a value for ΔH_r

_____

_____

_____

_____

_____

(3)

(Total 5 marks)

Mark Scheme

Q17.

(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 $\Delta H = \sum \Delta H_f$ (**products**) - $\sum \Delta H_f$ (**reactants**)

OR a correct cycle of balanced equations

M2 $\Delta H = 3(-394) - 3(-111) - (-971)$
(This also scores M1)

M3 = **(+) 122**(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) $TiCl_4 + \mathbf{4}Na \longrightarrow Ti + \mathbf{4}NaCl$

Allow multiples

OR

$TiCl_4 + \mathbf{2}Mg \longrightarrow Ti + \mathbf{2}MgCl_2$

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]

Q18.

(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 **<u>and</u>** 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 exact / precise amount of water

Not just "the reaction is incomplete"

OR

Very difficult to measure the temperature rise of a solid

OR

Difficult to prevent solid dissolving

OR

(Copper sulfate) solution will form

1

[8]

Q19.

(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 $\Delta H_r = -201 + (-242) - (-394)$
$\Delta H_r = -201 - 242 + 394$
$\Delta H_r = -443 + 394$
(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 + **1½** O_2 CO_2 + **2**H_2O
Ignore state symbols
Accept multiples

1

(iii) **3**H_2 + **1½** O_2 **3**H_2O
Ignore state symbols

OR

Accept multiples

2H_2 + O_2 **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 ΔT = 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]

Q20.

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

Not "oxidation" alone

1

(ii) Fe^{3+} + **3**e^- ⟶ Fe

Ignore state symbols

Do not penalise absence of charge on electron

Credit Fe^{3+} ⟶ *Fe – **3**e^-*

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 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 only M1*

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 the same reaction / same equation / same reactants and products

Penalise reference to CO_2 being produced by a different route

OR

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

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

OR

The same number and same type of bonds are broken and formed

1

[12]

Q21.

(a) One from

- Ti is not produced
- TiC / carbide is produced OR titanium reacts with carbon
- Product is brittle
- Product is a poor engineering material

Penalise "titanium carbonate"

Ignore "impure titanium"

Credit "titanium is brittle"

1

(b) Heat (energy) change at constant pressure

QoL

1

(c) The <u>enthalpy change</u> in a reaction is independent of the route taken (and depends only on the initial and final states)

Credit ''heat change at constant pressure" as an alternative to ''enthalpy change''

1

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

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

M2 is formed from its (constituent) <u>elements</u>

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

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

Ignore reference to 1 atmosphere

3

(e) (i) Na / it is not in its <u>standard state</u> / <u>normal state under standard conditions</u>

OR

<u>Standard state</u> / <u>normal state under standard conditions</u> for Na is solid / (s)

QoL

Ignore ''sodium is a liquid or sodium is not a solid''

1

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

M2 $\Delta H_r = 4(-411) - (-720) - 4(+3)$
$= -1644 + 720 - 12$
(This also scores M1)

M3 $= \mathbf{-936}$ (kJ mol^{-1})

Correct answer gains full marks

Credit 1 mark for + 936 *(kJ mol^{-1})*

Credit 1 mark for – 924 *(kJ mol^{-1})*
i.e. assuming value for Na(l) = 0

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 $2Cl_2$ and 4Na OR a **clear complete statement** of M1 which could be in words and scores <u>only M1</u>*

3

(iii) Reducing agent

Ignore "reduces titanium"

OR reductant OR reduces $TiCl_4$

OR electron donor

1

[7]

Q22.

(a) Heat (energy) change at constant pressure

Ignore references to standard conditions, but credit specified pressure.

1

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

1

(c) $\Delta H + 963 = -75 - 432$ OR $\Delta H + 963 = -507$ (**M1**)

$\Delta H = -75 - 432 - 963$ (**M1** and **M2**)

$\Delta H =$ **-1470** (kJ mol^{-1})

Award 1 mark for + 1470

Award full marks for correct answer

Ignore units.

Ignore numbers on the cycle

***M1** and **M2** can score for an arithmetic error*

3

[5]