# Topic Test: OxfordAQA International A level Chemistry

A2 Physical Chemistry: Unit 3 content

Name: ______________________

Class: ______________________

Date: ______________________

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Time: **78 minutes**

Marks: **66 marks**

Comments:

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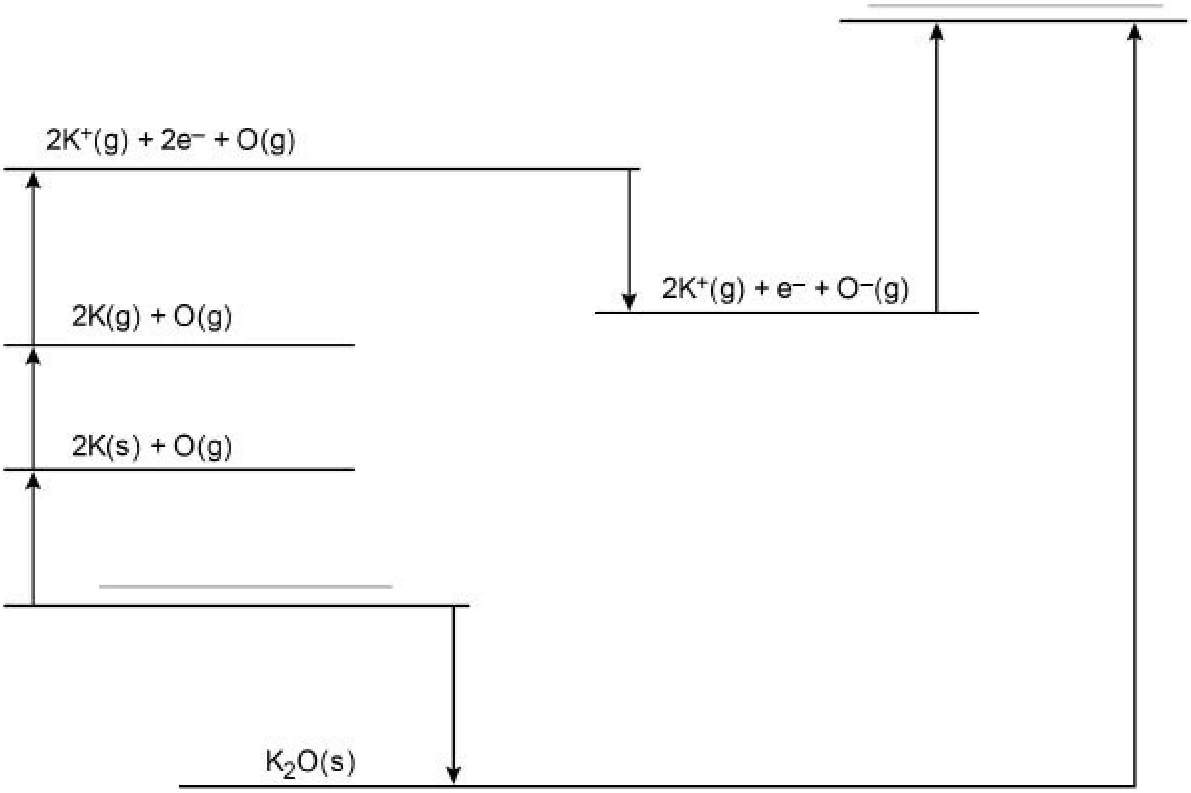
**1** Born−Haber cycles can be used to show the enthalpy changes involved in the formation of an ionic compound.

The diagram below shows an incomplete Born−Haber cycle for the formation of potassium oxide ($K_2O$).

The Born−Haber cycle is not to scale.



(a) Complete the diagram above by writing the formulae, including state symbols, of the appropriate species on each of the two blank lines.

**(2)**

The table below shows the enthalpy changes involved in the formation of potassium oxide.

| **Enthalpy change** | **$\Delta H$/kJ mol$^{-1}$** |
|---|---|
| Enthalpy of atomisation of potassium | +90 |
| Enthalpy of formation of potassium oxide | −362 |
| Enthalpy of atomisation of oxygen | +248 |
| First electron affinity of oxygen | −142 |
| First ionisation energy of potassium | +418 |
| Second electron affinity of oxygen | +844 |

(b) Give the meaning of the term enthalpy of atomisation.

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**(2)**

(c) Suggest why the second electron affinity of oxygen is endothermic.

______________________________________________________________________

**(1)**

(d) Use the data in the table above to calculate the enthalpy of lattice dissociation of potassium oxide.

enthalpy of lattice dissociation = ______________________ kJ mol$^{-1}$

**(3)**

(e) A theoretical value for the enthalpy of lattice dissociation can be calculated using a perfect ionic model.

The theoretical enthalpy of lattice dissociation for silver fluoride is +870 kJ mol$^{-1}$

Explain why the theoretical enthalpy of lattice dissociation for silver fluoride is different from the experimental value calculated using a Born−Haber cycle.

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

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**(2)**

(f) The theoretical enthalpy of lattice dissociation for silver chloride is +770 kJ mol$^{-1}$

Explain why this value is less than the value for silver fluoride.

**(2)**

**(Total 12 marks)**

**2** This question is about ionic solids dissolving in water.

The table shows four enthalpy changes, **A**, **B**, **C** and **D**.

| | **Enthalpy change** | **$\Delta H$ / kJ mol$^{-1}$** |
|---|---|---|
| **A** | Enthalpy of hydration of chloride ions | –364 |
| **B** | Enthalpy of hydration of magnesium ions | |
| **C** | Enthalpy of lattice dissociation of magnesium chloride | +2493 |
| **D** | Enthalpy of solution of magnesium chloride | –155 |

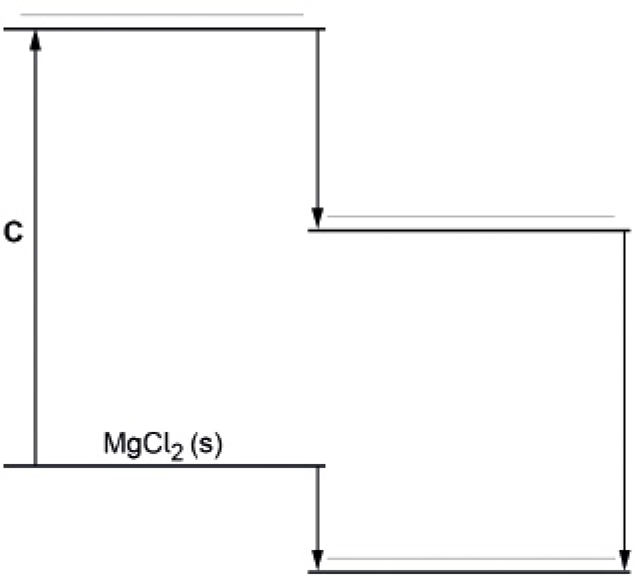
(a) Give the meaning of the term enthalpy of hydration.

**(1)**

(b) The diagram below shows an incomplete enthalpy cycle for the dissolving of magnesium chloride.

On the diagram

- Write the missing species on each of the three blank lines.
- Label each arrow using the appropriate letters from the table.



**(4)**

(c) Use the data in the table to calculate the enthalpy of hydration of magnesium ions.

Show your working.

Enthalpy of hydration of magnesium ions ____________________ kJ $mol^{-1}$

**(2)**

(d) Heat-packs can be used to treat muscular injuries. Some heat-packs work by dissolving an ionic compound in water.

In one type of heat-pack, 10.0 g of magnesium chloride were dissolved in water at 20.0 °C to give 150 g of solution.

Calculate the maximum temperature, in °C, of the heat-pack.
Give your answer to **three** significant figures.

The enthalpy of solution of magnesium chloride = $-155$ kJ $\text{mol}^{-1}$
The specific heat capacity of the solution = 4.18 J $\text{K}^{-1}$ $\text{g}^{-1}$

Maximum temperature ____________________ °C

**(4)**

**(Total 11 marks)**

**3** Which reaction has a negative value of entropy change, $\Delta S$?

**A** $CO_2(g) + C(s) \longrightarrow 2CO(g)$ ○

**B** $2H_2S(g) + SO_2(g) \longrightarrow 3S(s) + 2H_2O(l)$ ○

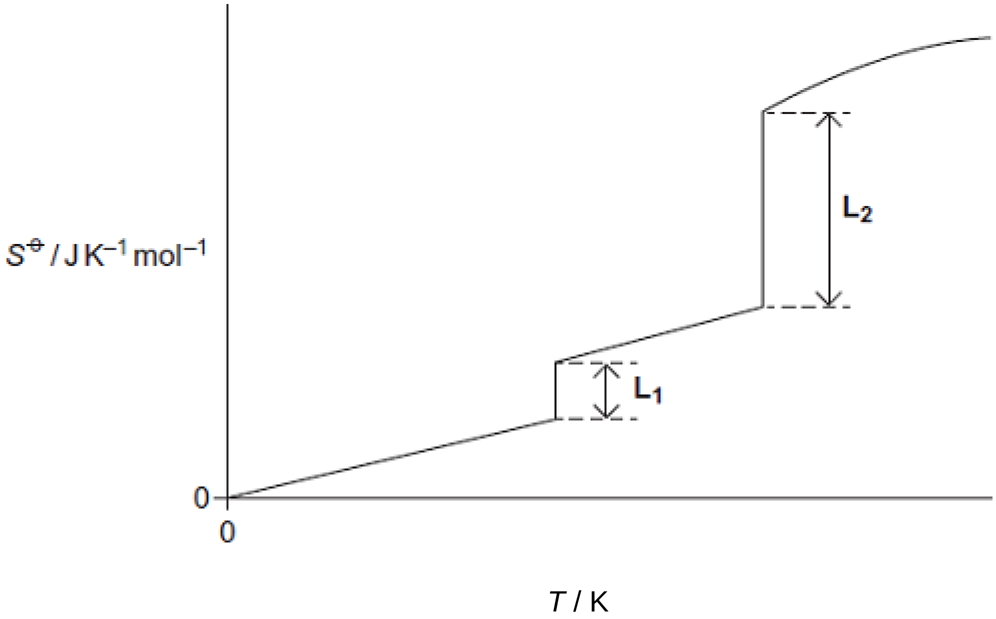
**C** $2CH_3OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 4H_2O(g)$ ○

**D** $CH_4(g) + H_2O(g) \longrightarrow CO(g) + 3H_2(g)$ ○

**(Total 1 mark)**

**4** (a) **Figure 1** shows how the entropy of a molecular substance **X** varies with temperature.

**Figure 1**



(i) Explain, in terms of molecules, why the entropy is zero when the temperature is zero Kelvin.

**(2)**

(ii) Explain, in terms of molecules, why the first part of the graph in **Figure 1** is a line that slopes up from the origin.

**(2)**

(iii) On **Figure 1**, mark on the appropriate axis the boiling point ($T_b$) of substance **X**.

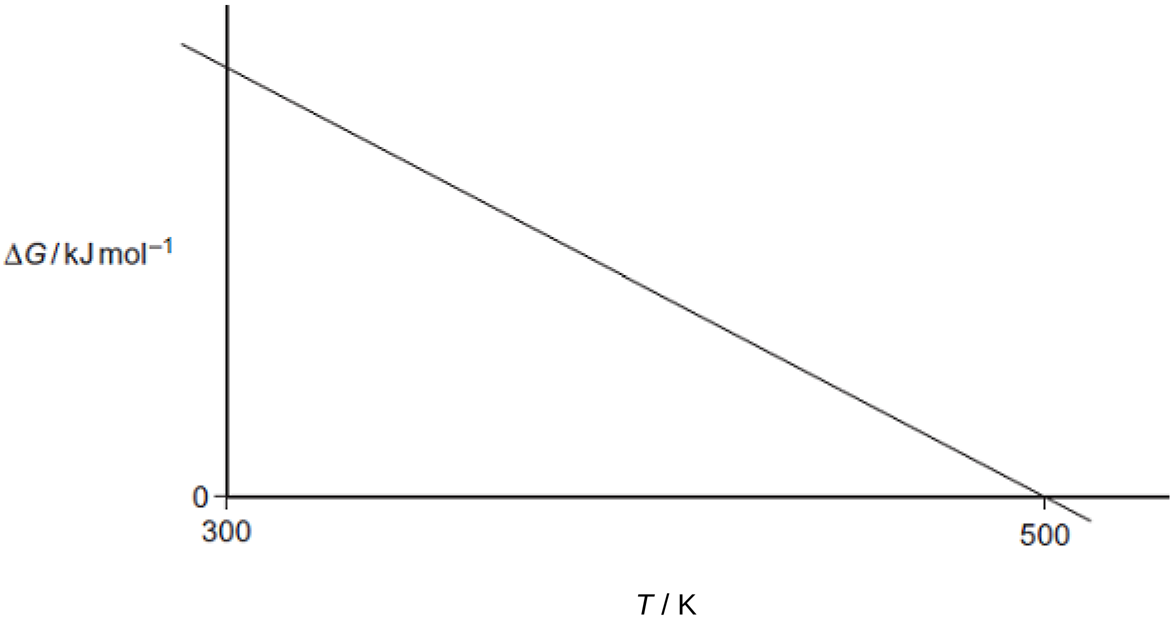
**(1)**

(iv) In terms of the behaviour of molecules, explain why $\mathbf{L_2}$ is longer than $\mathbf{L_1}$ in **Figure 1**.

**(2)**

(b) **Figure 2** shows how the free-energy change for a particular gas-phase reaction varies with temperature.

**Figure 2**



(i) Explain, with the aid of a thermodynamic equation, why this line obeys the mathematical equation for a straight line, $y = mx + c$.

**(2)**

(ii) Explain why the magnitude of *ΔG* decreases as *T* increases in this reaction.

**(1)**

(iii) State what you can deduce about the feasibility of this reaction at temperatures lower than 500 K.

**(1)**

(c) The following reaction becomes feasible at temperatures above 5440 K.

$$H_2O(g) \longrightarrow H_2(g) + \frac{1}{2}O_2(g)$$

The entropies of the species involved are shown in the following table.

| | $H_2O(g)$ | $H_2(g)$ | $O_2(g)$ |
|---|---|---|---|
| **S / J $K^{-1}$ $mol^{-1}$** | 189 | 131 | 205 |

(i) Calculate the entropy change *ΔS* for this reaction.

**(1)**

(ii) Calculate a value, with units, for the enthalpy change for this reaction at 5440 K.

(If you have been unable to answer part (c)(i), you may assume that the value of the entropy change is +98 J $K^{-1}$ $mol^{-1}$. This is **not** the correct value.)

**(3)**

**(Total 15 marks)**

**5** The following cell has an EMF of +0.46 V.

$$\mathrm{Cu}\,\big|\,\mathrm{Cu}^{2+}\,\big\|\,\mathrm{Ag}^{+}\,\big|\,\mathrm{Ag}$$

Which statement is correct about the operation of the cell?

**A** Metallic copper is oxidised by $\mathrm{Ag}^{+}$ ions. ○

**B** The silver electrode has a negative polarity. ○

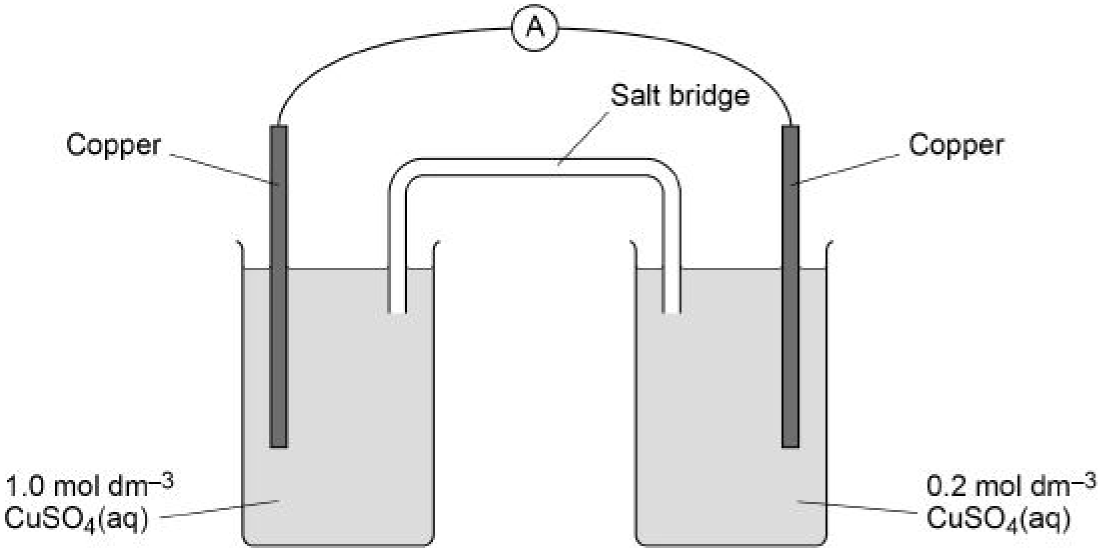
**C** The silver electrode gradually dissolves to form $\mathrm{Ag}^{+}$ ions. ○

**D** Electrons flow from the silver electrode to the copper electrode via an external circuit. ○

**(Total 1 mark)**

**6** This question is about electrochemical cells.

The diagram below shows an electrochemical cell.



(a) Explain how the salt bridge provides an electrical connection between the two half-cells.

____________________________________________________________

____________________________________________________________

**(1)**

(b) Suggest why potassium chloride would **not** be a suitable salt for the salt bridge in this cell.

____________________________________________________________

____________________________________________________________

**(1)**

(c) Suggest why the current in the external circuit of this cell falls to zero after the cell has operated for some time.

__________________________________________________________________

__________________________________________________________________

**(1)**

(d) A different electrochemical cell was made from a copper half-cell and a manganese half-cell.

$Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$ $E^\ominus = +0.34$ V
$Mn^{2+}(aq) + 2e^- \longrightarrow Mn(s)$ $E^\ominus = -1.18$ V

Give the conventional representation for this cell.

Calculate the EMF of this cell.

Cell representation ________________________________________________

__________________________________________________________________

__________________________________________________________________

EMF ________________________________ V

**(2)**

The table below shows some standard electrode potential data.

| **Electrode half-equation** | **$E^\ominus$ / V** |
|---|---|
| $Fe^{3+} + e^- \longrightarrow Fe^{2+}$ | +0.77 |
| $Cu^{2+} + 2e^- \longrightarrow Cu$ | +0.34 |
| $Fe^{2+} + 2e^- \longrightarrow Fe$ | −0.44 |
| $Zn^{2+} + 2e^- \longrightarrow Zn$ | −0.76 |

Use these data to answer the following questions.

(e) Iron filings are added to a solution that contains the ions $Cu^{2+}$, $Fe^{3+}$ and $Zn^{2+}$, all with concentration 1.00 mol $dm^{-3}$

Give the formula of the metal ion in the solution that does **not** react when iron filings are added.

Give a reason for your answer.

**(2)**

(f) Deduce the equation for each of the two reactions that occur.

**(2)**

**(Total 9 marks)**

**7** This question is about alkalis and carboxylic acids.

In this question, all data are quoted at 25 °C.

(a) Carboxylic acids are weak acids.

State the meaning of the term **weak** as applied to carboxylic acids.

**(1)**

(b) Write an equation for the reaction of propanoic acid with sodium carbonate.

**(1)**

(c) Calculate the pH of a 0.0120 mol dm$^{-3}$ solution of calcium hydroxide.
The ionic product of water $K_w = 1.00 \times 10^{-14}$ mol$^2$ dm$^{-6}$.
Give your answer to 2 decimal places.

**(3)**

(d) The value of the acid dissociation constant $K_a$ for benzenecarboxylic acid ($C_6H_5COOH$) is 6.31 × $10^{-5}$ mol dm$^{-3}$.

(i) Write an expression for the acid dissociation constant $K_a$ for benzenecarboxylic acid.

**(1)**

(ii) Calculate the pH of a 0.0120 mol dm$^{-3}$ solution of benzenecarboxylic acid.
Give your answer to 2 decimal places.

**(3)**

(iii) A buffer solution with a pH of 4.00 is made using benzenecarboxylic acid and sodium benzenecarboxylate.

Calculate the mass of sodium benzenecarboxylate ($M_r$ = 144.0) that should be dissolved in 1.00 $dm^3$ of a 0.0120 mol $dm^{-3}$ solution of benzenecarboxylic acid to produce a buffer solution with a pH of 4.00

The value of the acid dissociation constant $K_a$ for benzenecarboxylic acid ($C_6H_5COOH$) is $6.31 \times 10^{-5}$ mol $dm^{-3}$.

**(5)**

(e) Two solutions, one with a pH of 4.00 and the other with a pH of 9.00, were left open to the air.

The pH of the pH 9.00 solution changed more than that of the other solution.

Suggest what substance might be present in the air to cause the pH to change.
Explain how and why the pH of the pH 9.00 solution changes.

Substance present in air ______________________________

Explanation ______________________________

**(3)**

**(Total 17 marks)**

## Mark schemes

**1** (a) $2\ K^+(g) + O^{2-}\ (g)$

1

$2\ K(s) + ½\ O_2\ (g)$

1

(b) the enthalpy change which accompanies the formation of one mole of gaseous atoms

*If one mole of element then do not award this mark*

1

from the element in its standard state (under standard conditions)

1

(c) electron and ion both have negative charges and so repel each other

*Allow have the same charge*

1

(d) (M1 expression in words or symbols)

*2328 scores 3 marks*

$\Delta_f H = \Delta_a H(\text{oxygen}) + 2 \times \Delta_a H(\text{K}) + 2 \times \Delta_{IE1} H + \Delta_{1EA} H + \Delta_{2EA} H - \text{X}$
OR
$\text{X} = \Delta_a H(\text{oxygen}) + 2 \times \Delta_a H(\text{K}) + 2 \times \Delta_{IE1} H + \Delta_{1EA} H + \Delta_{2EA} H - \Delta_f H$

*Allow answers given to 3 significant figures*

(M2 expression with correct numbers)
$-362 = 248 + (2 \times 90) + (2 \times 418) + -142 + 844 + -\text{X}$
OR
$\text{X} = 248 + (2 \times 90) + (2 \times 418) + -142 + 844 + 362$

enthalpy of lattice dissociation = (+)2328 kJ $\text{mol}^{-1}$

3

(e) Experimental lattice enthalpy value allows for/includes covalent interaction/non-spherical ions/distorted ions/polarisation

*Allow discussion of AgCl instead of AgF.*

1

Theoretical lattice enthalpy value assumes only ionic interaction/point charges/no covalent/perfect spheres/perfectly ionic

*Allow AgF has covalent character OR AgF is not perfectly ionic in place of either point for 1 mark.*

*CE = 0 for mention of molecules, atoms, macromolecular, mean bond enthalpy, intermolecular forces, electronegativity*

1

(f) chloride ion larger (than fluoride ion) (or reverse argument)

*Penalise chlorine ion once only.*

1

Attraction between $Ag^+$ and $Cl^-$ weaker (or reverse argument)

*Allow chloride ion has smaller charge density but do not allow mass to charge ratio*

1

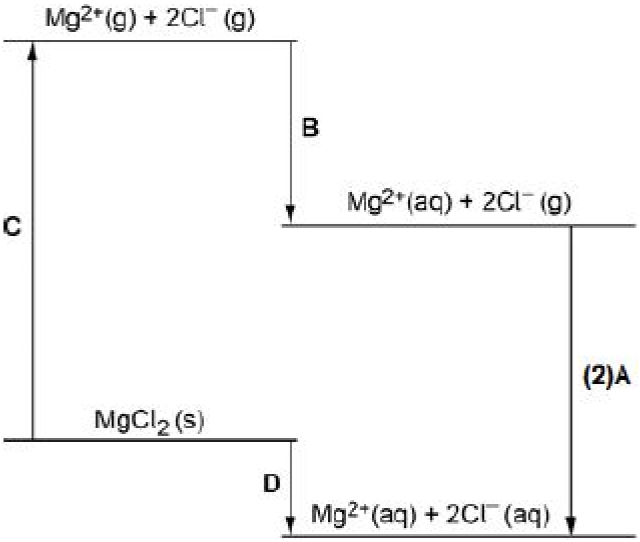
**[12]**

**2** (a) (Enthalpy change when) 1 mole of gaseous ions (dissolve in water) to form 1 mole of aqueous ions.

*1 mole need only be mentioned once*

1

(b)



**M1** $Mg^{2+}(g) + 2Cl^-$

1

**M2** $Mg^{2+}(aq) + 2Cl^-(g)$ **OR** $Mg^{2+}(g) + 2Cl^-(aq)$

1

**M3** $Mg^{2+}(aq) + 2Cl^-(aq)$

1

**M4** **A**, **B** and **D** labels, B and A may be either way round

1

*full marks can only be awarded if species match letters of steps.*

(c) −155 = 2493 + X + (2 × −364)
OR
X = −155 − 2493 + (2 × 364)

*If the “2 ×” is missing, then CE = 0*

1

enthalpy of hydration = −1920 kJ $mol^{-1}$

1

(d) **M1** amount $MgCl_2$ (= 10.0 / 95.3) = 0.1049317 mol

1

**M2** q = (0.1049317 × 155) = 16.264428 kJ

*M2 = M1 × 155*

1

**M3** $\Delta T$ = 16264.4286 / (150 × 4.18) = 25.94....

*M3 = their Q over mc*

1

**M4** max temp = 25.94 + 20.0 = 45.94.... = 45.9 °C

*accept 3 sig figs only*

1

**[11]**

**3** B

**[1]**

**4** (a) (i) (At 0 K) particles are stationary / not moving / not vibrating

*Allow have zero energy.*

*Ignore atoms / ions.*

1

No disorder / perfect order / maximum order

*Mark independently.*

1

(ii) As *T* increases, particles start to move / vibrate

*Ignore atoms / ions.*

*Allow have more energy.*

*If change in state, CE = 0*

1

<u>Disorder / randomness</u> increases / order decreases

1

(iii) Mark <u>on temperature axis</u> vertically below second 'step'

*Must be marked as a line, an 'x' , $T_b$ or 'boiling point' <u>on the temperature axis</u>.*

1

(iv) $L_2$ corresponds to boiling / evaporating / condensing / l → g / g → l

And L1 corresponds to melting / freezing / s → l / l → s

*There must be a clear link between $L_1$, $L_2$ and the change in state.*

1

Bigger change in <u>disorder</u> for $L_2$ / boiling compared with $L_1$ / melting

*M2 answer must be in terms of changes in state and not absolute states eg must refer to change from liquid to gas not just gas.*

*Ignore reference to atoms even if incorrect.*

1

(b) (i) $\Delta G = \Delta H - T\Delta S$

1

$\Delta H = c$ and $(-)\Delta S = m$ / $\Delta H$ and $\Delta S$ are constants (approx)

*Allow ΔH is the intercept, and (−)ΔS is the slope / gradient.*

*Can only score M2 if M1 is correct.*

1

(ii) Because the entropy change / ΔS is positive / $T\Delta S$ gets bigger

*Allow -TΔS gets more negative*

1

(iii) <u>Not</u> feasible / <u>un</u>feasible / <u>not</u> spontaneous

1

(c) (i) + 44.5 J $K^{-1}$ $mol^{-1}$

*Allow answer without units but if units given they must be correct (including* $mol^{-1}$*)*

1

(c) (ii) At 5440 $\Delta H = T\Delta S$

= 5440 × 44.5 = 242 080

1

(***OR*** using given value = 5440 × 98 = 533 120)

*Mark is for answer to (c)(i) × 5440*

1

ΔH = 242 kJ $mol^{-1}$

(***OR*** using given value $\Delta H$ = 533 kJ $mol^{-1}$)

*Mark is for correct answer to M2 with correct units (J* $mol^{-1}$ *or kJ* $mol^{-1}$*) linked to answer.*

*If answer consequentially correct based on (c)(i) except for incorrect sign (eg −242), max 1 / 3 provided units are correct.*

1

**[15]**

**5** A

**[1]**

**6** (a) It has mobile ions or ions can move through it or free ions

*Do not allow electrons*

1

(b) Chloride ions react with copper(II) ions/$Cu^{2+}$

**OR**

$[CuCl_4]^{2-}$ formed

*Allow reacts with the metal ions in the solution*

1

(c) (eventually) the $Cu^{2+}$ ions/$CuSO_4$ in each electrode will be at the same concentration

**1**

(d) $Mn \mid Mn^{2+} \parallel Cu^{2+} \mid Cu$

*Ignore state symbols*

**1**

(+) 1.52 V

**1**

(e) $Zn^{2+}$

**1**

because iron (filings) cannot reduce $Zn^{2+}$ ions
OR
because the half-reaction involving
$Zn^{2+}$ / Zn has a more negative $E^\ominus$ value than the one involving Fe

*Allow* $E^\ominus\ Zn^{2+}\ (/Zn) < E^\ominus\ Fe^{2+}\ (/\ Fe)$

**1**

(f) $Cu^{2+}(aq) + Fe(s) \longrightarrow Cu(s) + Fe^{2+}(aq)$

*State symbols not required*
*Award 2 marks for*
$Cu(s) + 2Fe^{3+}(aq) \longrightarrow Cu^{2+}(aq) + 2Fe^{2+}(aq)$

**1**

$2Fe^{3+}(aq) + Fe(s) \longrightarrow 3Fe^{2+}(aq)$

**1**

**[9]**

**7** (a) (only) slightly or partially dissociated / ionised

*Ignore 'not fully dissociated'.*

*Allow low tendency to dissociate or to lose / donate a proton.*

*Allow shown equilibrium well to the left.*

*Otherwise ignore equations.*

**1**

(b) $2CH_3CH_2COOH + Na_2CO_3 \longrightarrow 2CH_3CH_2COONa + H_2O + CO_2$

**OR**

$2CH_3CH_2COOH + CO_3^{2-} \longrightarrow 2CH_3CH_2COO^- + H_2O + CO_2$

**OR**

$CH_3CH_2COOH + Na_2CO_3 \longrightarrow CH_3CH_2COONa + NaHCO_3$

**OR**

$CH_3CH_2COOH + CO_3^{2-} \longrightarrow CH_3CH_2COO^- + HCO_3^-$

*Must be propanoic acid, allow $C_2H_5COOH$.*
*Not molecular formulae.*
*Allow multiples.*
*Ignore reversible sign.*
*Not $H_2CO_3$.*

1

(c) $[OH^-] = 2 \times 0.0120 = 0.0240$ M1

*Correct answer for pH with or without working scores 3.*

1

$[H^+] = \frac{1 \times 10^{-14}}{0.0240} = 4.166 \times 10^{-13}$ ***OR*** pOH = 1.62 M2

*If × 2 missed or used wrongly can only score M3 for correct calculation of pH from their $[H^+]$.*

1

pH = $12.\underline{38}$ M3

*Lose M3 if not 2 decimal places: 12.4 scores 2.*
*12.08 scores 1 (missing × 2) ; 12.1 scores 0.*
*11.78 scores 1 (dividing by 2) 11.8 scores 0.*

1

(d) (i) $K_a = \frac{[H^+][C_6H_5COO^-]}{[C_6H_5COOH]}$

*Ignore ( ) here but brackets must be present.*
*Must be correct acid and salt.*
*If wrong, mark part (ii) independently.*

1

(ii) M1 $K^a = \dfrac{[H^+]^2}{[C_6H_5COOH]}$ **OR** with numbers

*Correct answer for pH with or without working scores 3.*

*Allow HX, HA and ignore ( ) here.*

*May score M1 in part (i).*

**1**

M2 $[H^+] = \sqrt{}(6.31 \times 10^{-5} \times 0.0120)$ or $\sqrt{}(K_a \times [C_6H_5COOH])$

$(= \sqrt{}(7.572 \times 10^{-7} = 8.70 \times 10^{\times 4})$

*pH = 6.12 may score 2 if correct working shown and they show the square root but fail to take it.*

*But if no working shown or wrong* $K^a = \dfrac{[H^+]}{[C_6H_5COOH]}$

*used which also leads to 6.12, then zero scored.*

**1**

M3 pH = 3.<u>06</u>

*Must be 2 decimal places ie 3.1 loses M3.*

**1**

(iii) M1 $[H^+] = 10^{-4.00} = 1.00 \times 10^{-4}$

*Correct answer for mass with or without working scores 5.*

*Allow* $1 \times 10^{-4}$.

**1**

M2 $[X^-] = \dfrac{Ka \ x \ [HX]}{[H^+]}$

*Ignore ( ) here.*

*If [HX] / [X⁻] upside down, can score M1 plus*
*M4 for* $5.26 \times 10^{-7}$.

**1**

M3 $= \dfrac{6.31 \times 10^{-5} \ x \ 0.0120}{1.00 \times 10^{-4}}$

*And M5 for* $7.57 \times 10^{-5}$ *g.*

**1**

M4 $= 7.572 \times 10^{-3}$

**1**

M5 Mass ($C_6H_5COONa$) = $7.572 \times 10^{-3} \times 144$ =1.09 g
or 1.1 g

*Wrong method, eg using $[H^+]^2$ may only score M1 and M5 for correct multiplication of their M4 by 144*

*(provided not of obviously wrong substance).*

1

(e) M1 $CO_2$

*Allow $NO_x$ and $SO_2$.*

1

M2 <u>pH</u> <u>(It)</u> <u>falls / decreases</u>

*If M1 wrong, no further marks.*

1

M3 mark M2 & M3 independently

acidic (gas)

**OR** reacts with alkali(ne solution) / $OH^-$

**OR** $CO_2 + 2OH^- \longrightarrow CO_3^{2-} + H_2O$

**OR** $CO_2 + OH^- \longrightarrow HCO_3^-$

*Not forms $H_2CO_3$ $H_2SO_3$ $H_2SO_4$ etc OR $H^+$ ions.*

1

**[17]**