

THERMODYNAMICS

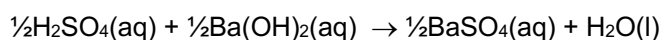
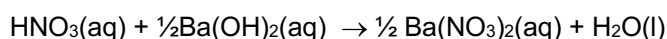
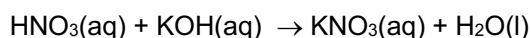
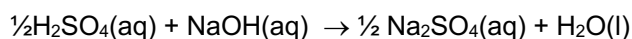
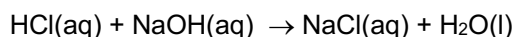
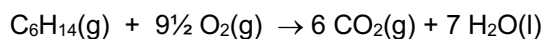
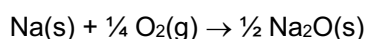
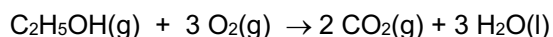
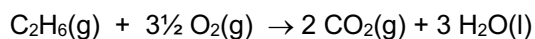
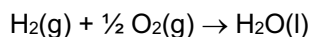
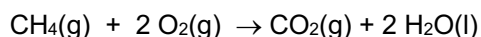
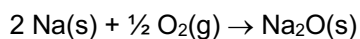
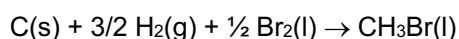
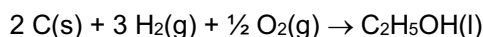
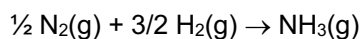
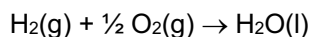
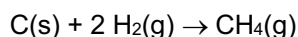


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Most answers in this topic are to the nearest unit unless stated otherwise (as data is to nearest unit and it is addition or subtraction)

PAGE 3 EXAMPLES



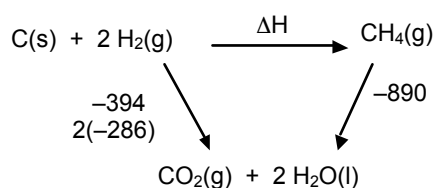
PAGE 4 EXAMPLES

Ex1 ΔH = [Sum of ΔH_f products] – [Sum ΔH_f reactants]
 = [-394 + 2(-286)] – [-75 + 0]
 = **-891 kJ mol⁻¹**

Ex2 ΔH = [Sum of ΔH_f products] – [Sum ΔH_f reactants]
 -2877 = [4(-394) + 5(-286)] – [$\Delta_f H$ + 0]
 $\Delta_f H$ = 2877 + 4(-394) + 5(-286)
 = **-129 kJ mol⁻¹**

PAGE 5 EXAMPLES

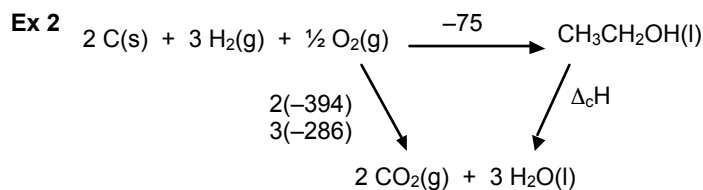
Ex 1



$$\Delta H - 890 = -394 + 2(-286)$$

$$\Delta H = -394 + 2(-286) + 890$$

$$= \textbf{-76 kJ mol}^{-1}$$

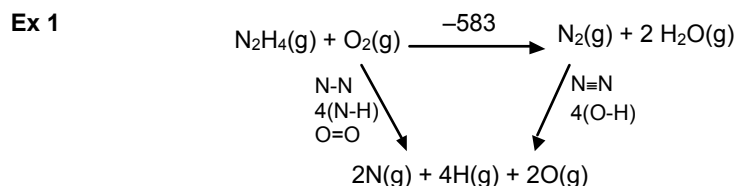


$$\Delta_c H - 75 = 2(-394) + 3(-286)$$

$$\Delta_c H = 2(-394) + 3(-286) + 75$$

$$= -1571 \text{ kJ mol}^{-1}$$

PAGE 6/7 EXAMPLES

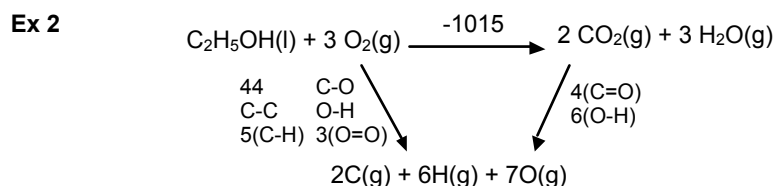


$$-583 + (\text{N}\equiv\text{N}) + 4(\text{O-H}) = (\text{N-N}) + 4(\text{N-H}) + (\text{O=O})$$

$$(\text{N-N}) = -583 + (\text{N}\equiv\text{N}) + 4(\text{O-H}) - 4(\text{N-H}) - (\text{O=O})$$

$$(\text{N-N}) = -583 + 944 + 4(463) - 4(388) - (498)$$

$$= +163 \text{ kJ mol}^{-1}$$



$$-1015 + 4(\text{C=O}) + 6(\text{O-H}) = 44 + (\text{C-C}) + 5(\text{C-H}) + (\text{C-O}) + (\text{O-H}) + 3(\text{O=O})$$

$$(\text{C-C}) = -1015 + 4(\text{C=O}) + 6(\text{O-H}) - 44 - 5(\text{C-H}) - (\text{C-O}) - (\text{O-H}) - 3(\text{O=O})$$

$$(\text{C-C}) = -1015 + 4(743) + 6(463) - 44 - 5(412) - (360) - (463) - 3(498)$$

$$= +314 \text{ kJ mol}^{-1}$$

PAGE 8 EXAMPLES

Ex 1

$$q = mc\Delta T$$

$$= 100 \times 4.18 \times 36 = 15048 \text{ J} = 15.048 \text{ kJ}$$

$$\text{moles CH}_3\text{CH}_2\text{CH}_2\text{OH} = \text{mass} / M_r = 0.500 / 60.0 = 0.00833$$

$$\Delta H = q / \text{moles} = -15.048 / 0.00833$$

$$= -1810 \text{ kJ mol}^{-1} \text{ (3sf)}$$

Ex 2 $q = mc\Delta T$
 $= 50 \times 4.18 \times 6.7 = 1400 \text{ J} = 1.400 \text{ kJ}$

moles NaOH = conc x vol (dm³) = $1.0 \times 25/1000 = 0.0250$

moles HCl = conc x vol (dm³) = $1.0 \times 25/1000 = 0.0250$

$\Delta H = q / \text{moles} = -1.400 / 0.0250$

$= -56 \text{ kJ mol}^{-1} \text{ (2sf)}$

Ex 3 $q = mc\Delta T$
 $= 50 \times 4.18 \times 24 = 5016 \text{ J} = 5.016 \text{ kJ}$

moles CuSO₄ = conc x vol (dm³) = $0.5 \times 50.0/1000 = 0.0250$

moles Zn = mass / M_r = $2.0 / 65.4 = 0.0306$

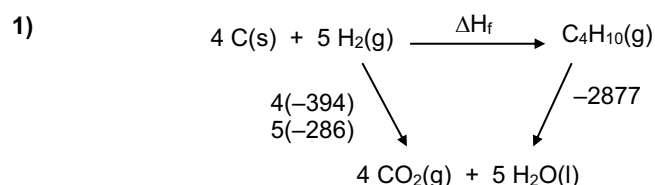
∴ zinc is in excess and 0.0250 moles of CuSO₄ reacts with 0.025 moles of Zn

$\Delta H = q / \text{moles} = -5.016 / 0.0250$

$= -201 \text{ kJ mol}^{-1} \text{ (3sf)}$

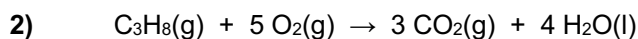
TASK 1 – AS Energetics Revision

- | | | |
|------------------------------------|------------------------------------|------------------------------|
| 1 -129 kJ mol ⁻¹ | 2 -2222 kJ mol ⁻¹ | 3 -1194 kJ mol ⁻¹ |
| 4 -2008 kJ mol ⁻¹ | 5 -184 kJ mol ⁻¹ | 6 -125 kJ mol ⁻¹ |
| 7 -1700 kJ mol ⁻¹ (2sf) | 8 -57.3 kJ mol ⁻¹ (3sf) | 9 -5116 kJ mol ⁻¹ |
| 10 +507 kJ mol ⁻¹ | | |



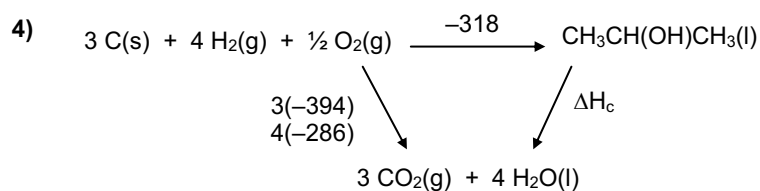
$$\begin{aligned}
 \Delta H_f - 2877 &= 4(-394) + 5(-286) & \Delta H_f &= 4(-394) + 5(-286) + 2877 \\
 & & &= -129 \text{ kJ mol}^{-1}
 \end{aligned}$$

OR $\Delta H = [\text{Sum of } \Delta H_c \text{ reactants}] - [\text{Sum } \Delta H_c \text{ products}]$
 $= [4(-394) + 5(-286)] - [-2877]$
 $= -129 \text{ kJ mol}^{-1}$



$$\begin{aligned}
 \Delta H &= [\text{Sum of } \Delta H_f \text{ products}] - [\text{Sum } \Delta H_f \text{ reactants}] \\
 &= [3(-394) + 4(-286)] - [-104] \\
 &= -2222 \text{ kJ mol}^{-1}
 \end{aligned}$$

3) Broken $\text{C}-\text{C} + 6 \text{C}-\text{H} + 3\frac{1}{2} \text{O}=\text{O} = 348 + 6(412) + 3\frac{1}{2}(496) = 4556$
 Made $4 \text{C}=\text{O} + 6 \text{O}-\text{H} = 4(743) + 6(463) = 5750$
 $\Delta H = [\text{Bond broken}] - [\text{Bonds made}] = 4556 - 5750 = \mathbf{-1194 \text{ kJ mol}^{-1}}$

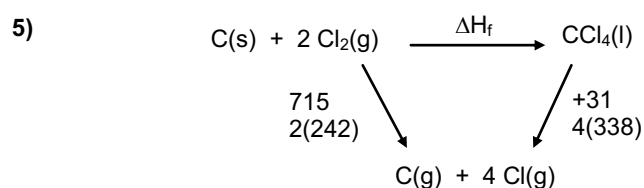


$$\begin{aligned}
 -318 + \Delta H_c &= 3(-394) + 4(-286) & \Delta H_c &= 3(-394) + 4(-286) + 318 \\
 & & &= \mathbf{-2008 \text{ kJ mol}^{-1}}
 \end{aligned}$$

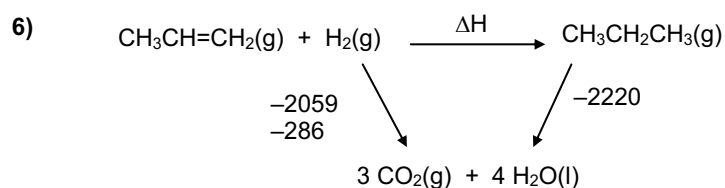
OR $\Delta H = [\text{Sum of } \Delta H_c \text{ reactants}] - [\text{Sum } \Delta H_c \text{ products}]$

$$-318 = [3(-394) + 4(-286)] - [\Delta H_c]$$

$$\Delta H_c = 3(-394) + 4(-286) + 318 = \mathbf{-2008 \text{ kJ mol}^{-1}}$$



$$\begin{aligned}
 \Delta H_f + 31 + 4(338) &= 715 + 2(242) & \Delta H_f &= 715 + 2(242) - 31 - 4(338) \\
 & & &= \mathbf{-184 \text{ kJ mol}^{-1}}
 \end{aligned}$$



$$\begin{aligned}
 \Delta H - 2220 &= -2059 - 286 & \Delta H &= -2059 - 286 + 2220 \\
 & & &= \mathbf{-125 \text{ kJ mol}^{-1}}
 \end{aligned}$$

OR $\Delta H = [\text{Sum of } \Delta H_c \text{ reactants}] - [\text{Sum } \Delta H_c \text{ products}]$

$$= [-2059 - 286] - [-2220]$$

$$= \mathbf{-125 \text{ kJ mol}^{-1}}$$

7) $q = mc\Delta T$
 $= 80 \times 4.18 \times 47.3 = 15820 \text{ J} = 15.82 \text{ kJ}$

$$\text{moles CH}_3\text{COCH}_3 = \text{mass} / M_r = 0.55 / 58.0 = 0.00948$$

$$\begin{aligned}
 \Delta H &= q / \text{moles} = -15.82 / 0.00948 \\
 &= \mathbf{-1700 \text{ kJ mol}^{-1} (2\text{sf})}
 \end{aligned}$$

8) $q = mc\Delta T$
 $= 50 \times 4.18 \times (33.9 - 20.2) = 2863 \text{ J} = 2.863 \text{ kJ}$

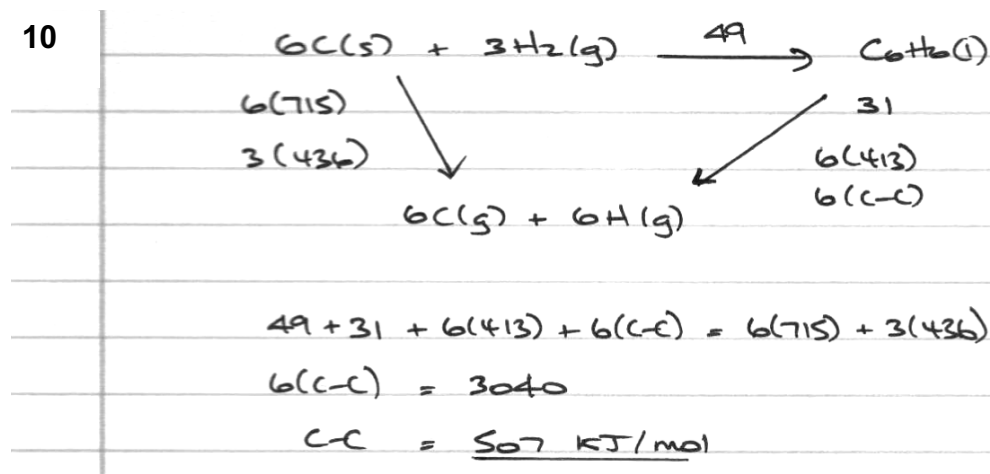
moles KOH = conc x vol (dm³) = $2.0 \times 25/1000 = 0.0500$

moles HNO₃ = conc x vol (dm³) = $2.0 \times 25/1000 = 0.0500$

$\Delta H = q / \text{moles} = -2.863 / 0.0500$

$= -57.3 \text{ kJ mol}^{-1} \text{ (3sf)}$

9 $\Delta H = (\text{Sum } \Delta H_f^{\circ} \text{ products}) - (\text{Sum } \Delta H_f^{\circ} \text{ reactants})$
 $= [4(-393) + 12(-286) + 0] - [4(53) + 5(-20)]$
 $= -5116 \text{ kJ/mol}$



TASK 2 – Enthalpy Change Definitions

- 1 $\Delta_f H$ of $C_6H_6(l)$ $6C(s) + 3H_2(g) \rightarrow C_6H_6(l)$
- 2 $\Delta_f H$ of $CH_3COOH(l)$ $2C(s) + 2H_2(g) + O_2(g) \rightarrow CH_3COOH(l)$
- 3 $\Delta_c H$ of $H_2(g)$ $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$
- 4 $\Delta_c H$ of $CH_3COOH(l)$ $CH_3COOH(l) + 2O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l)$
- 5 1st ionisation energy of aluminium $Al(g) \rightarrow Al^+(g) + e^-$
- 6 2nd ionisation energy of aluminium $Al^+(g) \rightarrow Al^{2+}(g) + e^-$
- 7 3rd ionisation energy of aluminium $Al^{2+}(g) \rightarrow Al^{3+}(g) + e^-$
- 8 1st electron affinity of chlorine $Cl(g) + e^- \rightarrow Cl^-(g)$
- 9 lattice enthalpy of formation of sodium oxide $2Na^+(g) + O^{2-}(g) \rightarrow Na_2O(s)$
- 10 lattice enthalpy of dissociation of aluminium oxide $Al_2O_3(s) \rightarrow 2Al^{3+}(g) + 3O^{2-}(g)$
- 11 $\Delta_{hyd} H$ of sodium ions $Na^+(g) \xrightarrow{aq} Na^+(aq)$
- 12 Enthalpy of vaporisation of bromine $Br_2(l) \rightarrow Br_2(g)$
- 13 $\Delta_{sol} H$ of sodium hydroxide $NaOH(s) \xrightarrow{aq} Na^+(aq) + OH^-(aq)$
- 14 Enthalpy of fusion of sodium chloride $NaCl(s) \rightarrow NaCl(l)$
- 15 Bond dissociation enthalpy of water $\frac{1}{2}H_2O(g) \rightarrow H(g) + \frac{1}{2}O(g)$
- 16 Bond dissociation enthalpy of hydrogen $H_2(g) \rightarrow 2H(g)$
- 17 $\Delta_{atm} H$ of bromine $\frac{1}{2}Br_2(l) \rightarrow Br(g)$
- 18 Bond dissociation enthalpy of bromine $Br_2(g) \rightarrow 2Br(g)$
- 19 1st electron affinity of bromine $Br(g) + e^- \rightarrow Br^-(g)$
- 20 2nd electron affinity of sulfur $S^-(g) + e^- \rightarrow S^{2-}(g)$

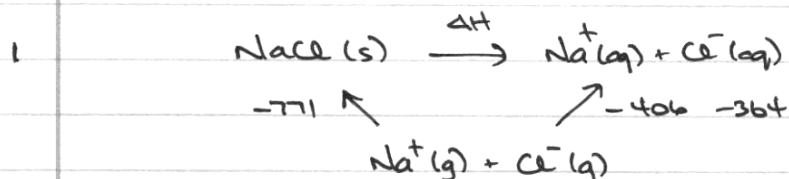
TASK 3 – More Enthalpy Change Definitions

- 1) $\text{Ca(g)} \rightarrow \text{Ca}^+(\text{g}) + \text{e}^-$ 1st ionisation of Ca
- 2) $\text{S(g)} + 2 \text{e}^- \rightarrow \text{S}^{2-}(\text{g})$ 1st + 2nd electron affinity S
- 3) $\text{Al}_2\text{O}_3(\text{s}) \rightarrow 2 \text{Al}^{3+}(\text{g}) + 3 \text{O}^{2-}(\text{g})$ lattice dissociation Al_2O_3
- 4) $\text{NaBr(s)} \rightarrow \text{Na}^+(\text{aq}) + \text{Br}^-(\text{aq})$ solution NaBr
- 5) $\text{I}_2(\text{s}) \rightarrow 2 \text{I(g)}$ 2 x atomisation of I
- 6) $\text{C}_3\text{H}_8(\text{g}) + 5 \text{O}_2(\text{g}) \rightarrow 3 \text{CO}_2(\text{g}) + 4 \text{H}_2\text{O(l)}$ combustion C_3H_8
- 7) $4 \text{Al(s)} + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{Al}_2\text{O}_3(\text{s})$ 2 x formation Al_2O_3
- 8) $\text{Ca}^{2+}(\text{g}) + \text{O}^{2-}(\text{g}) \rightarrow \text{CaO(s)}$ lattice formation CaO
- 9) $\text{Na(s)} \rightarrow \text{Na(g)}$ atomisation Na
- 10) $\text{P}_4(\text{s}) \rightarrow 4 \text{P(g)}$ 4 x atomisation P
- 11) $\text{HCl(g)} \rightarrow \text{H(g)} + \text{Cl(g)}$ bond enthalpy HCl
- 12) $\text{H}_2\text{O(l)} \rightarrow 2 \text{H(g)} + \text{O(g)}$ vaporisation H_2O + 2 x bond enthalpy O-H
- 13) $\text{Al(g)} \rightarrow \text{Al}^{3+}(\text{g}) + 3 \text{e}^-$ 1st + 2nd + 3rd ionisation Al
- 14) $\text{Ca}^{2+}(\text{g}) \rightarrow \text{Ca}^{2+}(\text{aq})$ hydration Ca^{2+}
- 15) $\text{Mg(s)} \rightarrow \text{Mg}^{2+}(\text{g}) + 2 \text{e}^-$ atomisation Mg + 1st + 2nd ionisation Mg
- 16) $\text{Mg(s)} + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{MgO(s)}$ formation MgO

TASK 4 – Enthalpy of solution calculations

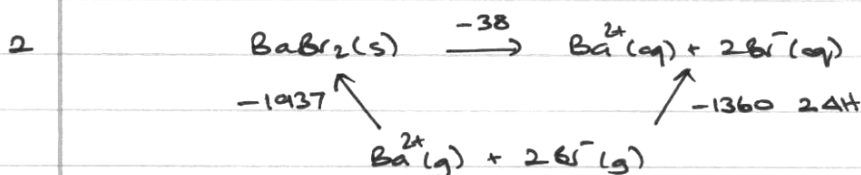
- 1 +1 kJ mol⁻¹
3 -2116 kJ mol⁻¹

- 2 -307.5 kJ mol⁻¹
4 -25 kJ mol⁻¹



$$\Delta H - 771 = -406 - 364$$

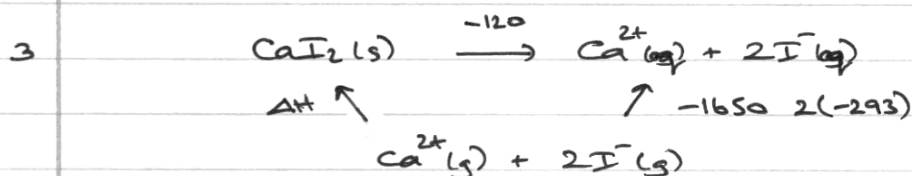
$$\Delta H = \underline{+1 \text{ kJ/mol}}$$



$$-1360 + 2\Delta H = -1937 - 38$$

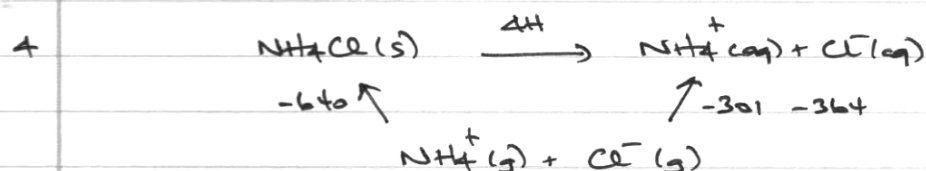
$$2\Delta H = -615$$

$$\Delta H = \underline{-307.5 \text{ kJ/mol}}$$



$$\Delta H - 120 = -1650 + 2(-293)$$

$$\Delta H = -2116 \text{ kJ/mol}$$



$$\Delta H - 640 = -301 - 364$$

$$\Delta H = \underline{-25 \text{ kJ/mol}}$$

PAGE 14 EXAMPLE

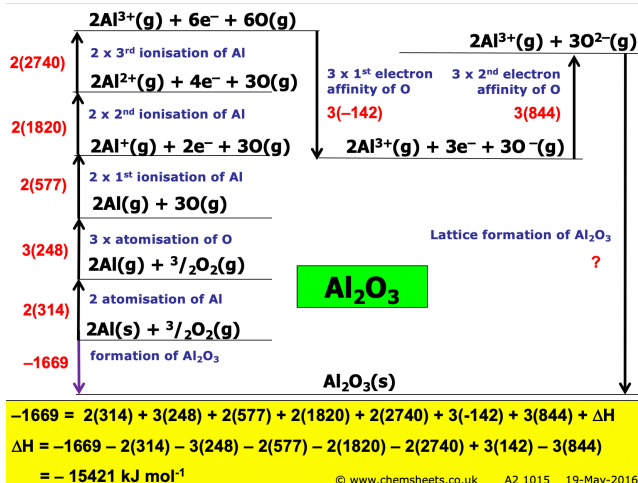
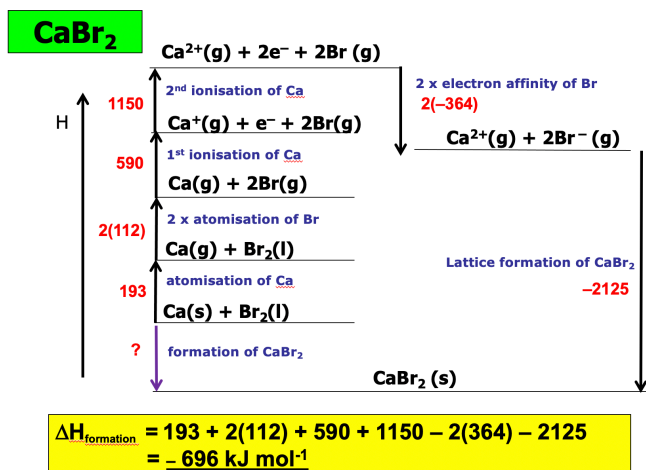
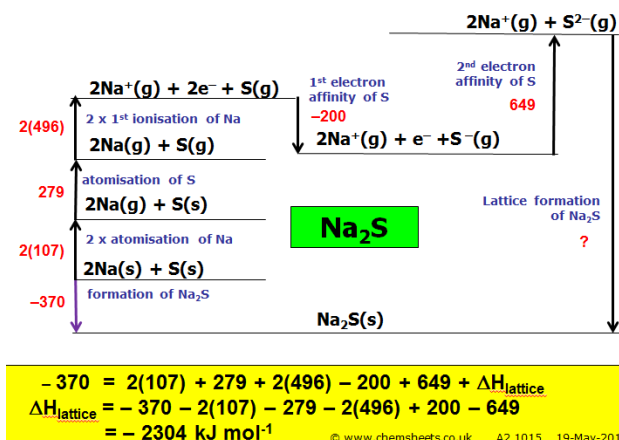
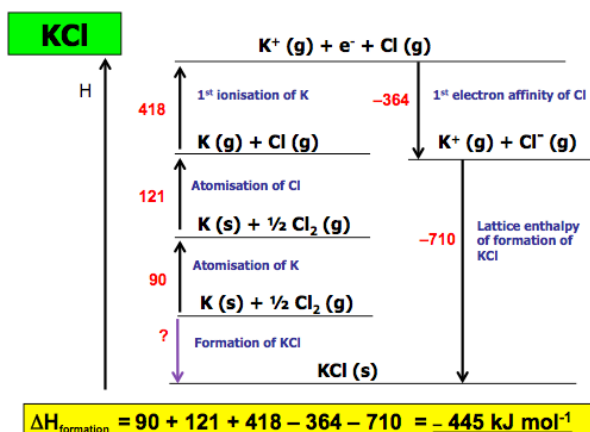


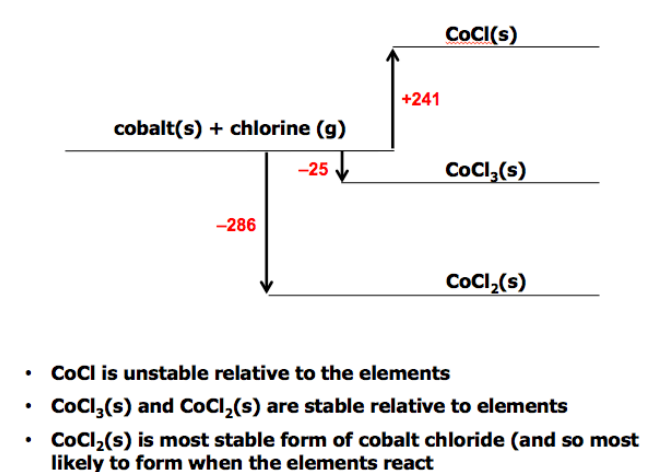
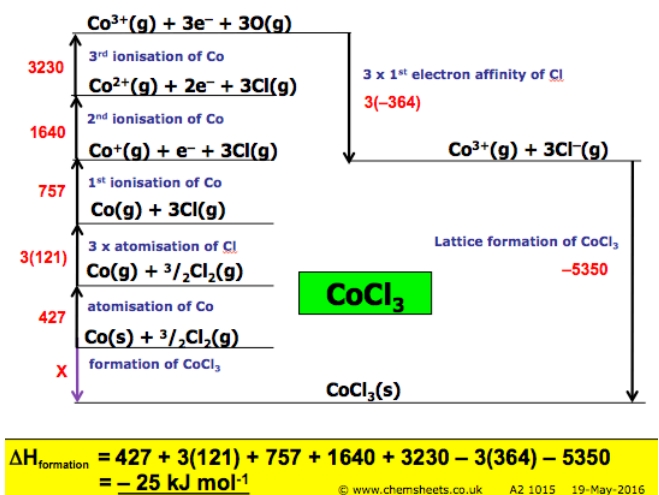
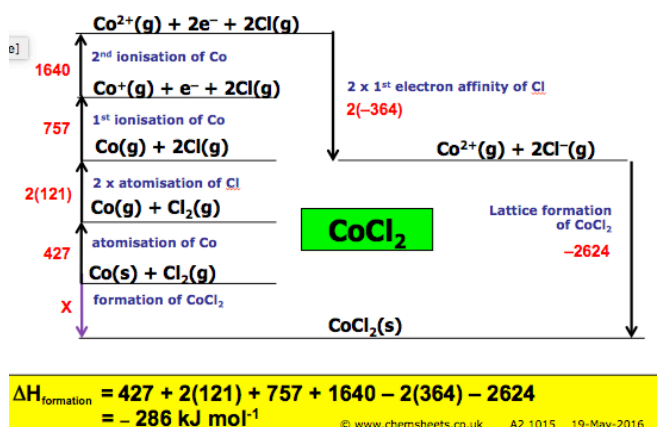
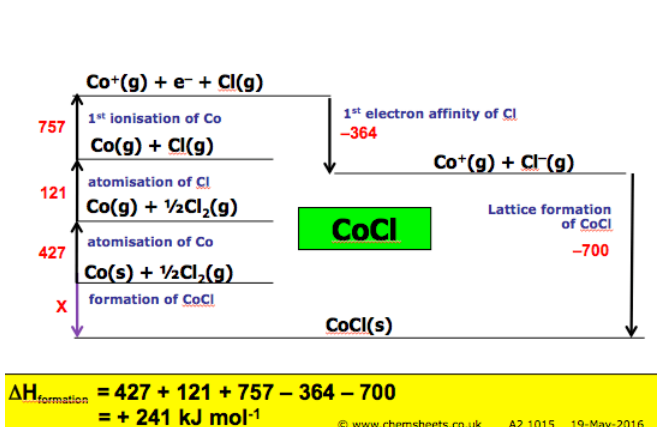
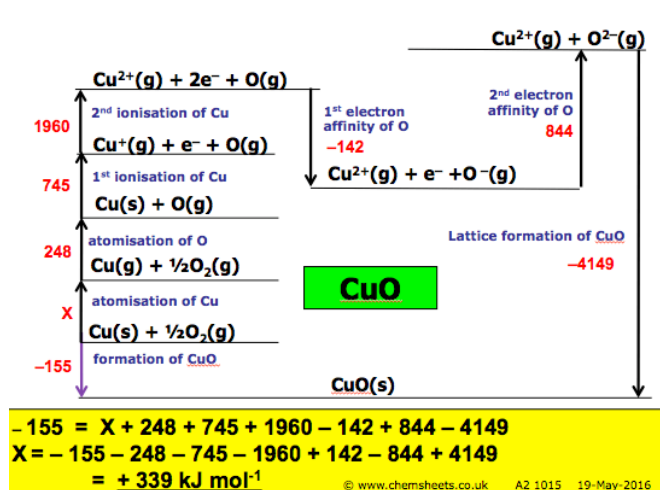
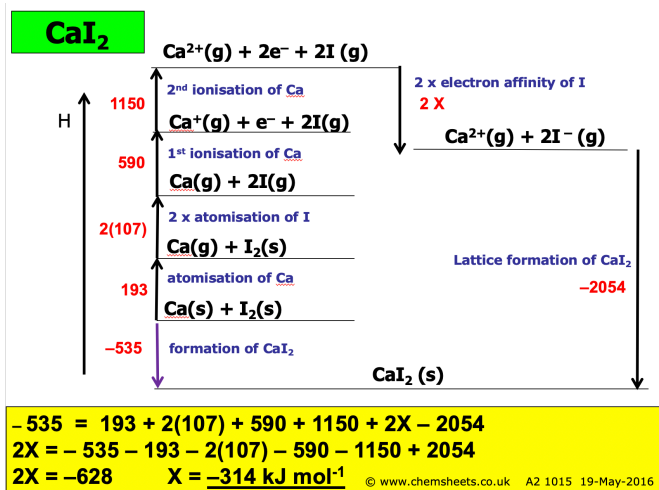
Al^{3+} has highest charge and smallest of the three positive ions and so the strongest attraction between the positive ions and the oxide ions

Of the other two positive ions, Mg^{2+} is smaller than Ca^{2+} and therefore there will be a stronger attraction between the Mg^{2+} and oxide ions than between the Ca^{2+} and oxide ions

TASK 5 – Born-Haber cycle problems

- | | | | | | |
|---|---|---|-----------------------------|---|----------------------------|
| 1 | -445 kJ mol^{-1} | 2 | $-2304 \text{ kJ mol}^{-1}$ | 3 | -652 kJ mol^{-1} |
| 4 | $-15421 \text{ kJ mol}^{-1}$ | 5 | -314 kJ mol^{-1} | 6 | $+339 \text{ kJ mol}^{-1}$ |
| 6 | $\text{CoCl} = +241 \text{ kJ mol}^{-1}, \text{CoCl}_2 = -286 \text{ kJ mol}^{-1}, \text{CoCl}_3 = -25 \text{ kJ mol}^{-1}$ | | | | |

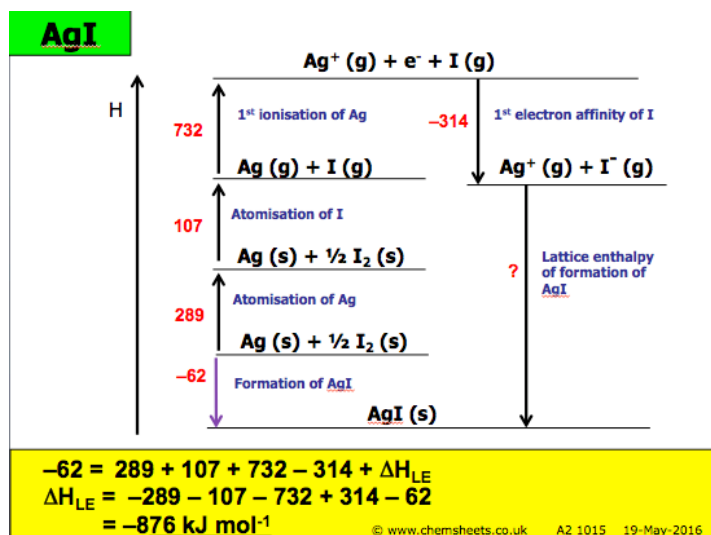




TASK 6 – Lattice enthalpy problems

- 1 a) formation – as energy is released when electrostatic attractions between ions form
 b) silver bromide – greatest magnitude of lattice enthalpy (using real values, i.e. the experimental values)
 c) silver bromide – greatest difference between experimental and theoretical lattice enthalpy values
 d) silver bromide has significant covalent character
- 2 a) $100 \times 36/3513 = 1.02\%$
 b) high lattice enthalpy (NB – not due to covalent character as it is only small)

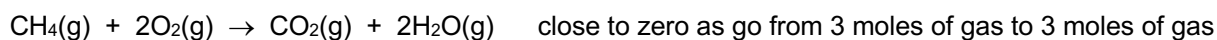
3 a)



- b) using the charge and size of ions assuming that the structure is perfectly ionic
 c) -876 kJ mol^{-1}
 d) significant covalent character

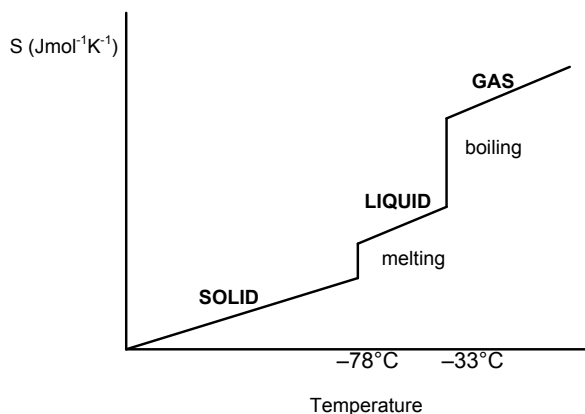
PAGE 21 EXAMPLES

$$\begin{aligned} \Delta S &= [\text{Sum of } S \text{ products}] - [\text{Sum } S \text{ reactants}] \\ &= [2(214) + 3(70)] - [161 + 3(205)] \\ &= -138 \text{ kJ mol}^{-1} \end{aligned}$$



TASK 7 – Entropy change calculations

1



- 2
- increase as go from one mole of solid to two moles of aqueous ions (one mole of $\text{Na}^+(\text{aq})$ and one mole of $\text{Cl}^-(\text{aq})$)
 - decrease as go from one mole of liquid to one mole of solid
 - increase as go from two moles of gas to three moles of gas
 - decrease as go from four moles of gas to two moles of gas
 - close to zero as go from two moles of gas to two moles of gas
 - increase as go from one mole of solid to one mole of solid and one mole of gas
 - decrease as go from six moles of aqueous ions (Ba^{2+} , 2NO_3^- , 2K^+ , SO_4^{2-}) to four moles of aqueous ions (2K^+ , 2NO_3^-) and one mole of solid

- 3
- $$\Delta S = [\text{Sum of } S \text{ products}] - [\text{Sum } S \text{ reactants}]$$

$$= [70] - [189]$$

$$= -119 \text{ J mol}^{-1} \text{ K}^{-1}$$
 - $$\Delta S = [\text{Sum of } S \text{ products}] - [\text{Sum } S \text{ reactants}]$$

$$= [40 + 214] - [93]$$

$$= +161 \text{ J mol}^{-1} \text{ K}^{-1}$$
 - $$\Delta S = [\text{Sum of } S \text{ products}] - [\text{Sum } S \text{ reactants}]$$

$$= [3(214) + 4(70)] - [270 + 5(205)]$$

$$= -373 \text{ J mol}^{-1} \text{ K}^{-1}$$
 - $$\Delta S = [\text{Sum of } S \text{ products}] - [\text{Sum } S \text{ reactants}]$$

$$= [2(35) + 3(214)] - [90 + 3(198)]$$

$$= +28 \text{ J mol}^{-1} \text{ K}^{-1}$$

PAGE 24 EXAMPLE

a) $\Delta H = [\text{Sum of } \Delta H_f \text{ products}] - [\text{Sum } \Delta H_f \text{ reactants}]$
 $= [-348 - 394] - [-812]$
 $= +70 \text{ kJ mol}^{-1}$

$$\Delta S = [\text{Sum of } S \text{ products}] - [\text{Sum } S \text{ reactants}]$$
$$= [44 + 214] - [83]$$
$$= +175 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$\Delta G = \Delta H - T\Delta S$$
$$= 70 - 298(175/1000)$$
$$= +17.9 \text{ kJ mol}^{-1}$$

b) Reaction is not feasible at 298 K (as ΔG is positive)

c) When $\Delta G = 0$:

$$0 = \Delta H - T\Delta S$$

$$\Delta H = T\Delta S$$

$$T = \frac{\Delta H}{\Delta S} = \frac{70}{175/1000} = 400 \text{ K (2sf)}$$

Reaction is feasible at temperatures greater and above 400 K

PAGE 25 EXAMPLES

Ex1 When $\Delta G = 0$:

$$0 = \Delta H - T\Delta S$$

$$\Delta H = T\Delta S$$

$$T = \frac{\Delta H}{\Delta S} = \frac{25.5}{24.5/1000} = 1040 \text{ K (3 sf)}$$

Ex2 When $\Delta G = 0$:

$$0 = \Delta H - T\Delta S$$

$$\Delta H = T\Delta S$$

$$\Delta S = \frac{\Delta H}{T} = \frac{43.5}{351} = 0.124 \text{ kJ mol}^{-1} \text{ K}^{-1} = 124 \text{ J mol}^{-1} \text{ K}^{-1} \text{ (allow 2 or 3 sf)}$$

TASK 8 – Gibbs free energy calculations

- 1 a) -191 kJ mol^{-1} (3sf), b) yes, feasible, c) high activation energy
- 2 a) $\Delta H = +129 \text{ kJ mol}^{-1}$, $\Delta S = +335 \text{ J mol}^{-1} \text{ K}^{-1}$, b) $+29.2 \text{ kJ mol}^{-1}$ (3sf), c) $T \geq 385 \text{ K}$ (3sf)
- 3 a) $\Delta H = -822 \text{ kJ mol}^{-1}$, $\Delta S = -272 \text{ J mol}^{-1} \text{ K}^{-1}$, b) $\Delta G = -741 \text{ kJ mol}^{-1}$ (3sf), c) $T \leq 3030 \text{ K}$ (3sf)
- 4 a) $\Delta S = -107 \text{ J mol}^{-1} \text{ K}^{-1}$
- 5 a) $\Delta H = +96 \text{ kJ mol}^{-1}$, $\Delta S = +138 \text{ J mol}^{-1} \text{ K}^{-1}$, $\Delta G = +54.9 \text{ kJ mol}^{-1}$ (3sf), b) no, c) $T \geq 696 \text{ K}$ (3sf)
- 6 a) $\Delta S = +10 \text{ J mol}^{-1} \text{ K}^{-1}$ (2sf), b) 110 K (2sf)
- 7 a) $\Delta H = +15 \text{ kJ mol}^{-1}$, d) $\Delta S = +50.3 \text{ J mol}^{-1} \text{ K}^{-1}$
- 8 a) $\Delta H = +178 \text{ kJ mol}^{-1}$, $\Delta S = +164 \text{ J mol}^{-1} \text{ K}^{-1}$, $\Delta G = +129 \text{ kJ mol}^{-1}$ (3sf), $T \geq 1090 \text{ K}$ (3sf)
- b) $\Delta H = +117 \text{ kJ mol}^{-1}$, $\Delta S = +175 \text{ J mol}^{-1} \text{ K}^{-1}$, $\Delta G = +64.9 \text{ kJ mol}^{-1}$ (3sf), $T \geq 669 \text{ K}$ (3sf)

$$\begin{aligned}
 1 \quad a) \quad \Delta G &= \Delta H - T\Delta S \\
 &= -185 - 298 \left(\frac{29}{1000} \right) \\
 &= -191 \text{ kJ mol}^{-1}
 \end{aligned}$$

b) Yes – feasible

c) High E_a

$$\begin{aligned}
 2 \quad a) \quad \Delta H &= [\text{Sum } \Delta H_f \text{ products}] - [\text{Sum } \Delta H_f \text{ reactants}] \\
 &= [-1131 - 394 - 242] - [2(-948)] \\
 &= +129 \text{ kJ mol}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 \Delta S &= [\text{Sum } S \text{ products}] - [\text{Sum } S \text{ reactants}] \\
 &= [136 + 214 + 189] - [2(102)] \\
 &= +335 \text{ J mol}^{-1} \text{ K}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 b) \quad \Delta G &= \Delta H - T\Delta S \\
 &= 129 - 298 \left(\frac{335}{1000} \right) \\
 &= +29.2 \text{ kJ mol}^{-1} \quad \underline{\underline{3sf}}
 \end{aligned}$$

$$c) \quad \text{When } \Delta G = 0 \quad T = \frac{\Delta H}{\Delta S} = \frac{129}{\frac{335}{1000}} = 385 \text{ K}$$

$\therefore$ feasible when $T \geq 385 \text{ K}$ 3sf

3

$$\Delta H = (-822) - (0 + 0) = -822 \text{ kJ mol}^{-1}$$

$$\Delta S = (90) - (2(27) + 3/2(205)) = -271.5 \text{ J mol}^{-1} \text{K}^{-1}$$

$$\Delta G = -822 - 298 \left(\frac{-271.5}{1000} \right) = -741 \text{ kJ mol}^{-1} \quad \underline{3sf}$$

$$\Delta G = 0 \quad T = \frac{\Delta H}{\Delta S} = \frac{-822}{\frac{-271.5}{1000}} = 3030 \text{ K} \quad \underline{3sf}$$

Feasible if $T \leq 3028 \text{ K}$

4

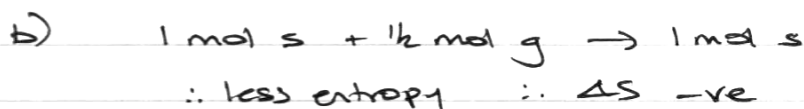
$$a) \quad \Delta G = \Delta H - T\Delta S$$

$$T\Delta S = \Delta H - \Delta G$$

$$\Delta S = \frac{\Delta H - \Delta G}{T} = \frac{-602 - (-570)}{298}$$

$$= -0.107 \text{ kJ mol}^{-1} \text{K}^{-1}$$

$$= -107 \text{ J mol}^{-1} \text{K}^{-1}$$



5

$$a) \quad \Delta H = [0 + 3(-242)] - [-822 + 0] = +96 \text{ kJ mol}^{-1}$$

$$\Delta S = [2(27) + 3(189)] - [90 + 3(131)] = +138 \text{ J mol}^{-1} \text{K}^{-1}$$

$$\Delta G = 96 - 298 \left(\frac{138}{1000} \right) = +54.9 \text{ kJ mol}^{-1} \quad \underline{3sf}$$

b) not feasible

$$c) \quad \Delta G = 0 \quad T = \frac{\Delta H}{\Delta S} = \frac{96}{\frac{138}{1000}} = 696 \text{ K} \quad \underline{3sf}$$

Feasible if $T \geq 696 \text{ K}$

6

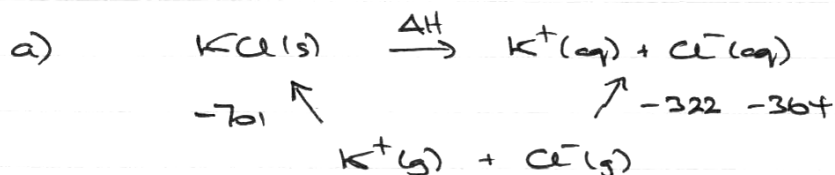
a) At 91 K, $\Delta G = 0$ $\therefore \Delta H - T\Delta S = 0$
 $\Delta H = T\Delta S$
 $\Delta S = \frac{\Delta H}{T} = \frac{0.94}{91} = 0.0103 \text{ kJ mol}^{-1} \text{ K}^{-1}$
 $= 10 \text{ J mol}^{-1} \text{ K}^{-1}$ 2sf

b) At bpt $\Delta G = 0$ $T = \frac{\Delta H}{\Delta S} = \frac{8.2}{\frac{73.2}{1000}} = 110 \text{ K}$ 2sf

c) $\Delta S_{\text{boiling}}^{(73.2)} > \Delta S_{\text{melting}}^{(10.3)}$
 increase in disorder of particles much greater on
 liquid $\rightarrow$ gas than solid $\rightarrow$ liquid

d) driving force is increase in entropy

7



$$\Delta H - 701 = -322 - 364$$

$$\Delta H = +15 \text{ kJ mol}^{-1}$$

b) ΔS +ve
 + c) increase in disorder as ions become dissolved
 ΔS must be +ve for $\Delta G \leq 0$ as ΔH +ve

d) if $\Delta G = 0$ $\Delta H = T\Delta S$
 $\Delta S = \frac{\Delta H}{T} = \frac{15}{298} = 0.0503 \text{ kJ mol}^{-1} \text{ K}^{-1}$
 $= 50.3 \text{ J mol}^{-1} \text{ K}^{-1}$

a) i) $\Delta H = [\text{Sum } \Delta H_f \text{ products}] - [\text{Sum } \Delta H_f \text{ reactants}]$
 $= [-635 - 394] - [-1207]$
 $= \underline{+178 \text{ kJ mol}^{-1}} \quad \checkmark$

ii) $\Delta S = [\text{Sum } S \text{ products}] - [\text{Sum } S \text{ reactants}]$
 $= [40 + 214] - [90]$
 $= \underline{+164 \text{ J mol}^{-1} \text{ K}^{-1}} \quad \checkmark$

iii) $\Delta G = \Delta H - T\Delta S$
 $= 178 - 298 \left(\frac{164}{1000} \right)$
 $= \underline{+129 \text{ kJ mol}^{-1}} \quad \checkmark \quad \underline{3sf}$

iv) $\checkmark$ reaction is not spontaneous / feasible at 298 K

v) $\Delta G = 178 - T \left(\frac{164}{1000} \right)$
 $\checkmark$ as T increases, ΔG more -ve

vi) $\checkmark \Delta G = 0, T = \frac{\Delta H}{\Delta S}$
 $\checkmark T = \frac{178}{\left(\frac{164}{1000} \right)}$

$\checkmark = 1090 \text{ K} \quad \underline{3sf} \quad \text{allow } 1080 \text{ K}$

vii) $\checkmark$ spontaneous if $T \geq 1090 \text{ K}$

viii) $\checkmark$ due to increase in entropy

b) i) $\Delta H = [-602 - 394] - [-1113] = +117 \text{ kJ mol}^{-1} \quad \checkmark$

ii) $\Delta S = [27 + 214] - [66] = +175 \text{ J mol}^{-1} \text{ K}^{-1} \quad \checkmark$

iii) $\Delta G = 117 - 298 \left(\frac{175}{1000} \right) = +64.9 \text{ kJ mol}^{-1} \quad \underline{3sf} \quad \checkmark$

iv) $T = \frac{117}{\left(\frac{175}{1000} \right)} = 669 \text{ K} \quad \underline{3sf} \quad \checkmark$

c) $\checkmark \text{ CaCO}_3$ more stable

$\checkmark \text{ Ca}^{2+}$ less polarising than Mg^{2+}