



Oxford Cambridge and RSA

Tuesday 06 October 2020 – Afternoon

A Level Chemistry A

H432/01 Periodic table, elements and physical chemistry

Time allowed: 2 hours 15 minutes

You must have:

- the Data Sheet for Chemistry A

You can use:

- a scientific or graphical calculator
- an HB pencil



Please write clearly in black ink. **Do not write in the barcodes.**

Centre number

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Candidate number

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First name(s)

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Last name

StemUp Model Solution

INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION

- The total mark for this paper is **100**.
- The marks for each question are shown in brackets [].
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **28** pages.

ADVICE

- Read each question carefully before you start your answer.

SECTION A

You should spend a maximum of 20 minutes on this section.

Write your answer to each question in the box provided.

Answer **all** the questions.

- 1 Several students titrate 25.00 cm^3 of the same solution of sodium hydroxide, NaOH(aq) with hydrochloric acid, HCl(aq) .

One student obtains a smaller titre than the other students.

Which procedure explains the smaller titre?

- A The burette readings are taken from the top of the meniscus instead of the bottom of the meniscus.
- B The conical flask is rinsed with water before carrying out the titration.
- C An air bubble is released from the jet of the burette during the titration.
- D The pipette is rinsed with water before filling with NaOH(aq) .

Your answer

D

[1]

- 2 Which statement gives the numerical value of the Avogadro constant?

- A The number of moles in 12g of carbon-12.
- B The number of electrons lost by 20.05g of calcium when it reacts with oxygen.
- C The number of molecules in 16.0g of oxygen.
- D The number of atoms in 1 mole of chlorine molecules.

Your answer

B

[1]

- 3 0.80 g of element **X** is reacted with 0.40 g of O_2 to form an oxide with the formula X_2O_3 .

What is the identity of element **X**?

- A Aluminium
- B Titanium
- C Germanium
- D Molybdenum

Your answer

B

[1]

- 4 Phosphoric acid is a tribasic acid.

What is the mass of $Ca(OH)_2$ that completely neutralises 100 cm^3 of 0.100 mol dm^{-3} phosphoric acid?

- A 0.49 g
- B 0.74 g
- C 1.11 g
- D 2.22 g

Your answer

C

[1]

- 5 Which statement about elements in the d block of Period 4 of the periodic table is correct?

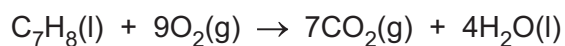
- A Cr atoms have the electron configuration: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$.
- B Cu^+ ions contain an incomplete 3d sub-shell.
- C Fe^{2+} ions contain 3 unpaired electrons.
- D Sc forms ions with different oxidation states.

Your answer

A

[1]

- 6 The equation for the combustion of C_7H_8 is shown in the following equation.



Enthalpy changes of formation are shown in the table.

Substance	$C_7H_8(l)$	$CO_2(g)$	$H_2O(l)$
$\Delta_f H / kJ mol^{-1}$	+12	-394	-286

Calculate the enthalpy of combustion, in $kJ mol^{-1}$, for the hydrocarbon C_7H_8 .

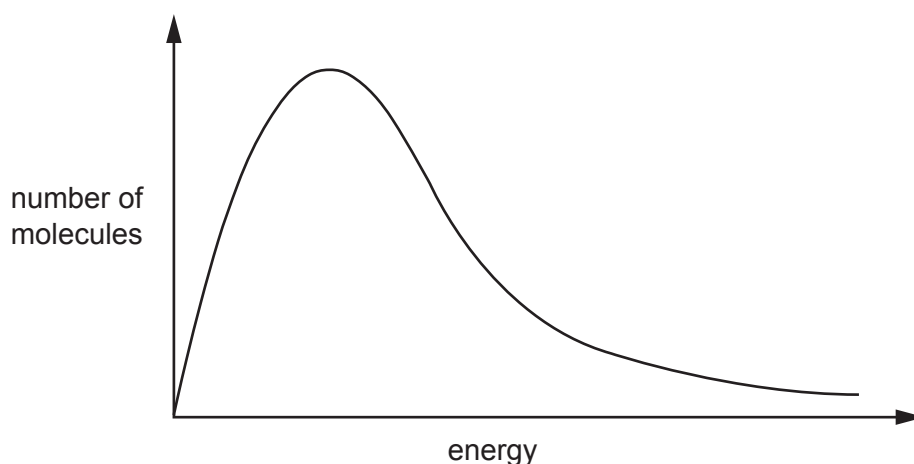
- A -3914
B -692
C +692
D +3914

Your answer

A

[1]

- 7 The diagram represents a Boltzmann distribution curve of molecules at a given temperature.



Which statement for this Boltzmann distribution curve is correct at a higher temperature?

- A The peak increases in height and moves to the left.
B The peak increases in height and moves to the right.
C The peak decreases in height and moves to the left.
D The peak decreases in height and moves to the right.

Your answer

D

[1]

- 8 A graph is plotted of $\ln(k)$ against $1/T$.
(k = rate constant, T = temperature in K)

The gradient has the numerical value of $-55\,000$.

What is the activation energy, in kJ mol^{-1} ?

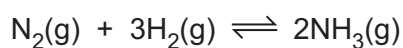
- A $+1.5 \times 10^{-7}$
B $+2.22 \times 10^{-6}$
C $+6.62$
D $+457$

Your answer

D

[1]

- 9 The reversible reaction of nitrogen and hydrogen to form ammonia is shown below.



In the equilibrium mixture, the partial pressure of N_2 is 18.75 MPa and the partial pressure of H_2 is 2.50 MPa .

The total pressure is 25 MPa .

What is the value of K_p , in MPa^{-2} ?

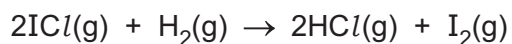
- A 1.2×10^{-4}
B 0.048
C 0.075
D 21

Your answer

B

[1]

- 10 The equation for the reaction of ICl and H_2 is shown below.



The rate constant k for this reaction is $1.63 \times 10^{-6} \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$.

What is the overall order of the reaction?

- A 0
- B 1
- C 2
- D 3

Your answer

C

[1]

- 11 20 cm^3 of 0.10 mol dm^{-3} hydrochloric acid is added to 10 cm^3 of 0.10 mol dm^{-3} sodium hydroxide.

What is the pH of the resulting mixture?

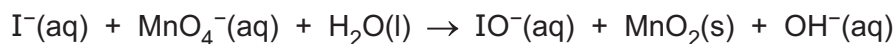
- A 1.00
- B 1.18
- C 1.30
- D 1.48

Your answer

D

[1]

- 12 Iodide ions, $\text{I}^-(\text{aq})$, react with $\text{MnO}_4^-(\text{aq})$. The unbalanced equation is shown below.



What is the ratio of $\text{MnO}_2(\text{s})$ to $\text{OH}^-(\text{aq})$ in the balanced equation?

- A 1 : 3
- B 1 : 2
- C 1 : 1
- D 3 : 2

Your answer

C

[1]

13 Which statement(s) is/are correct when a catalyst is added to a system in dynamic equilibrium?

- 1 The rates of the forward and reverse reactions increase by the same amount.
- 2 The concentrations of the reactants and products do not change.
- 3 The value of K_c increases.

- A** 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer

B

[1]

14 Which statement(s) for Group 2 elements is/are correct?

- 1 The 2nd ionisation energy of magnesium is greater than the 2nd ionisation energy of calcium.
- 2 A strontium ion, Sr^{2+} , contains a total of 6 electrons in s orbitals.
- 3 The equation for the reaction of barium with water is:
$$2\text{Ba} + 2\text{H}_2\text{O} \rightarrow 2\text{BaOH} + \text{H}_2.$$

- A** 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer

D

[1]

15 Which statement(s) for the complex ion $[\text{Co}(\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2)_3]^{2+}$ is/are correct?

- 1 It has *cis* and *trans* isomers.
- 2 It has optical isomers.
- 3 It is six-fold coordination.

- A 1, 2 and 3
- B Only 1 and 2
- C Only 2 and 3
- D Only 1

Your answer

C

[1]

SECTION B

Answer **all** the questions.

16 This question is about magnesium, bromine and magnesium bromide.

- (a) Relative atomic mass is defined as ‘the weighted mean mass compared with 1/12th mass of carbon-12’.

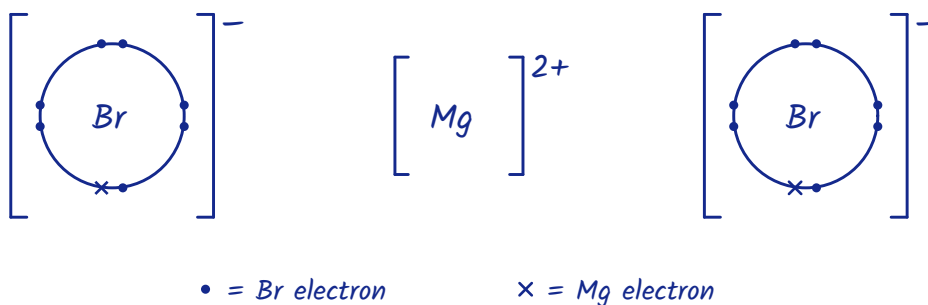
Explain what is meant by the term **weighted mean mass**.

The average mass of an atom of the element, taking into account the relative abundances of all its isotopes (sum of isotopic mass $\times$ % abundance $\div 100$).

[1]

- (b) (i) Draw a ‘dot-and-cross’ diagram for MgBr_2 .

Show outer electron shells only.



[2]

- (ii) Calculate the total number of **ions** in 1.74 g of magnesium bromide, MgBr_2 .

Give your answer to **3** significant figures.

$$M(\text{MgBr}_2) = 24.3 + 2(79.9) = 184.1 \text{ g mol}^{-1}$$

$$n(\text{MgBr}_2) = 1.74 \div 184.1 = 9.45 \times 10^{-3} \text{ mol}$$

$$n(\text{ions}) = 3 \times 9.45 \times 10^{-3} = 2.835 \times 10^{-2} \text{ mol (Mg}^{2+} + 2\text{Br}^-)$$

$$\text{ions} = 2.835 \times 10^{-2} \times 6.02 \times 10^{23} = 1.71 \times 10^{22}$$

number of ions = ... 1.71×10^{22} [3]

(c)* **Table 16.1** shows some physical properties of magnesium, bromine and magnesium bromide.

Substance	Melting point/°C	Electrical conductivity	
		Solid	Liquid
Magnesium	711	Good	Good
Bromine	-7	Poor	Poor
Magnesium bromide	650	Poor	Good

Table 16.1

Explain the physical properties shown in **Table 16.1** using your knowledge of structure and bonding. [6]

Magnesium has a giant metallic lattice: metallic bonding is the strong electrostatic attraction between positive Mg^{2+} ions and delocalised electrons.

A lot of energy is needed to overcome the metallic bonds, so the melting point is high (711 °C).

Magnesium conducts electricity when solid and when liquid because the delocalised electrons are mobile and can move through the structure.

Magnesium bromide has a giant ionic lattice: ionic bonding is the strong electrostatic attraction between oppositely charged ions (Mg^{2+} and Br^{-}). A lot of energy is needed to overcome the ionic bonds, so the melting point is high (650 °C).

Solid magnesium bromide does not conduct because the ions are fixed in the lattice and cannot move. When liquid (molten) the ions can move, so it conducts.

Bromine has a simple molecular (simple covalent) lattice of Br_2 molecules.

On melting only the weak induced dipole-dipole interactions (London forces)

Additional answer space if required

between the molecules are overcome; the covalent bonds do not break. Little energy is needed, so the melting point is low (-7 °C).

Metallic and ionic bonds are much stronger than London forces, so they
need much more energy to break, which is why Mg and MgBr_2 melt at
much higher temperatures than bromine.

Bromine is a poor conductor as a solid and as a liquid because it has no
mobile charged particles (no delocalised electrons and no ions).

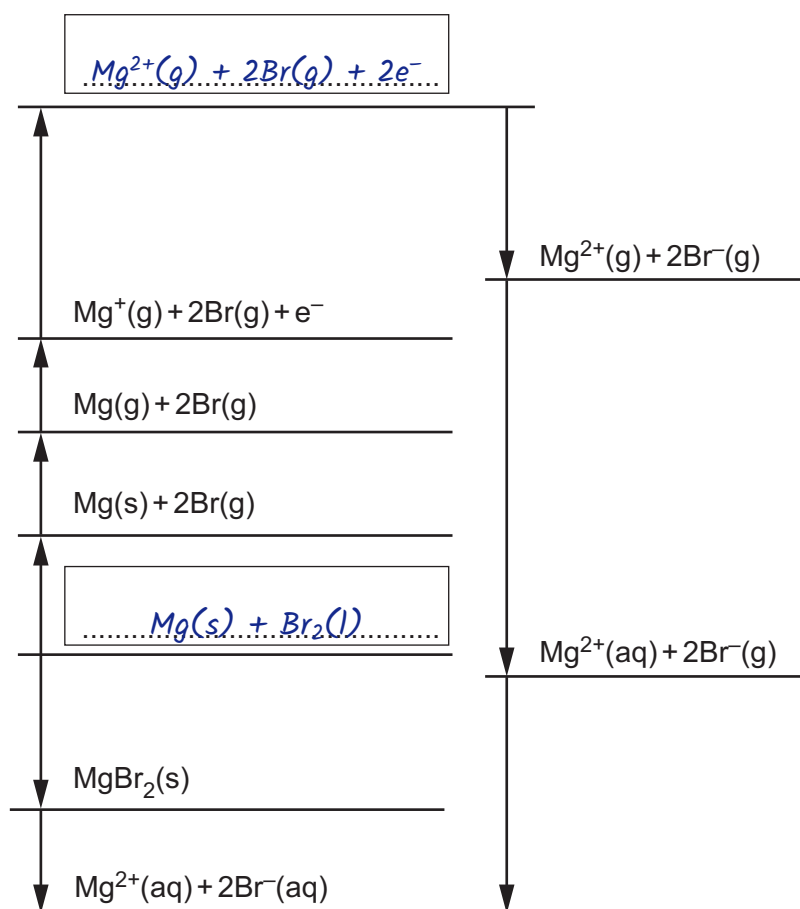
- (d) The enthalpy change of hydration of bromide ions can be determined using the enthalpy changes in **Table 16.2**.

Enthalpy change	Energy / kJ mol^{-1}
1st ionisation energy of magnesium	+736
2nd ionisation energy of magnesium	+1450
atomisation of bromine	+112
atomisation of magnesium	+148
electron affinity of bromine	-325
formation of magnesium bromide	-525
hydration of bromide ion	to be calculated
hydration of magnesium ion	-1926
solution of magnesium bromide	-186

Table 16.2

- (i) An incomplete energy cycle based on **Table 16.2** is shown below.

On the dotted lines, add the species present, including state symbols.



[2]

- (ii) Using your completed energy cycle in **16(d)(i)**, calculate the enthalpy change of hydration of bromide ions.

$\Delta H_f(\text{MgBr}_2) + \Delta H_{\text{sol}}(\text{MgBr}_2) = \text{all other steps in the cycle:}$

$$-525 + (-186) = 148 + 2(112) + 736 + 1450$$

$$+ 2(-325) - 1926 + 2\Delta H_{\text{hyd}}(\text{Br}^-)$$

$$2\Delta H_{\text{hyd}}(\text{Br}^-) = -525 - 186 - 148 - 224 - 736 - 1450 + 650 + 1926$$

$$2\Delta H_{\text{hyd}}(\text{Br}^-) = -693$$

$$\Delta H_{\text{hyd}}(\text{Br}^-) = -693 \div 2 = -346.5 \text{ kJ mol}^{-1}$$

enthalpy change of hydration = ...**-346.5**..... kJ mol^{-1} [2]

- (iii) Write the equation for the lattice enthalpy of magnesium bromide and calculate the lattice enthalpy of magnesium bromide.

Equation **$\text{Mg}^{2+}(\text{g}) + 2\text{Br}^-(\text{g}) \rightarrow \text{MgBr}_2(\text{s})$**

Calculation

$$\text{Lattice enthalpy} = \Delta H_{\text{hyd}}(\text{Mg}^{2+}) + 2\Delta H_{\text{hyd}}(\text{Br}^-) - \Delta H_{\text{sol}}(\text{MgBr}_2)$$

$$= -1926 + 2(-346.5) - (-186)$$

$$= -1926 - 693 + 186$$

$$= -2433 \text{ kJ mol}^{-1}$$

lattice enthalpy = ...**-2433**..... kJ mol^{-1} [3]

- 17 Methanol, CH_3OH , can be made industrially by the reaction of carbon monoxide with hydrogen, as shown in **equilibrium 1**.



- (a) Predict the conditions of pressure and temperature that would give the maximum equilibrium yield of CH_3OH in **equilibrium 1**.

Explain your answer.

High pressure and low temperature.

High pressure: the right-hand side has fewer gaseous moles (1 mol compared with 3 mol), so the equilibrium shifts to the right.

Low temperature: the forward reaction is exothermic (ΔH is negative), so the equilibrium shifts to the right. [3]

- (b) A catalyst is used in the production of methanol in **equilibrium 1**.

State **two** ways that the use of catalysts helps chemical companies to make their processes more sustainable and less harmful to the environment.

1 *The reaction can be carried out at a lower temperature, so less energy is needed.*

2 *Less fossil fuel is burnt, so there are less CO_2 emissions.*

[2]

(c) Standard entropy values are given below.

Substance	CO(g)	H ₂ (g)	CH ₃ OH(g)
S°/JK ⁻¹ mol ⁻¹	198	131	238

A chemist proposed producing methanol at 525 K using **equilibrium 1**.

Explain, with a calculation, whether the production of methanol is feasible at 525 K.

$$\Delta S = S(\text{CH}_3\text{OH}) - [S(\text{CO}) + 2S(\text{H}_2)]$$

$$\Delta S = 238 - (198 + 2 \times 131) = -222 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\Delta S = -0.222 \text{ kJ K}^{-1} \text{ mol}^{-1}$$

$$\Delta G = \Delta H - T\Delta S = -91 - (525 \times -0.222)$$

$$\Delta G = -91 + 116.55 = +25.55 \text{ kJ mol}^{-1}$$

$$\Delta G > 0, \text{ so the production of methanol is not feasible at 525 K.}$$

[5]

(d) At 298 K, the free energy change, ΔG , for the production of methanol in **equilibrium 1** is $-2.48 \times 10^4 \text{ J mol}^{-1}$.

ΔG is linked to K_p by the relationship: $\Delta G = -RT \ln K_p$.

R = gas constant

T = temperature in K.

Calculate K_p for **equilibrium 1** at 298 K.

Give your answer to 3 significant figures.

$$\ln K_p = -\Delta G \div RT$$

$$\ln K_p = 2.48 \times 10^4 \div (8.314 \times 298) = 10.01$$

$$K_p = e^{10.01} = 2.22 \times 10^4$$

$$K_p = 2.22 \times 10^4 \text{ units } \text{atm}^{-2} \text{ [3]}$$

- 18 This question is about reactions and uses of the weak acids methanoic acid, HCOOH , and ethanoic acid, CH_3COOH .

- (a) A student adds magnesium metal to an aqueous solution of ethanoic acid, CH_3COOH . A redox reaction takes place.

Write the overall equation for this reaction and explain, in terms of oxidation numbers, which element has been oxidised and which element has been reduced.

Equation $\text{Mg} + 2\text{CH}_3\text{COOH} \rightarrow (\text{CH}_3\text{COO})_2\text{Mg} + \text{H}_2$

Oxidation $\text{Mg is oxidised: its oxidation number increases from 0 to +2.}$

Reduction $\text{H is reduced: its oxidation number decreases from +1 to 0.}$

[3]

- (b) The K_a values of HCOOH and CH_3COOH are shown in **Table 18.1**.

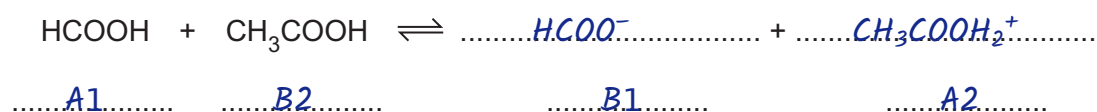
Weak acid	$K_a/\text{mol dm}^{-3}$
HCOOH	1.82×10^{-4}
CH_3COOH	1.78×10^{-5}

Table 18.1

A student adds methanoic acid to ethanoic acid.

An equilibrium is set up containing two acid-base pairs.

Complete the equilibrium and label the conjugate acid-base pairs as **A1**, **B1** and **A2**, **B2**.



[2]

(c) Use **Table 18.1** to answer the following questions.

- (i) The student measures the pH of $\text{CH}_3\text{COOH}(\text{aq})$ as 2.72.

Show that the concentration of the $\text{CH}_3\text{COOH}(\text{aq})$ is $0.204 \text{ mol dm}^{-3}$.

$$[\text{H}^+] = 10^{-2.72} = 1.905 \times 10^{-3} \text{ mol dm}^{-3}$$

$$K_a = [\text{H}^+]^2 \div [\text{CH}_3\text{COOH}], \text{ so } [\text{CH}_3\text{COOH}] = [\text{H}^+]^2 \div K_a$$

$$[\text{CH}_3\text{COOH}] = (1.905 \times 10^{-3})^2 \div 1.78 \times 10^{-5}$$

$$[\text{CH}_3\text{COOH}] = 0.204 \text{ mol dm}^{-3}$$

[2]

- (ii) The student plans to make a buffer solution of pH 4.00 from a mixture of $\text{CH}_3\text{COOH}(\text{aq})$ and sodium ethanoate, $\text{CH}_3\text{COONa}(\text{aq})$.

The student mixes 400 cm^3 of $0.204 \text{ mol dm}^{-3}$ $\text{CH}_3\text{COOH}(\text{aq})$ with 600 cm^3 of $\text{CH}_3\text{COONa}(\text{aq})$.

Calculate the concentration of $\text{CH}_3\text{COONa}(\text{aq})$ needed to prepare this buffer solution of pH 4.00.

$$[\text{H}^+] \text{ in buffer} = 10^{-4.00} = 1.00 \times 10^{-4} \text{ mol dm}^{-3}$$

$$\text{total volume} = 400 + 600 = 1000 \text{ cm}^3 = 1.00 \text{ dm}^3$$

$$n(\text{CH}_3\text{COOH}) = 0.204 \times 400 \div 1000 = 8.16 \times 10^{-2} \text{ mol}$$

$$\text{so } [\text{CH}_3\text{COOH}] \text{ in buffer} = 8.16 \times 10^{-2} \text{ mol dm}^{-3}$$

$$K_a = [\text{H}^+][\text{CH}_3\text{COO}^-] \div [\text{CH}_3\text{COOH}]$$

$$[\text{CH}_3\text{COO}^-] = K_a \times [\text{CH}_3\text{COOH}] \div [\text{H}^+]$$

$$= 1.78 \times 10^{-5} \times 8.16 \times 10^{-2} \div 1.00 \times 10^{-4}$$

$$= 1.45 \times 10^{-2} \text{ mol dm}^{-3} \text{ (in } 1.00 \text{ dm}^3\text{)}$$

$$[\text{CH}_3\text{COONa}] \text{ in } 600 \text{ cm}^3 = 1.45 \times 10^{-2} \times 1000 \div 600$$

$$= 2.42 \times 10^{-2} \text{ mol dm}^{-3}$$

concentration = ... 2.42×10^{-2} mol dm^{-3} [4]

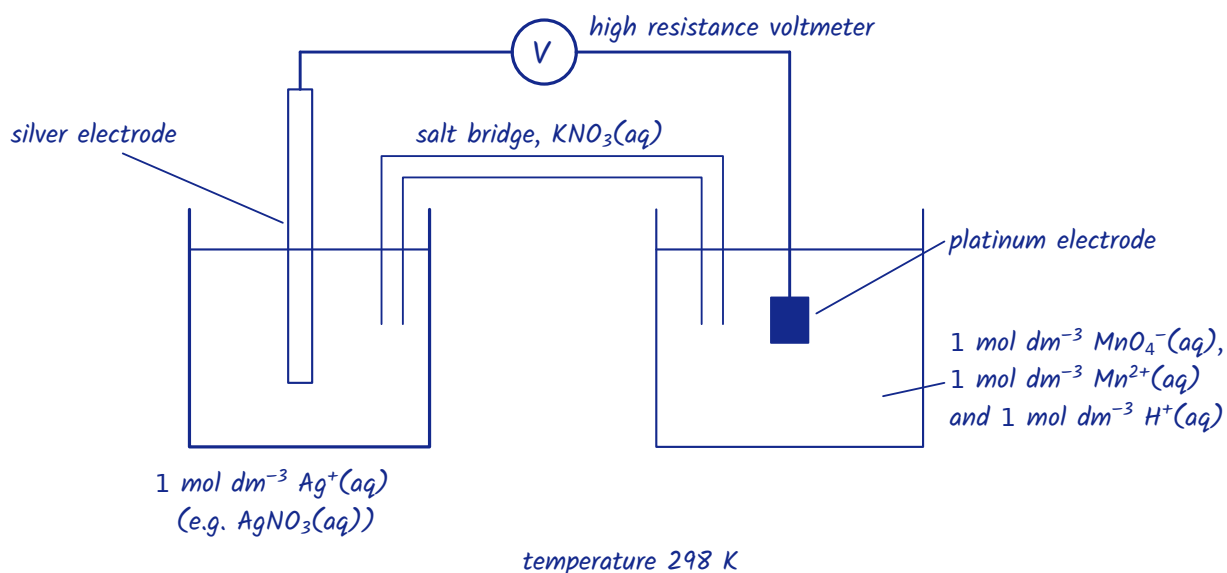
19 Standard electrode potentials for four redox systems are shown in **Table 19.1**.

Redox system	Half-equation	$E^\ominus/\text{V}$
1	$\text{CO}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{HCOOH}(\text{aq})$	-0.11
2	$\text{HCOOH}(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{HCHO}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	-0.03
3	$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
4	$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51

Table 19.1

(a) A student sets up a standard cell in the laboratory based on redox systems **3** and **4**.

Draw a labelled diagram to show how this cell could be set up to measure its standard cell potential at 298 K.



[3]

- (b) A student warms a mixture of methanal, HCHO , and acidified potassium manganate(VII).

The student observes gas bubbles.

Explain this observation in terms of electrode potentials and equilibria.

Include overall equations in your answer.

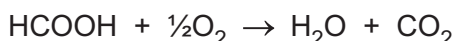
$E^\ominus$ of system 4 ($\text{MnO}_4^-/\text{Mn}^{2+}$, +1.51 V) is more positive than $E^\ominus$ of system 2 (HCOOH/HCHO , -0.03 V) and system 1 (CO_2/HCOOH , -0.11 V).
So equilibrium 4 shifts to the right (MnO_4^- is reduced) and equilibria 2 and 1 shift to the left (HCHO and HCOOH are oxidised).
Systems 2 and 4: $2\text{MnO}_4^- + 5\text{HCHO} + 6\text{H}^+ \rightarrow 2\text{Mn}^{2+} + 5\text{HCOOH} + 3\text{H}_2\text{O}$
Systems 1 and 4: $2\text{MnO}_4^- + 5\text{HCOOH} + 6\text{H}^+ \rightarrow 2\text{Mn}^{2+} + 5\text{CO}_2 + 8\text{H}_2\text{O}$
The gas bubbles are CO_2 .

[4]

- (c) Methanoic acid, HCOOH , can be used in a fuel cell. As with all fuel cells, the fuel (HCOOH) is supplied at one electrode and the oxidant (oxygen) at the other electrode.

The standard cell potential for this fuel cell is 1.34 V.

The overall reaction is shown below.



Using the information in **Table 19.1**, deduce the half-equation for the reaction at the oxygen electrode, and calculate the standard electrode potential for the oxygen half-cell.

$$E_{\text{cell}} = E^\ominus(\text{O}_2 \text{ half-cell}) - E^\ominus(\text{system 1})$$

$$1.34 = E^\ominus(\text{O}_2) - (-0.11)$$

$$E^\ominus(\text{O}_2) = 1.34 + (-0.11) = +1.23 \text{ V}$$

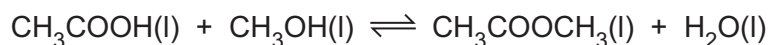
half-equation $\frac{1}{2}\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2\text{O}$

standard electrode potential = +1.23 V

[2]

Turn over

- 20 A student investigates the reaction between ethanoic acid, $\text{CH}_3\text{COOH(l)}$ and methanol, $\text{CH}_3\text{OH(l)}$, in the presence of an acid catalyst. The equation is shown below.

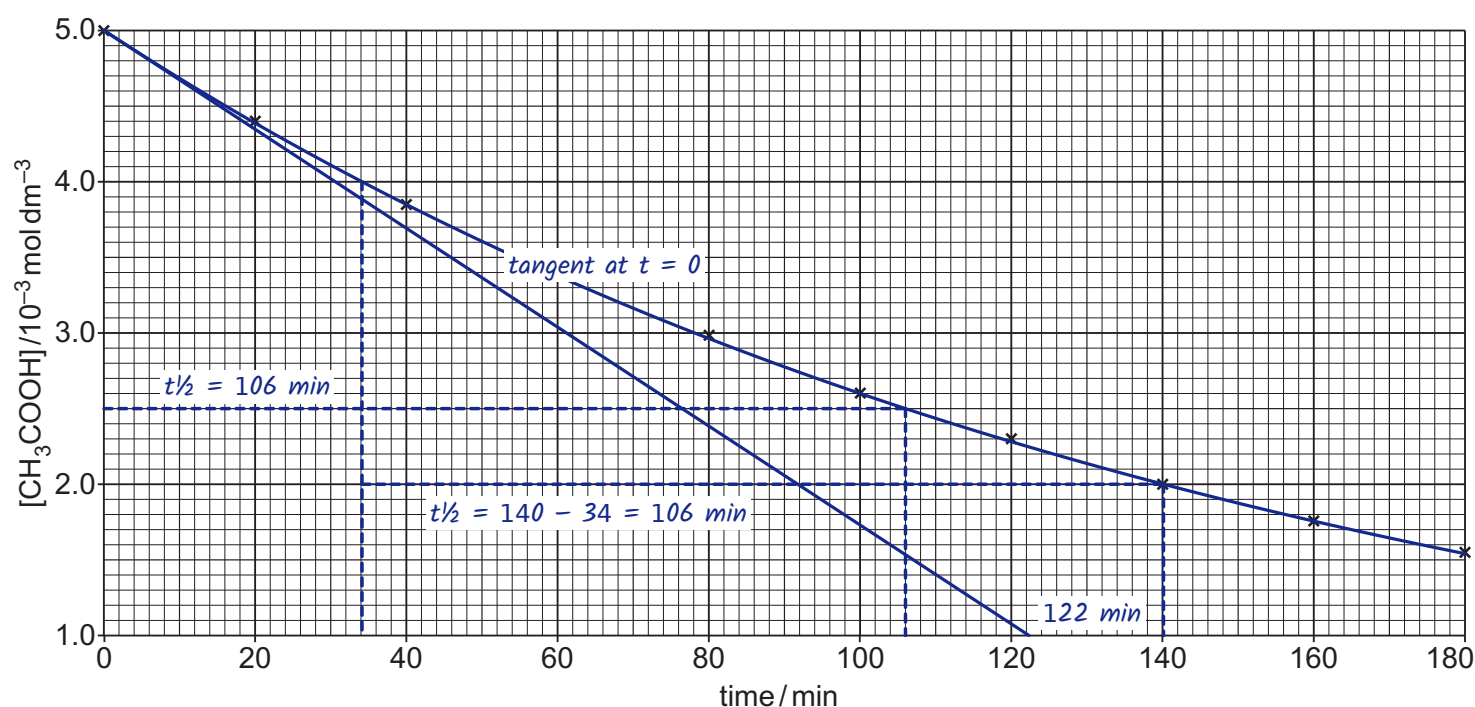


- (a) The student carries out an experiment to determine the order of reaction with respect to CH_3COOH .

The student uses a large excess of CH_3OH . The temperature is kept constant throughout the experiment.

The student takes a sample from the mixture every 20 minutes, and then determines the concentration of the ethanoic acid in each sample.

From the experimental results, the student plots the graph below.



- (i) Explain why the student uses a large excess of methanol in this experiment.

So that $[\text{CH}_3\text{OH}]$ stays effectively constant, so the reaction is effectively zero order with respect to CH_3OH . [1]

- (ii) Use the half-life of this reaction to show that the reaction is first order with respect to CH_3COOH .

Show your working on the graph and below.

$$5.0 \rightarrow 2.5 \times 10^{-3} \text{ mol dm}^{-3}; t_{1/2} = 106 \text{ min (0 to 106 min)}$$

$$4.0 \rightarrow 2.0 \times 10^{-3} \text{ mol dm}^{-3}; t_{1/2} = 140 - 34 = 106 \text{ min}$$

(both shown on the graph)

The half-life is constant (106 min), so the reaction is first order with respect to CH_3COOH . [2]

- (iii) Determine the initial rate of reaction.

Tangent drawn at $t = 0$: it falls from 5.0 to 1.0×10^{-3} at 122 min

$$\text{gradient} = (5.0 - 1.0) \times 10^{-3} \div (122 - 0) = 3.28 \times 10^{-5}$$

$$\text{initial rate} = 3.3 \times 10^{-5} \text{ mol dm}^{-3} \text{ min}^{-1}$$

$$\text{initial rate} = \dots 3.3 \times 10^{-5} \dots \text{ mol dm}^{-3} \text{ min}^{-1} \text{ [2]}$$

- (b) The student carries out a second experiment to determine the value of K_c for this reaction.

The student mixes 9.6 g of CH_3OH with 12.0 g of CH_3COOH and adds the acid catalyst.

When the mixture reaches equilibrium, 0.030 mol of CH_3COOH remains.

Calculate K_c for this equilibrium.

$$n(\text{CH}_3\text{OH}) = 9.6 \div 32.0 = 0.30 \text{ mol}$$

$$n(\text{CH}_3\text{COOH}) = 12.0 \div 60.0 = 0.20 \text{ mol}$$

$$n(\text{CH}_3\text{COOH})_{\text{reacted}} = 0.20 - 0.030 = 0.17 \text{ mol}$$

$$\text{equilibrium: } n(\text{CH}_3\text{OH}) = 0.30 - 0.17 = 0.13 \text{ mol}$$

$$n(\text{CH}_3\text{COOCH}_3) = n(\text{H}_2\text{O}) = 0.17 \text{ mol}$$

$$K_c = \frac{[\text{CH}_3\text{COOCH}_3][\text{H}_2\text{O}]}{[\text{CH}_3\text{COOH}][\text{CH}_3\text{OH}]} = \frac{0.17 \times 0.17}{0.030 \times 0.13} = 7.4$$

(volume V cancels)

$$K_c = \dots 7.4 \dots \text{ [4]}$$

21 This question is about halogens.

(a) A student adds a solution of bromine in an organic solvent to two test tubes.

The student adds aqueous sodium chloride to one test tube, and aqueous sodium iodide to the other test tube.

The student shakes the mixtures, allows them to settle, and records the colour of the organic layer in each mixture.

Sodium halide	Colour of organic layer
Sodium chloride	orange
Sodium iodide	violet

Explain how the student's results provide evidence for the trend in reactivity of the halogens down group 17(7) and write an ionic equation for any reaction that takes place.

Use your chemical knowledge to explain the trend in reactivity.

With NaCl(aq) the organic layer stays orange: this is bromine, so there is no reaction. Bromine cannot oxidise Cl^- , so Br_2 is less reactive than Cl_2 .

With NaI(aq) the organic layer turns violet: iodine has formed, so bromine has oxidised (displaced) I^- . Br_2 is more reactive than I_2 .

$\text{Br}_2 + 2\text{I}^- \rightarrow 2\text{Br}^- + \text{I}_2$

So reactivity (oxidising power) decreases down group 17: the halogen atoms gain an electron less easily.

Down the group the atomic radius increases (more shells) and there is more shielding, so there is less nuclear attraction for the electron being gained.

..... [5]

- (b) Chlorine is used in water treatment.

State **one** benefit and **one** risk of using chlorine in water treatment.

Benefit *kills bacteria, so the water is safe to drink*

Risk *chlorine is toxic; it can also form chlorinated hydrocarbons (carcinogens)*

[1]

- (c) Compound **A** contains bromine and fluorine only, and has a boiling point of 41 °C.

1.26 g of compound **A** is heated to 80 °C.
The volume of gas produced is 0.209 dm³.

Under the conditions used, 1 mol of gas molecules has a volume of 29.0 dm³.

Determine the molecular formula of compound **A**.

$$n(A) = 0.209 \div 29.0 = 7.21 \times 10^{-3} \text{ mol}$$

$$M_r = 1.26 \div 7.21 \times 10^{-3} = 174.8$$

$$\text{BrF}_n: 79.9 + 19.0n = 174.8, \text{ so } n = 5 \quad (79.9 + 95.0 = 174.9)$$

molecular formula = *BrF₅* [3]

22 (a)* **B** and **C** are compounds of two different transition elements.

A student carries out test tube reactions on aqueous solutions of **B** and **C**.
The observations of the student's tests are shown below.

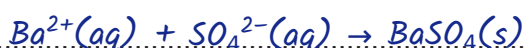
	Test	B(aq)	C(aq)
1	NH ₃ (aq) added dropwise excess NH ₃ (aq) added	green precipitate D no further change	grey-green precipitate E purple solution F
2	HNO ₃ (aq) followed by Ba(NO ₃) ₂ (aq)	no change white precipitate G	no change no change
3	HNO ₃ (aq) followed by AgNO ₃ (aq)	no change no change	no change white precipitate H

Analyse the results to identify **B** to **H**, and construct ionic equations for the formation of products **D** to **H**. [6]

B is iron(II) sulfate, FeSO₄. Test 1: the green precipitate D shows Fe²⁺ ions; D is iron(II) hydroxide, Fe(OH)₂.



Test 2: the white precipitate G with Ba(NO₃)₂ shows SO₄²⁻ ions; G is barium sulfate, BaSO₄.



Test 3: no precipitate with AgNO₃, so B contains no halide ions.

C is chromium(III) chloride, CrCl₃. Test 1: the grey-green precipitate E shows Cr³⁺ ions; E is chromium(III) hydroxide, Cr(OH)₃.



With excess NH₃, E dissolves to form the purple solution F, [Cr(NH₃)₆]³⁺ (ligand substitution).



Test 3: the white precipitate H with AgNO₃ shows Cl⁻ ions; H is silver chloride, AgCl.

Additional answer space if required



Test 2: no precipitate with $\text{Ba}(\text{NO}_3)_2$, so C contains no sulfate ions.

HNO_3 is added first to remove carbonate ions, which would also give precipitates.

- (b) A compound of nickel, **J**, has the formula $(\text{NH}_4)_2[\text{Ni}(\text{SCN})_x(\text{NH}_3)_y]$ and contains SCN^- and NH_3 ligands.

The percentage by mass of three of the elements in compound **J** is shown below:
Ni, 16.26%; S, 35.56%; N, 31.00%.

- (i) Calculate the values of x and y in the formula of compound **J**.

$$\text{Ni} : \text{S} : \text{N} = 16.26 \div 58.7 : 35.56 \div 32.1 : 31.00 \div 14.0$$

$$= 0.277 : 1.108 : 2.214 = 1 : 4 : 8$$

$$4 \text{ S atoms, so } x = 4 \text{ (4 } \text{SCN}^- \text{)}$$

$$8 \text{ N} = 2 \text{ (from } \text{NH}_4^+) + 4 \text{ (from } \text{SCN}^-) + y, \text{ so } y = 2$$

$$x = 4$$

$$y = 2$$

[3]

- (ii) Determine the oxidation number of nickel in compound **J**.

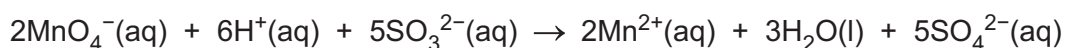
$$[\text{Ni}(\text{SCN})_4(\text{NH}_3)_2]^{2-}: \text{Ni} + 4(-1) + 2(0) = -2$$

$$\text{oxidation number: } +2 \quad [1]$$

- (c) Sodium sulfite(IV), Na_2SO_3 , is used as a preservative in some foods. Food safety legislation allows a maximum of 850 mg Na_2SO_3 per kg of burger meat.

A chemist determines the amount of Na_2SO_3 in a sample of burger meat using a manganate(VII) titration.

- Step 1** The Na_2SO_3 from 525 g of burger meat is extracted to form a solution containing $\text{SO}_3^{2-}(\text{aq})$ ions.
- Step 2** The solution from **step 1** is made up to 250.0 cm^3 in a volumetric flask with water. 25.0 cm^3 of this diluted solution is pipetted into a conical flask.
- Step 3** The pipetted solution from **step 2** is acidified with dilute sulfuric acid and then titrated with $0.0100 \text{ mol dm}^{-3}$ potassium manganate(VII), KMnO_4 .



12.60 cm^3 of $\text{KMnO}_4(\text{aq})$ is required to reach the endpoint.

Analyse the results to determine whether the burger meat complies with food safety legislation.

$$n(\text{MnO}_4^-) = 0.0100 \times 12.60 \div 1000 = 1.26 \times 10^{-4} \text{ mol}$$

$$n(\text{SO}_3^{2-}) \text{ in } 25.0 \text{ cm}^3 = 1.26 \times 10^{-4} \times 5/2 = 3.15 \times 10^{-4} \text{ mol}$$

$$n(\text{SO}_3^{2-}) \text{ in } 250.0 \text{ cm}^3 = 3.15 \times 10^{-4} \times 10 = 3.15 \times 10^{-3} \text{ mol}$$

$$M(\text{Na}_2\text{SO}_3) = 2(23.0) + 32.1 + 3(16.0) = 126.1 \text{ g mol}^{-1}$$

$$\text{mass of } \text{Na}_2\text{SO}_3 \text{ in } 525 \text{ g meat} = 3.15 \times 10^{-3} \times 126.1 = 0.397 \text{ g}$$

$$\text{mass per kg of meat} = 0.397 \times 1000 \div 525 = 0.757 \text{ g} = 757 \text{ mg}$$

$757 \text{ mg} < 850 \text{ mg per kg}$, so the burger meat complies with the food safety legislation.

[5]

END OF QUESTION PAPER

This image shows a blank sheet of white paper designed for handwriting practice. It features a solid vertical line on the left side, creating a narrow margin. The rest of the page is filled with evenly spaced horizontal dashed lines, providing guides for letter height and placement. There are no other markings, text, or illustrations on the page.

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