M1.(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 $Fe^{3+} \longrightarrow Fe - 3e^-$

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 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

(iii) **M1** The enthalpy change / heat change at constant pressure when 1 molof a compound / substance / element

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

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

M3 with all reactants and products / all substances in standard states

For M3

Ignore reference to 1 atmosphere

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

3

(c) **M1 (could be scored by a correct mathematical expression which must have all ΔH symbols and the ∑)**

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 correct cycle of balanced equations with 2Fe, 3C and $3O_2$

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) 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 <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]

M2. (a) One from

- Ti is not produced
- TiC / <u>carbide</u> 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) <u>Heat</u> (energy) <u>change at constant pressure</u>

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</u>

standard states

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

Ignore reference to 1 atmosphere

3

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

OR

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

QoL

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

1

(ii) **M1** ΔH_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 = **−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 only M1*

3

(iii) Reducing agent

Ignore "reduces titanium"

OR reductant OR reduces $TiCl_4$

OR electron donor

1

[7]

M3. (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]

M4. (a) Enthalpy change for the formation of 1 mol of gaseous atoms

allow heat energy change for enthalpy change

1

From the element (in its standard state)

ignore reference to conditions

1

Enthalpy change to separate 1 mol of an ionic lattice/solid/compound

enthalpy change not required but penalise energy

1

Into (its component) gaseous ions

mark all points independently

1

(b) $\Delta H_L = {}^{-}\Delta H_f + \Delta H_a$ + I.E. + 1/2E(Cl-Cl) + EA

Or correct Born-Haber cycle drawn out

1

= +411 + 109 + 494 + 121 – 364

1

= +771 (kJ mol^{-1})

–771 scores 2/3

+892 scores 1/3

–51 scores 1/3

–892 scores zero

+51 scores zero *ignore units*

1

(c) (i) Ions are perfect spheres (or point charges)

1

Only electrostatic attraction/no covalent interaction

mention of molecules/intermolecular forces/covalent bonds CE = 0

allow ionic bonding only

If mention of atoms CE = 0 for M2

1

(ii) Ionic

Allow no covalent character/bonding

1

(iii) Ionic with additional covalent bonding

Or has covalent character/partially covalent

Allow mention of polarisation of ions or description of polarisation

1

[11]

M5. (a) The molecular ion is

- The molecule with one/an electron knocked off/lost
  Ignore the highest or biggest m/z peak

OR

- The molecule with a (single) positive charge

OR

- the ion with/it has the largest/highest/biggest m/z (value/ratio)
  Ignore "the peak to the right"

OR

- the ion with/it has an m/z equal to the M_r
  Ignore "compound"

1

(b) (i) 2(14.00307) + 15.99491 = 44.00105
A sum is needed to show this

1

(ii) Propane/C_3H_8 and carbon dioxide/CO_2 (and N_2O) or
they or both the gases/molecules or all three gases/molecules have an (imprecise) M_r of 44.0 (OR 44)

OR

they have the same $\boldsymbol{M_r}$ or molecular mass (to one d.p)
This could be shown in a calculation of relative masses for propane and carbon dioxide

1

(iii) By definition

OR

The standard/reference (value/isotope)
Ignore "element"

Ignore "atom"

1

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

$\Delta H = \Sigma \Delta H_{products} - \Sigma \Delta H_{reactants}$

OR a correct cycle of balanced equations

M1 and M2 can be scored with correct moles as follows
$\Delta H + 2(-46) = +82 + 3(-286)$

$\Delta H - 92 = -776$

$\Delta H = 92 - 776$ OR $92 + 82 - 858$

M3
$\Delta H = -684$ (kJ mol^{-1}) (This is worth 3 marks)

Award 1 mark ONLY for + 684

Full marks for correct answer.
Ignore units.
Deduct one mark for an arithmetic error.

3

(ii) The value is quoted at a pressure of 100 kPa OR 1 bar or 10^5 Pa

OR

All reactants and products are in their standard states/their normal states at 100 kPa or 1 bar

Ignore 1 atmosphere/101 kPa
Ignore "constant pressure"

1

[8]