OCR
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.

## 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, 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.

**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 ☐ **[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 ☐ **[1]**

**3** 0.80 g of element **X** is reacted with 0.40 g of $O_2$ to form an oxide with the formula $\mathbf{X}_2O_3$.

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

**A** Aluminium

**B** Titanium

**C** Germanium

**D** Molybdenum

Your answer ☐ **[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 ☐ **[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 ☐ **[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 |

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

**A** −3914

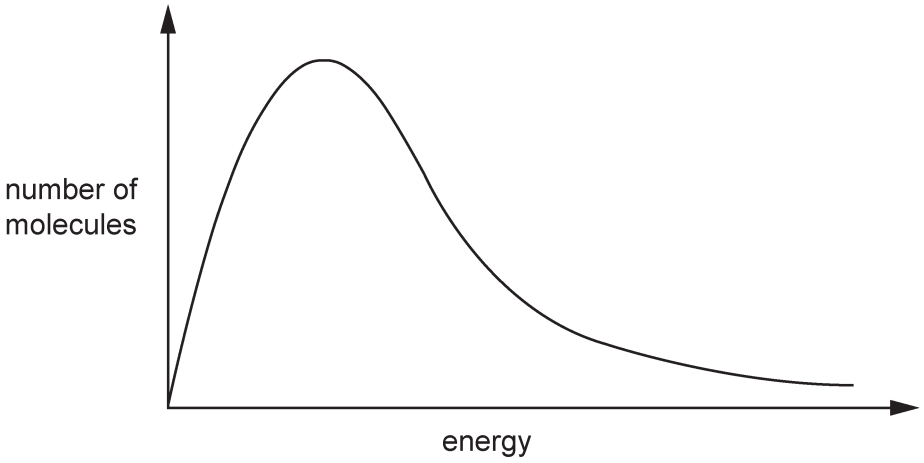
**B** −692

**C** +692

**D** +3914

Your answer ☐ **[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 ☐ **[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 ☐ **[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** $1.2 \times 10^{-4}$

**B** 0.048

**C** 0.075

**D** 21

Your answer ☐ **[1]**

**10** The equation for the reaction of IC*l* and $H_2$ is shown below.

$2IC\mathit{l}(g) + H_2(g) \rightarrow 2HC\mathit{l}(g) + I_2(g)$

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?

**A** 0

**B** 1

**C** 2

**D** 3

Your answer ☐ **[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 ☐ **[1]**

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

$I^-(aq) + MnO_4^-(aq) + H_2O(l) \rightarrow IO^-(aq) + MnO_2(s) + OH^-(aq)$

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

Your answer ☐ **[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 ☐ **[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:
$2Ba + 2H_2O \rightarrow 2BaOH + H_2$.

**A** 1, 2 and 3

**B** Only 1 and 2

**C** Only 2 and 3

**D** Only 1

Your answer ☐ **[1]**

**15** Which statement(s) for the complex ion $[Co(NH_2CH_2CH_2NH_2)_3]^{2+}$ 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 ☐ **[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**.

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..... **[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.

number of ions = ..... **[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]**

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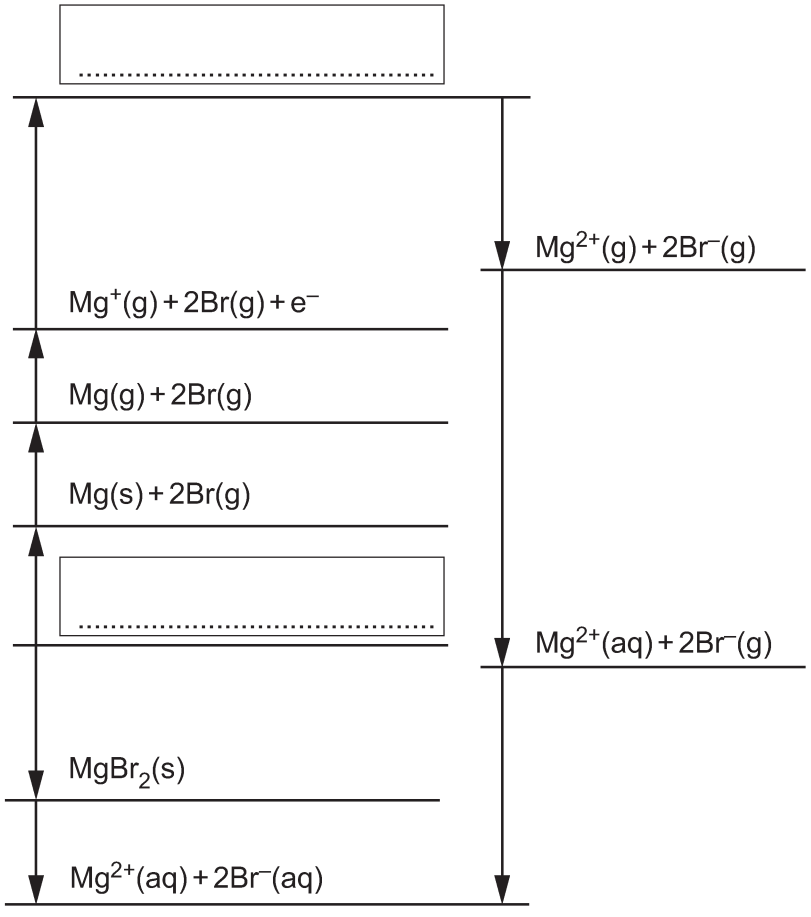
**(d)** The enthalpy change of hydration of bromide ions can be determined using the enthalpy changes in **Table 16.2**.

| 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.

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

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

Equation .....

Calculation

lattice enthalpy = ..... $kJ\,mol^{-1}$ **[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**.

Explain your answer.

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..... **[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** .....

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**2** .....

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**[2]**

**(c)** Standard entropy values are given below.

| **Substance** | CO(g) | $H_2(g)$ | $CH_3OH(g)$ |
|---|---|---|---|
| $S^{\ominus}$ / 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.

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..... **[5]**

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

$\Delta G$ 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.

$K_p$ = ..... units ..... **[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 .....

Oxidation .....

.....

Reduction .....

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**[3]**

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

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

**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**.

HCOOH + $CH_3COOH$ $\rightleftharpoons$ ..... + .....

..... ..... ..... .....

**[2]**

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

**(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 $dm^{-3}$.

**[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.

concentration = ..... mol $dm^{-3}$ **[4]**

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

| Redox system | Half-equation | $E^{\ominus}$/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.

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**(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.

half-equation .....

standard electrode potential = ..... 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.

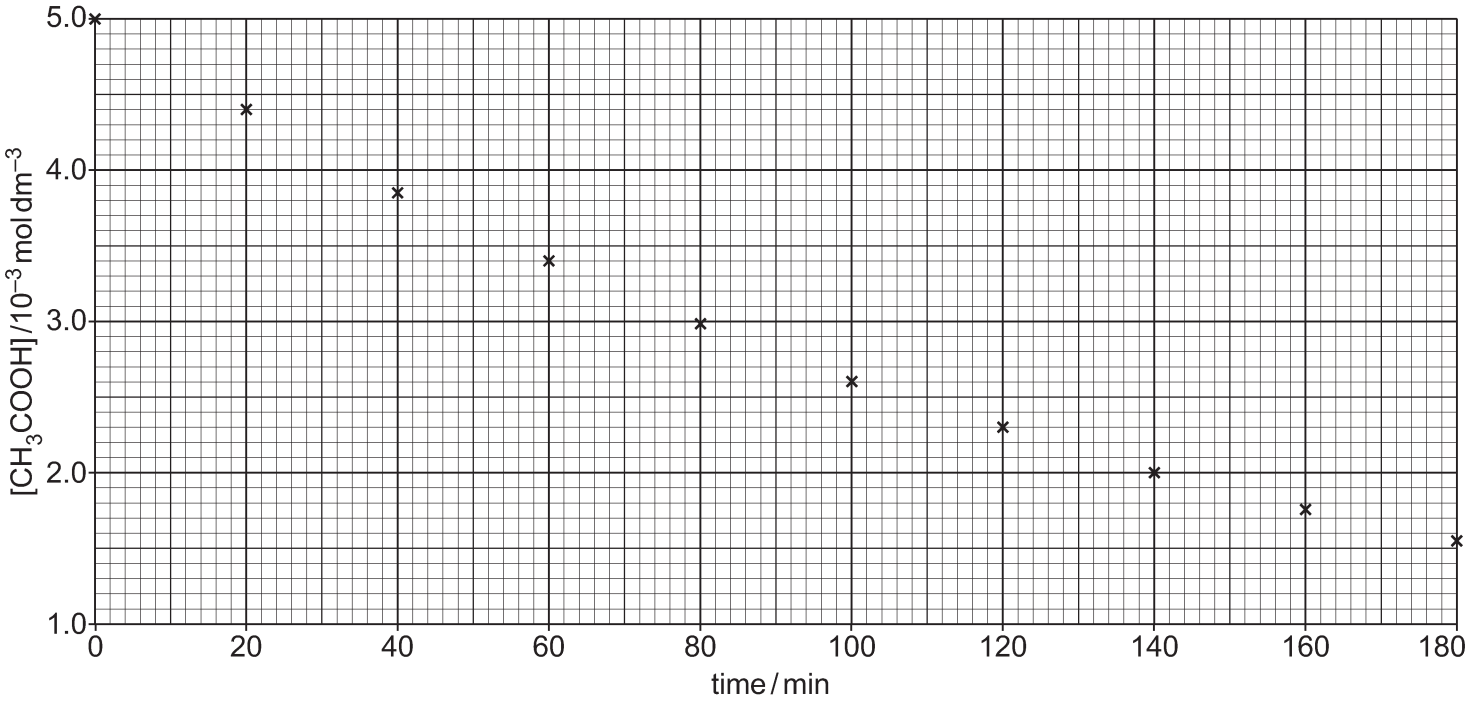
$$CH_3COOH(l) + CH_3OH(l) \rightleftharpoons CH_3COOCH_3(l) + H_2O(l)$$

**(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.

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..... **[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.

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..... **[2]**

**(iii)** Determine the initial rate of reaction.

initial rate = ..... $mol\,dm^{-3}\,min^{-1}$ **[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.

$K_c$ = ..... **[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.

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**(b)** Chlorine is used in water treatment.

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

Benefit .....

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Risk .....

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**[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**.

molecular formula = ..... **[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<br>excess $NH_3$(aq) added | green precipitate **D**<br>no further change | grey-green precipitate **E**<br>purple solution **F** |
| **2** | $HNO_3$(aq)<br>followed by $Ba(NO_3)_2$(aq) | no change<br>white precipitate **G** | no change<br>no change |
| **3** | $HNO_3$(aq)<br>followed by $AgNO_3$(aq) | no change<br>no change | no change<br>white precipitate **H** |

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

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**(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.

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**.

x = .....

y = .....
**[3]**

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

oxidation number: ..... **[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.

**[5]**

**END OF QUESTION PAPER**

## ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).