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						Candidate number				

First name(s) ______________________

Last name ______________________

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.

Answer **all** the questions.

1 Several students titrate 25.00 cm^3 of the same solution of sodium hydroxide, NaOH(aq) with hydrochloric acid, HC*l*(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. no change

B The conical flask is rinsed with water before carrying out the titration. no change same molar ratio

C An air bubble is released from the jet of the burette during the titration. larger titre

D The pipette is rinsed with water before filling with NaOH(aq). lower titre: more dilute NaOH so less HCl needed

Your answer D **[1]**

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

A The number of moles in 12 g of carbon-12.

B The number of electrons lost by 20.05 g of calcium when it reacts with oxygen.

C The number of molecules in 16.0 g of oxygen.

D The number of atoms in 1 mole of chlorine molecules.

Your answer B **[1]**

A: $\frac{12}{12} = 1$ mole

B: $\frac{20.05}{40} = 0.5$ mol = 1 electron lost

$(0.5 \times 2) \times 6.023 \times 10^{23} = N_A$

C: $\frac{16}{16 \times 2} = 0.5$ mol $0.5 \times 6.023 \times 10^{23}$
$= 3.01 \times 10^{23}$ molecules

D: $2 \times 6.023 \times 10^{23} = 1.204 \times 10^{24}$ atoms

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**?

$4X + 3O_2 \longrightarrow 2X_2O_3$

A Aluminium

B Titanium

C Germanium

D Molybdenum

$\frac{0.4}{(16\times2)} = 0.0125$ mol O_2

$\frac{0.0125}{3} \times 4 = 0.017$ mol X

$\frac{0.8}{0.017} = 48 = Ti$

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?

$100 \times 10^{-3} \times 0.1 = 0.01$ mol

$40 + ((16+1)\times2) = 74$

$\frac{0.01}{2} \times 3 = 0.015$ mol $Ca(OH)_2$

$0.015 \times 74 = 1.11$ g

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: $1s^22s^22p^63s^23p^63d^54s^1$. Hund's Rule

~~B~~ Cu^+ ions contain an incomplete 3d sub-shell. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$ ~~$4s^1$~~

~~C~~ Fe^{2+} ions contain 3 unpaired electrons. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$ ~~$4s^2$~~

~~D~~ Sc forms ions with different oxidation states.

Sc doesn't lose e^-s to form an ion with incomplete d-subshell most stable Sc ion is Sc^{3+}

Your answer A **[1]**

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

$$C_7H_8(l) + 9O_2(g) \rightarrow 7CO_2(g) + 4H_2O(l)$$

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

exothermic = −ve ΔH_r

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

A −3914

B −692

C +692

D +3914

$$C_7H_8 + 9O_2 \longrightarrow 7CO_2 + 4H_2O$$

+12

7×-394

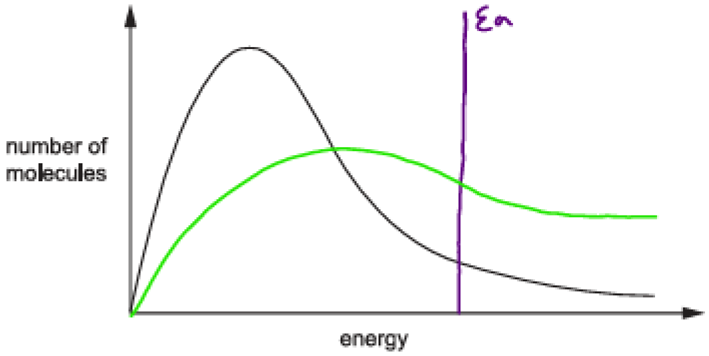
4×-286

$-12 + (7 \times -394) + (4 \times -286)$

$= -3914$ kJmol^{-1}

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

$$K = Ae^{-\frac{Ea}{RT}}$$

$$\ln k = -\frac{Ea}{R}\left(\frac{1}{T}\right) + \ln A$$

$$y = m \quad x + c$$

$$-55000 = -\frac{Ea}{R}$$

$$55000 \times 8.314 = Ea = 457270 \text{ Jmol}^{-1}$$

$$= 457.270 \text{ kJmol}^{-1}$$

Your answer D **[1]**

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

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

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

$$K_p = \frac{P(NH_3)^2}{P(N_2)\,P(H_2)^3}$$

$$18.75 + 2.5 = 21.25$$

$$25 - 21.25 = 3.75 \text{ MPa}$$

$$K_p = \frac{3.75^2}{18.75 \times (2.5)^3} = 0.048 \text{ MPa}^{-2}$$

Your answer B **[1]**

10 The equation for the reaction of I*Cl* and H_2 is shown below.

$2ICl(g) + H_2(g) \rightarrow 2HCl(g) + I_2(g)$

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

What is the overall order of the reaction?

overall 2nd order

$rate = k[A]^1[B]^1$

A 0

B 1

C 2

D 3

$\frac{rate}{[A][B]} = k = \frac{\cancel{mol dm^{-3}} s^{-1}}{\cancel{mol dm^{-3}} mol dm^{-3}}$

Your answer C [1

11 20 cm³ of 0.10 mol dm⁻³ hydrochloric acid is added to 10 cm³ of 0.10 mol dm⁻³ sodium hydroxide.

What is the pH of the resulting mixture?

n

v×c

A 1.00

B 1.18

C 1.30

D 1.48

$20 \times 10^{-3} \times 0.1 = 2 \times 10^{-3}$ mol HCl

$10 \times 10^{-3} \times 0.1 = 1 \times 10^{-3}$ mol NaOH

$2 \times 10^{-3} - 1 \times 10^{-3} = 1 \times 10^{-3}$ mol excess

$\frac{1 \times 10^{-3}}{(20+10) \times 10^{-3}} = \frac{1}{30}$ mol dm⁻³

$pH = -\log_{10}[H^+]$

Your answer D [1

$pH = -\log_{10}\left[\frac{1}{30}\right] = 1.48$

12 Iodide ions, $I^-(aq)$, react with $MnO_4^-(aq)$. The unbalanced equation is shown below.

$\overset{-1}{I^-}(aq) + \overset{+7}{MnO_4^-}(aq) + H_2O(l) \rightarrow \overset{+1}{IO^-}(aq) + \overset{+4}{MnO_2}(s) + OH^-(aq)$

What is the ratio of $MnO_2(s)$ to $OH^-(aq)$ in the balanced equation?

A 1 : 3

B 1 : 2

C 1 : 1

D 3 : 2

red. $3e^- + MnO_4^- + 2H_2O \longrightarrow MnO_2 + 4OH^-$

ox. $I^- + 2OH^- \longrightarrow IO^- + H_2O + 2e^-$

$\cancel{6e} + 2MnO_4^- + \overset{1}{\cancel{4}}H_2O \longrightarrow 2MnO_2 + \overset{2}{\cancel{8}}OH^-$

$3I^- + \cancel{6OH^-} \longrightarrow 3IO^- + \cancel{3H_2O} + \cancel{6e}$

Your answer C [1

$3I^- + 2MnO_4^- + H_2O \longrightarrow 3IO^- + 2MnO_2 + 2OH^-$

2 : 2 = 1 : 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. ✗

$2A + B \rightleftharpoons 3C + D$

$K_c = \frac{[C]^3[D]}{[A]^2[B]}$

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?

smaller so more nuclear attraction needs more energy

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~~ 8 electrons in s orbitals.

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6$ ~~$5s^2$~~

~~3~~ The equation for the reaction of barium with water is:
$2Ba + 2H_2O \rightarrow 2BaOH + H_2$.

$Ba + 2H_2O \rightarrow Ba(OH)_2 + H_2$

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer D **[1]**

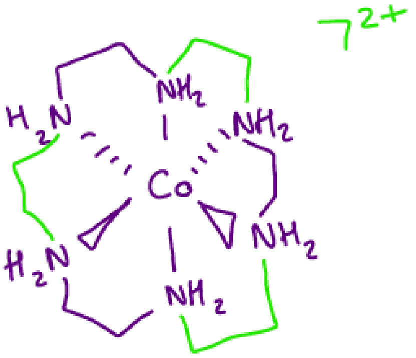
15 Which statement(s) for the complex ion $[Co(NH_2CH_2CH_2NH_2)_3]^{2+}$ is/are correct?

all same bidentate ligands so no cis and trans

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**.

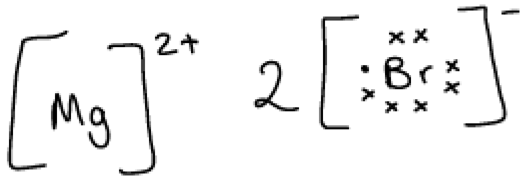
The mean taking into account the relative abundancies of the isotopes

[1]

(b) **(i)** Draw a 'dot-and-cross' diagram for $MgBr_2$.

ionic bonding

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.

$\frac{1.74}{24.3 + (2\times79.9)} = 9.45\times10^{-3}$ mol

3 ions: Mg^{2+}, Br^-, Br^-

$9.45\times10^{-3}\times3 = 0.0283$ mol

$0.0283\times6.023\times10^{23} = 1.71\times10^{22}$ ions

Avogadro's constant

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]**

Mg: giant lattice, metallic bonding with delocalised electrons so can conduct

Br: simple molecular, london forces (induced dipole dipole interactions between molecules so doesn't conduct

$MgBr_2$: giant lattice, ionic bonding between oppositely charged ions in solid ions can't move in solution ions can move and conduct

Metallic and ionic bonds are stronger than london forces so the melting points of Mg and $MgBr_2$ are greater.

Additional answer space if required

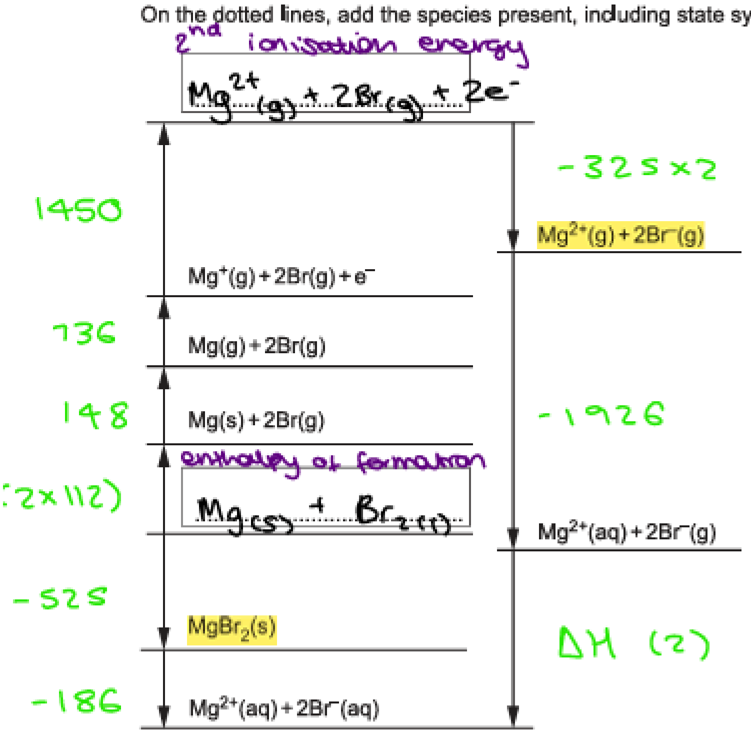
(d) The enthalpy change of hydration of bromide ions can be determined using the enthalpy changes in **Table 16.2**.

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.

1926 + (2×325) − 1450 − 736 − 148

− (2×112) − 525 − 186 = −693 kJmol⁻¹

$\frac{-693}{2}$ = −346.5 kJmol⁻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 $Mg^{2+}(g) + 2Br^{-}(g) \longrightarrow MgBr_2(s)$

Calculation

−1926 + (2×−346.5) + 186 = −2433 kJmol⁻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.**

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H = -91\,kJ\,mol^{-1}$ **Equilibrium 1**

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

↑ want to favour forwards reaction

Explain your answer.

Right hand side has fewer gaseous moles

so high pressure

Forwards reaction was exothermic so low

temperature

[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 lower energy demand

2 less CO_2 emissions

[2]

(c) Standard entropy values are given below.

Substance	$CO(g)$	$H_2(g)$	$CH_3OH(g)$
S° / J K^{-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.

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

$= -0.222 \ kJK^{-1} mol^{-1}$

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

$\Delta G = -91 - (525 \times -0.222) = 25.55$

$kJmol^{-1}$

not feasible as $\Delta G > 0$

[5]

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

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.

$\ln kp = \frac{\Delta G}{-RT}$

$\ln kp = \frac{-2.48 \times 10^4}{-8.314 \times 298}$

$= 10.01$

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

$kp = \frac{p(CH_3OH)}{p(CO) \times p(H_2)^2}$

K_p = 2.22×10^4 units atm^{-2} **[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 $\overset{0}{Mg} + 2\overbrace{CH_3COO}^{-1}\overset{+1}{H} \longrightarrow \overbrace{(CH_3COO)}^{-1}{}_2\overset{+2}{Mg} + \overset{0}{H_2}$

Oxidation Mg : $0 \longrightarrow +2$

Reduction H : $+1 \longrightarrow 0$

[3]

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

stronger acid

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

3.74

4.75

pka = pH

$pka = -\log_{10} ka$

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**.

$\underset{A1}{HCOOH} + \underset{B2}{CH_3COOH} \rightleftharpoons \underset{B1}{HCOO^-} + \underset{A2}{CH_3COOH_2^+}$

[2]

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

$10^{-pH} = [H^+]$

$\frac{[H^+]^2}{[HA]} = Ka$

rearrange for $[HA]$ $= [CH_3COOH]$

(i) The student measures the pH of $CH_3COOH(aq)$ as 2.72.

Show that the concentration of the $CH_3COOH(aq)$ is 0.204 mol dm^{-3}.

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

$[CH_3COOH] = \frac{(1.905 \times 10^{-3})^2}{1.78 \times 10^{-5}} = 0.204$ moldm^{-3}

[2]

(ii) The student plans to make a buffer solution of pH 4.00 from a mixture of $CH_3COOH(aq)$ and sodium ethanoate, $CH_3COONa(aq)$.

The student mixes 400 cm^3 of 0.204 mol dm^{-3} $CH_3COOH(aq)$ with 600 cm^3 of $CH_3COONa(aq)$.

Calculate the concentration of $CH_3COONa(aq)$ needed to prepare this buffer solution of pH 4.00.

$10^{-pH} = [H^+]$

part (i) $[H^+]_{buffer} = 10^{-4} = 1 \times 10^{-4}$ moldm^{-3}

$= 400cm^3 = 0.4dm^3$

$\frac{0.204}{1} \times 0.4 = 8.16 \times 10^{-2} = [CH_3COOH]_{buffer}$

$= 1dm^3 = 1000cm^3$

$\frac{[H^+][A^-]}{[HA]} = Ka$

$1.78 \times 10^{-5} = \frac{[1 \times 10^{-4}][CH_3COO^-]}{8.16 \times 10^{-2}}$

$[CH_3COO^-]_{buffer} = \frac{1.78 \times 10^{-5} \times 8.16 \times 10^{-2}}{1 \times 10^{-4}} = \boxed{1.5 \times 10^{-2}}$ moldm^{-3}

calculator answer

$\frac{\boxed{1.452\ldots} \times 10^{-2} \times 1}{0.6} = 2.4 \times 10^{-2} = [CH_3COO^-]_{initial}$

opposite actions to part (i)

concentration = 2.4 × 10^{-2} mol dm^{-3} **[4]**

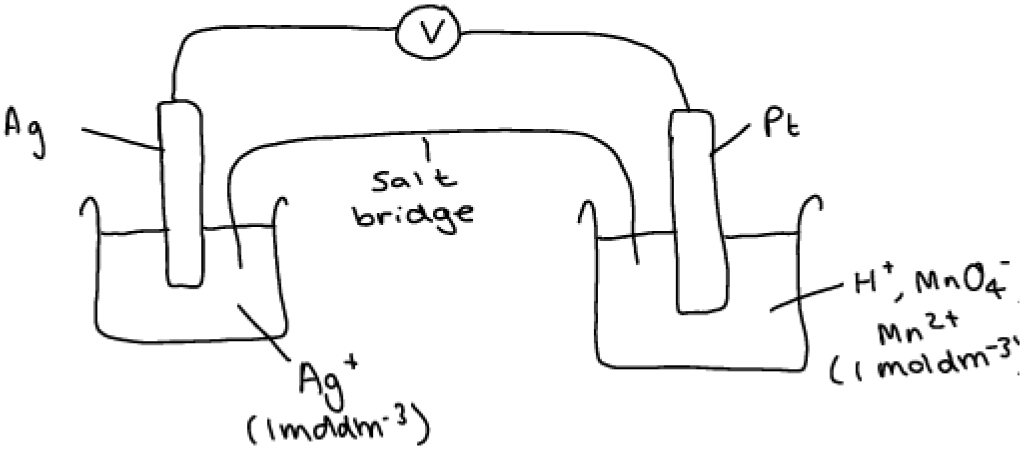
19 Standard electrode potentials for four redox systems are shown in **Table 19.1**.

Redox system	Half-equation	E°/V
1	$CO_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons HCOOH(aq)$	−0.11
2	$HCOOH(aq) + 2H^+(aq) + 2e^- \rightleftharpoons HCHO(aq) + H_2O(l)$	−0.03
3	$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
4	$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+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 redox system 4 is more positive than $E^{\ominus}$ of redox system 2 and 1. More negative systems 2 and 1 shift left

2 and 4:

$2MnO_4^- + \overset{\cancel{16}\ 6}{\cancel{8}}H^+ + \overset{\cancel{10e^-}}{\cancel{5e}} \longrightarrow 2Mn^{2+} + \overset{3}{\overset{\cancel{8}}{\cancel{4}}}H_2O$

$5HCHO + \cancel{5H_2O} \longrightarrow \cancel{10\cancel{2}H^+} + \overset{\cancel{10e^-}}{\cancel{2e^-}} + 5HCOOH$

$2MnO_4^- + 6H^+ + 5HCHO \longrightarrow 2Mn^{2+} + 3H_2O + 5HCOOH$

1 and 4: $2MnO_4^- + 6H^+ + 5HCOOH \longrightarrow 2Mn^{2+} + 8H_2O + 5CO_2$

$2MnO_4^- + \overset{\cancel{16}\ 6}{\cancel{8}}H^+ + \overset{\cancel{10e^-}}{\cancel{5e^-}} \longrightarrow 2Mn^{2+} + 8\cancel{4}H_2O$

$5HCOOH \longrightarrow \overset{\cancel{10}}{\cancel{2}}\cancel{H^+} + \underset{\cancel{10e^-}}{\cancel{2e^-}} + 5CO_2$ **[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.

$HCOOH + ½O_2 \rightarrow H_2O + CO_2$

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.

redox system 1:

$HCOOH \longrightarrow CO_2 + \cancel{2H^+} + \cancel{2e^-}$

$\cancel{2H^+} + ½O_2 + \cancel{2e^-} \longrightarrow H_2O$

$1.34 + (-0.11) = +1.23\ V$

half-equation $2H^+ + ½O_2 + 2e^- \longrightarrow H_2O$

standard electrode potential = +1.23 V

[2]

20 A student investigates the reaction between ethanoic acid, $CH_3COOH(l)$ and methanol, $CH_3OH(l)$, in the presence of an acid catalyst. The equation is shown below.

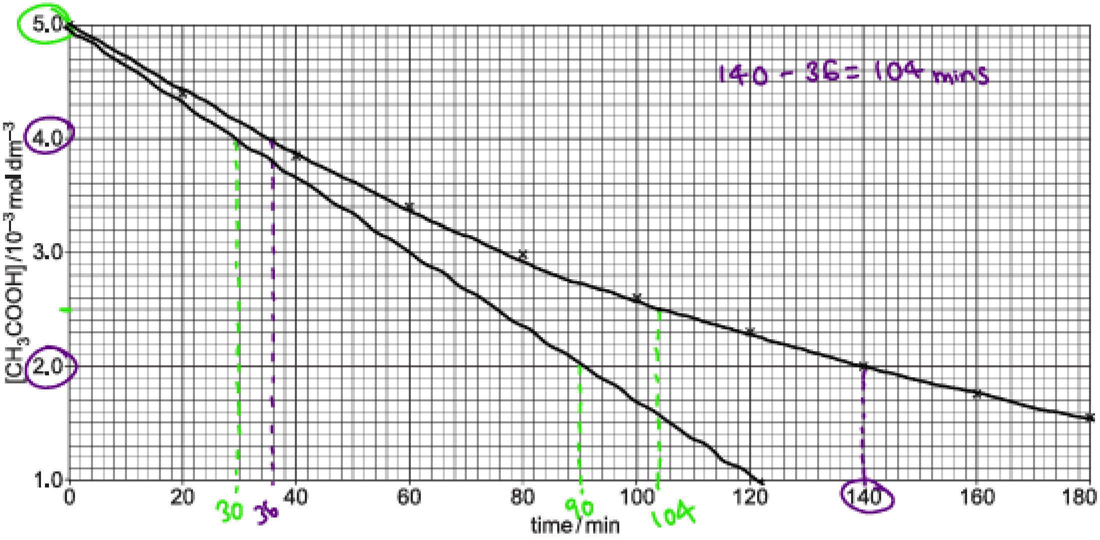
$$CH_3COOH(l) + CH_3OH(l) \rightleftharpoons CH_3COOCH_3(l) + H_2O(l)$$

(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.

- To keep $[CH_3OH]$ constant
- Zero order with respect to CH_3OH [1]
- To ensure equilibrium is far to the right.

(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.

constant ½ lives of 104 mins so first order **[2]**

(iii) Determine the initial rate of reaction.

$k = \frac{\ln 2}{t_{1/2}}$

(I) $k = \frac{\ln 2}{104} = 6.66 \times 10^{-3}\ \text{min}^{-1}$

$6.66 \times 10^{-3} \times 5 \times 10^{-3} = 3.33 \times 10^{-5}\ \text{mol dm}^{-3}\,\text{min}^{-1}$

(II) $\frac{(4-2) \times 10^{-3}}{90-30} = 3.33 \times 10^{-5}\ \text{mol dm}^{-3}\ \text{min}^{-1}$

initial rate = 3.33×10^{-5} mol dm^{-3} min^{-1} **[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.

$K_c = \frac{[CH_3COOCH_3][H_2O]}{[CH_3OH][CH_3COOH]}$

$\frac{9.6}{12+3+16+1} = 0.3\ \text{mol}\ \ CH_3OH$

$\frac{12}{12+3+12+(16 \times 2)+1} = 0.2\ \text{mol}\ \ CH_3COOH$

	CH_3OH	CH_3COOH	CH_3COOCH_3	H_2O
I	0.3	0.2	0	0
C	−0.17	−0.17	+0.17	+0.17
E	0.13	0.03	0.17	0.17

$K_c = \frac{[0.17/V][0.17/V]}{[0.13/V][0.03/V]} = 7.4$

K_c = 7.4 **[4]**

Turn over

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.

orange contains bromine and no reaction

violet contains iodine

$Br_2 + 2I^- \longrightarrow 2Br^- + I_2$

Down the group:

- reactivity decreases
- oxidising power decreases / gains electrons les easily / forms negative ion less easily / less energy released when electron gained / more negative electron affinity
- Greater atomic radius / more shells / more shielding so less nuclear attraction.

[5]

(b) Chlorine is used in water treatment.

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

Benefit kills bacteria

Risk toxic / forms chlorinated hydrocarbons / forms carcinogenic compounds

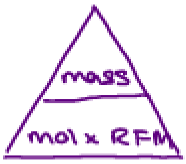
[1]

(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 dm^3.

Under the conditions used, 1 mol of gas molecules has a volume of 29.0 dm^3.

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



$\frac{0.209}{29} = 0.00721$ mol of A

similar to 24dm3 equation: mol = $\frac{\text{vol (dm}^3)}{24}$

Br = 79.9
F = 19

$\frac{1.26}{0.00721} = 174.8$ RFM of A

174.8 - 79.9 = 94.9
94.9 - 79.9 = 15 ← can't have more than one Br
94.9 ÷ 19 = 5

molecular formula = BrF_5 **[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 = $FeSO_4$
Test 1 : Fe^{2+} present
Test 2 : SO_4^{2-} present
D = $Fe(OH)_2$
G = $BaSO_4$
C = $CrCl_3$
Test 1 : Cr^{3+} present
Test 3 : Cl^- present
E = $Cr(OH)_3$
F = $[Cr(NH_3)_6]^{3+}$
H = AgCl
D : $Fe^{2+} + 2OH^- \longrightarrow Fe(OH)_2$
E : $Cr^{3+} + 3OH^- \longrightarrow Cr(OH)_3$
F : $Cr(OH)_3 + 6NH_3 \longrightarrow [Cr(NH_3)_6]^{3+} + 3OH^-$
G : $Ba^{2+} + SO_4^{2-} \longrightarrow BaSO_4$
H : $Ag^+ + Cl^- \longrightarrow AgCl$

(b) A compound of nickel, **J**, has the formula $(NH_4)_2[Ni(SCN)_x(NH_3)_y]$ and contains SCN^- and NH_3 ligands.

2 N's x N's y N's

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**.

Ni : S : N

1 : 4 : 8

$$\frac{16.26}{58.7} : \frac{35.56}{32.1} : \frac{31.0}{14}$$

empirical formula calculation

$$= \frac{0.277}{0.277} \qquad = \frac{1.11}{0.277} \qquad = \frac{2.21}{0.277}$$

$$= 1 \qquad = 4 \qquad = 8$$

$x = 4$

$2 + x + y = 8$

x = ...4..........

y = ...2..........

[3]

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

$$(NH_4)_2\,[Ni(SCN)_4(NH_3)_2]$$

+2 ? = +2 − 4

oxidation number: ....+2.......... **[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 SO_3^{2-}(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 mol dm^{-3} potassium manganate(VII), $KMnO_4$.

$$2MnO_4^-(aq) + 6H^+(aq) + 5SO_3^{2-}(aq) \rightarrow 2Mn^{2+}(aq) + 3H_2O(l) + 5SO_4^{2-}(aq)$$

12.60 cm^3 of $KMnO_4$(aq) is required to reach the endpoint.

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

$0.01 \times 12.6 \times 10^{-3} = 1.26 \times 10^{-4}$ mol MnO_4^-

$\frac{1.26 \times 10^{-3}}{2} \times 5 = 3.15 \times 10^{-4}$ mol SO_3^{2-} in 25 cm3

$3.15 \times 10^{-4} \times 10 = 3.15 \times 10^{-3}$ mol SO_3^{2-} in 250 cm^3

$3.15 \times 10^{-3} \times ((23 \times 2) + 32.1 + (16 \times 3)) = 0.397$g of Na_2SO_3 in 525g meat

$0.397 \times \frac{1000}{525} = 0.756.6$g $= 756.6$mg

756.6mg < 850mg

less than maximum permitted level