OCR
Oxford Cambridge and RSA

Monday 13 June 2022 – Morning

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 **32** 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 An aqueous solution contains a mixture of chloride, bromide and iodide ions.

$AgNO_3(aq)$ is added to this mixture, followed by an excess of dilute $NH_3(aq)$.

The resulting mixture is then filtered.

Which compound(s) is/are present in the residue on the filter paper?

A AgC*l* only

B AgC*l* and AgBr

C AgBr only

D AgBr and AgI

Your answer ☐ **[1]**

2 20 cm^3 of nitrogen gas reacts with 10 cm^3 of oxygen gas to form 20 cm^3 of a gaseous product.

Which equation is the most likely for the reaction?

A $N_2(g) + O_2(g) \rightarrow 2NO(g)$

B $N_2(g) + 2O_2(g) \rightarrow N_2O_4(g)$

C $2N_2(g) + O_2(g) \rightarrow 2N_2O(g)$

D $2N_2(g) + 2O_2(g) \rightarrow 4NO(g)$

Your answer ☐ **[1]**

3 0.541 g of an element **X** is reacted with oxygen to form 0.790 g of the oxide $\mathbf{X}_2O_3$.

What is the element **X**?

A A*l*

B Cr

C Ga

D Sc

Your answer [ ] **[1]**

4 Hydrogen peroxide, H_2O_2, can be oxidised by manganate(VII) ions under acid conditions as shown below.

$$2MnO_4^-(aq) + 5H_2O_2(aq) + 6H^+(aq) \longrightarrow 2Mn^{2+}(aq) + 5O_2(g) + 8H_2O(l)$$

In a titration, 25.00 cm^3 of a disinfectant containing hydrogen peroxide reacts with 22.00 cm^3 of 0.125 mol dm^{-3} $KMnO_4(aq)$.

What is the concentration of H_2O_2, in mol dm^{-3}, in the disinfectant?
Assume that $KMnO_4$ only reacts with H_2O_2 in the disinfectant.

A 0.0440

B 0.110

C 0.275

D 0.550

Your answer [ ] **[1]**

5 The mass of 4 molecules of a substance is 2.125×10^{-22} g.

What is the possible formula of the substance?

A CH_4

B O_2

C SO_2

D I_2

Your answer ☐ **[1]**

6 Prussian blue, $C_{18}Fe_7N_{18}$, is a deep blue pigment containing Fe^{2+}, Fe^{3+} and CN^- ions.

What are the numbers of Fe^{2+} and Fe^{3+} ions in one formula unit of $C_{18}Fe_7N_{18}$?

A 2 Fe^{2+} and 5 Fe^{3+}

B 3 Fe^{2+} and 4 Fe^{3+}

C 4 Fe^{2+} and 3 Fe^{3+}

D 5 Fe^{2+} and 2 Fe^{3+}

Your answer ☐ **[1]**

7 Bond enthalpies are shown in the table.

Bond	C–C	C–H	O–H	C–O	C=O	O–O	O=O
Bond enthalpy / kJ mol^{-1}	347	435	464	358	805	144	498

What is the enthalpy change, in kJ mol^{-1}, for the reaction below?

$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)$

A –730

B –544

C +544

D +730

Your answer ☐ **[1]**

8 The half-life for a first order reaction is 80 s.

What is the rate constant k, in s^{-1}, for this reaction?

A 8.66×10^{-3}

B 0.0125

C 55.5

D 115

Your answer ☐ **[1]**

9 Which equation represents the change that accompanies the standard enthalpy change of atomisation of bromine?

A $\frac{1}{2}\,Br_2(l) \longrightarrow Br(g)$

B $Br_2(l) \longrightarrow 2Br(g)$

C $\frac{1}{2}\,Br_2(g) \longrightarrow Br(g)$

D $Br_2(g) \longrightarrow 2Br(g)$

Your answer ☐ **[1]**

10 For the condensation of ammonia gas, what are the signs of ΔH and ΔS?

A ΔH –ve ΔS –ve

B ΔH –ve ΔS +ve

C ΔH +ve ΔS +ve

D ΔH +ve ΔS –ve

Your answer ☐ **[1]**

11 The equilibrium equation for an indicator, HA, is shown below.

Equation: $HA(aq) \rightleftharpoons A^-(aq) + H^+(aq)$

Colour: Blue Yellow

The indicator is added to a solution. The indicator turns a yellow colour.
An excess of aqueous sodium hydroxide is then added.

Which statement describes how the colour of this solution would be expected to change?

A Colour changes from yellow to blue.

B Colour changes from yellow to green.

C Colour changes from yellow to green and then to blue.

D Colour stays yellow.

Your answer ☐ **[1]**

12 Ammonia and water react to set up an acid–base equilibrium.

What are the Brønsted–Lowry acids in the equilibrium mixture?

A H_2O and OH^-

B OH^- and NH_3

C NH_4^+ and H_2O

D NH_4^+ and NH_3

Your answer ☐ **[1]**

13 Standard electrode potentials for two redox systems are shown below.

$Cr^{3+}(aq) + 3e^- \rightleftharpoons Cr(s)$ –0.74 V

$Cr^{3+}(aq) + e^- \rightleftharpoons Cr^{2+}(aq)$ –0.42 V

What is the standard electrode potential for $Cr^{2+}(aq) + 2e^- \rightleftharpoons Cr(s)$?

A –0.32 V

B –0.90 V

C –1.16 V

D –1.80 V

Your answer ☐ **[1]**

14 The three reactions below each form one product only.

Which reaction(s) form(s) a product with non-polar molecules?

1 $2CO + O_2 \rightarrow$

2 $Si + 2Cl_2 \rightarrow$

3 $S + 3F_2 \rightarrow$

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

15 Which ion(s) contain(s) one or more unpaired electrons?

1 Mn^{3+}

2 V^{3+}

3 Cu^{+}

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

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SECTION B

Answer **all** the questions.

16 A catalytic converter in a car removes nitrogen monoxide, NO, and carbon monoxide, CO, from the exhaust gases.

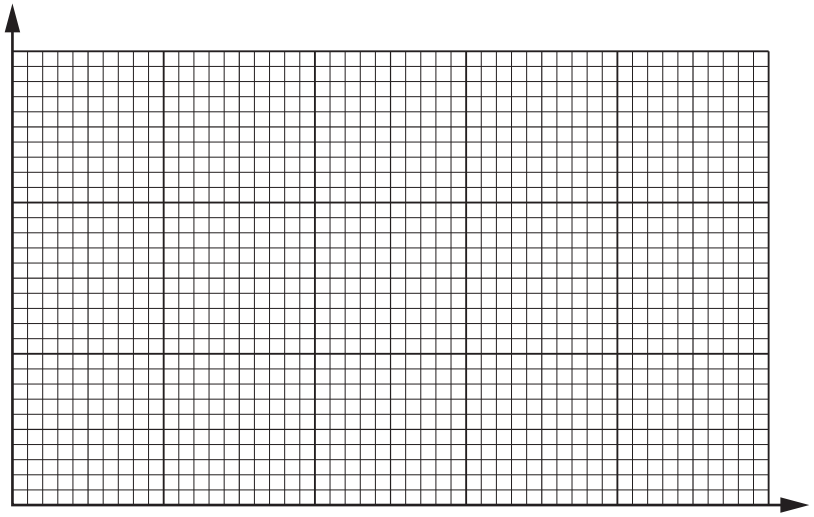
(a) One reaction that happens in a catalytic converter is shown below.

$2CO(g) + 2NO(g) \rightarrow N_2(g) + 2CO_2(g)$ **Reaction 16.1**

(i) Explain how increasing the temperature increases the rate of **Reaction 16.1**.

Include a labelled sketch, using Boltzmann distributions, on the grid below.

Label the axes.



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..... **[3]**

(ii) The rate of **Reaction 16.1** is investigated by carrying out three experiments at the same temperature. The results are shown below.

Experiment	[NO(g)] / mol dm^{-3}	[CO(g)] / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	2.75×10^{-4}	7.25×10^{-4}	1.85×10^{-4}
2	5.50×10^{-4}	7.25×10^{-4}	7.40×10^{-4}
3	1.10×10^{-3}	2.90×10^{-3}	1.18×10^{-2}

Determine the orders with respect to NO and CO, the rate equation, and the rate constant, *k*, including units.

Explain your reasoning.

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k = ... units ..... **[5]**

(b) Carbon monoxide also reacts with nitrogen dioxide as shown in **Reaction 16.2**.

$CO(g) + NO_2(g) \longrightarrow NO(g) + CO_2(g)$ **Reaction 16.2**

The rate equation for **Reaction 16.2** is shown below:

rate = $k[NO_2(g)]^2$

Suggest a possible two-step mechanism for **Reaction 16.2**.
The first step is much slower than the second step.

step 1 .....

step 2 .....

[2]

17 This question is about energy changes.

(a) Magnesium reacts with aqueous silver nitrate, $AgNO_3(aq)$ as shown below.

$$Mg(s) + 2AgNO_3(aq) \longrightarrow 2Ag(s) + Mg(NO_3)_2(aq) \qquad \Delta H = -678\,kJ\,mol^{-1}$$

A student adds an excess of magnesium to 100.0 cm^3 of 0.400 $mol\,dm^{-3}$ $AgNO_3(aq)$.
The initial temperature is 20.0 °C.

(i) Determine the maximum temperature reached in this reaction.
Give your answer to **3** significant figures.

Assume that the specific heat capacity and density of the solution are the same as for water, and that there are no heat losses.

maximum temperature reached = ... °C **[4]**

(ii) The student wants to repeat the experiment, but there is not enough $AgNO_3(aq)$ left to use another $100.0\,cm^3$ portion.

The student decides to modify the method by adding an excess of magnesium to $50.0\,cm^3$ of $0.400\,mol\,dm^{-3}$ $AgNO_3(aq)$.

Predict, with reasons, how this modification would affect the maximum temperature reached. Assume that there are no heat losses.

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..... **[1]**

(b) Nitric acid is manufactured from ammonia in a multi-stage process.
The equation for the first stage in this process is shown in **Reaction 17.1**.

$4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(l)$ $\Delta H^{\ominus} = -1172\,kJ\,mol^{-1}$ **Reaction 17.1**

Some standard enthalpy changes of formation are shown in the table.

Compound	$\Delta_f H^{\ominus}$ / kJ mol^{-1}
$NH_3(g)$	–46
$H_2O(l)$	–286

(i) Explain the term **enthalpy change of formation**.

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..... **[1]**

(ii) Calculate the standard enthalpy change of formation, $\Delta_f H^{\ominus}$, of NO(g).

$\Delta_f H^{\ominus}$ of NO(g) = ... kJ mol^{-1} **[2]**

(c) Carbon disulfide, CS_2, reacts with dinitrogen oxide, N_2O, as shown in **Reaction 17.2**.

$4CS_2(l) + 8N_2O(g) \longrightarrow S_8(s) + 4CO_2(g) + 8N_2(g)$ **Reaction 17.2**

Standard entropies, $S^{\ominus}$, are shown in the table.

Substance	$CS_2(l)$	$N_2O(g)$	$S_8(s)$	$CO_2(g)$	$N_2(g)$
$S^{\ominus}$ **/ J K^{-1} mol^{-1}**	151	220	256	214	192

(i) Explain the term **entropy**.

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..... **[1]**

(ii) The free energy change, ΔG, of **Reaction 17.2** is –2672 kJ mol^{-1} at 25 °C.

Calculate the enthalpy change, ΔH, of **Reaction 17.2**, in kJ mol^{-1}.

ΔH = ... kJ mol^{-1} **[3]**

(iii) A student concludes that **Reaction 17.2** is feasible at all temperatures.

Explain whether the student is correct or not.

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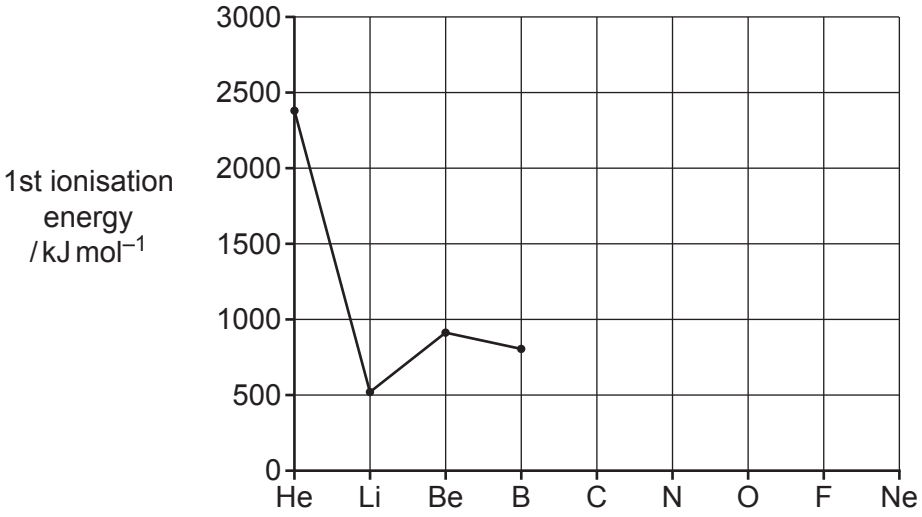
..... **[2]**

18 The graph shows the first ionisation energies for elements from helium, He, to boron, B, in the periodic table.



(a) Complete the graph for C, N, O, F and Ne. **[2]**

(b) Estimate the energy required to form **one** $Li^+(g)$ ion from one Li(g) atom.

Give your answer in kJ, in standard form, and to **two** significant figures.

energy = ... kJ **[1]**

(c) Explain why the first ionisation energies of He and Be are both higher than the first ionisation energy of Li.

Explanation for He: .....

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Explanation for Be: .....

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[4]

(d) Explain why the first ionisation energy of Be is higher than the first ionisation energy of B.

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

19 This question is about acids and buffer solutions.

(a) Succinic acid, $HOOC(CH_2)_2COOH$, is a weak dibasic acid that is used in tablet form in health supplements.

A student plans to determine the mass of succinic acid in one tablet of a succinic acid health supplement.

The student carries out a titration with potassium hydroxide.

The end point occurs when both acidic protons in succinic acid have been replaced as shown in **Equation 19.1**.

$$HOOC(CH_2)_2COOH + 2KOH \longrightarrow KOOC(CH_2)_2COOK + 2H_2O \qquad \textbf{Equation 19.1}$$

The student uses the following method.

Stage 1 The student crushes four tablets of the health supplement and dissolves the powdered tablets in distilled water.

Stage 2 The student makes up the solution from **Stage 1** to 250.0 cm^3 in a volumetric flask.

Stage 3 The student titrates 10.0 cm^3 portions of the solution obtained in **Stage 2** with 0.0600 $mol\,dm^{-3}$ potassium hydroxide, using phenolphthalein as the indicator.

The student carries out a trial titration, followed by three further titrations.
The results are shown below.

Titration	Trial	1	2	3
Final burette reading / cm^3	25.25	23.75	25.35	25.75
Initial burette reading / cm^3	2.50	1.30	2.65	3.20
Titre / cm^3				

(i) Complete the table and calculate the mean titre that the student should use for analysing the results.

mean titre = ... cm^3 **[2]**

(ii) Use the student's results and **Equation 19.1** to calculate the mass, in mg, of succinic acid in **one** tablet of the health supplement.

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

mass = ... mg **[5]**

(b) Glycolic acid, $HOCH_2COOH$, (pK_a = 3.83) is a weak monobasic acid used in some skincare products.

A buffer solution is prepared by adding 60.0 cm^3 of 0.750 mol dm^{-3} glycolic acid to 40.0 cm^3 of 0.625 mol dm^{-3} potassium hydroxide, KOH.

(i) Explain why a buffer solution is formed.

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..... **[1]**

(ii) Calculate the pH of the buffer solution that has been prepared.

Give your answer to **2** decimal places.

pH = ... **[4]**

(iii) A small amount of aqueous ammonia, $NH_3(aq)$, is added to the buffer solution.

Explain, in terms of equilibrium, how the buffer solution would respond to the added $NH_3(aq)$.

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

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20 This question is about equilibria involving hydrogen.

(a)* Hydrogen is used industrially to manufacture ammonia.

The equilibrium is shown below.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H = -92\,kJ\,mol^{-1}$ **Equilibrium 20.1**

1.20 mol $N_2(g)$ is mixed with 3.60 mol $H_2(g)$ in a 8.00 dm^3 container.

The mixture is heated to 550 °C with an iron catalyst and allowed to reach equilibrium.

The equilibrium mixture contains 0.160 mol of NH_3.

Determine the equilibrium constant K_c for **Equilibrium 20.1**, and explain why the operational conditions used by industry may be different from those required for a maximum equilibrium yield of ammonia. **[6]**

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(b) In industry, hydrogen is also used to reduce the iron oxide Fe_3O_4 as shown in **Equilibrium 20.2**.

The reaction is carried out at 500 °C.

$Fe_3O_4(s) + 4H_2(g) \rightleftharpoons 3Fe(s) + 4H_2O(g)$ **Equilibrium 20.2**

(i) When the temperature is decreased, the value of K_p decreases.

Determine whether the forward reaction is exothermic or endothermic.
Explain your answer.

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..... **[1]**

(ii) Two students are discussing the effect of pressure on the equilibrium position of **Equilibrium 20.2**.

Student 1 says:

"There are more moles of products than reactants, so increasing the pressure will shift the equilibrium to the left hand side."

Student 2 disagrees.

Determine which student is correct. Justify your answer.

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..... **[1]**

21 This question is about the reactions of Group 2 metals and their compounds.

(a) A student adds magnesium to dilute hydrochloric acid in one test tube.
The student adds calcium to dilute hydrochloric acid in a second test tube.

A redox reaction takes place in each test tube.

(i) Suggest **two** observations from the student's experiment that would show that calcium is more reactive than magnesium.

1 .....

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2 .....

..... **[1]**

(ii) Write half-equations for the reaction of magnesium with hydrochloric acid.

Oxidation half-equation: .....

Reduction half-equation: .....

[2]

(b) A sample of barium oxide is added to distilled water at 25 °C.
A colourless solution forms containing barium hydroxide, $Ba(OH)_2$.

The solution is made up to 250.0 cm^3 with distilled water.
The pH of this solution is 13.12.

(i) Determine the mass of barium oxide that was used.

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

mass of barium oxide = ... g **[5]**

(ii) 10 cm^3 of dilute sulfuric acid is added to 10 cm^3 of the colourless solution of $Ba(OH)_2$.

Write an ionic equation, including state symbols, for the reaction.

..... **[1]**

(c) Limestone and huntite are two calcium minerals.

(i) A typical sample of limestone contains 95.0% by mass of calcium carbonate, $CaCO_3$.

Fertiliser **Z**, $Ca_5NH_4(NO_3)_{11}•10H_2O$ (M_r = 1080.5 g mol^{-1}) can be made from limestone.

Calculate the mass, in g, of limestone needed to make 1.50 kg of fertiliser **Z**.

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

mass of limestone = ... g **[3]**

(ii) Huntite is a carbonate mineral with the chemical formula $Mg_3Ca(CO_3)_4$.

Huntite reacts with dilute hydrochloric acid to produce bubbles of a gas and a colourless solution.

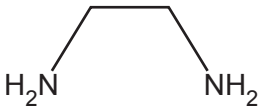
Construct the equation for the reaction. Include state symbols.

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

22 This question is about reactions of transition metal compounds.

(a) Ethane-1,2-diamine, $H_2NCH_2CH_2NH_2$, is a bidentate ligand.

The structure of ethane-1,2-diamine is shown below.



(i) Explain why ethane-1,2-diamine can act as a bidentate ligand.

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..... **[1]**

(ii) The iron(III) ion, Fe^{3+}, forms a complex ion **A** with two ethane-1,2-diamine ligands and two chloride ligands.

Complex ion **A** has *cis* and *trans* stereoisomers.
One of these stereoisomers exists as optical isomers.

Determine the empirical formula, with charge, of complex ion **A** and draw the 3-D structures of the three stereoisomers.

Empirical formula with charge .....

Structures

[4]

(b) Aqueous sodium hydroxide is added to an aqueous solution of iron(II) sulfate.
A pale green precipitate forms which turns brown when left to stand in air.

(i) Write an ionic equation for the formation of the pale green precipitate.

..... **[1]**

(ii) Use the information below to explain why the pale green precipitate turns brown when left to stand in air and construct an equation for the reaction which occurs.

Redox System	Equation	$E^{\ominus}$ / V
1	$Fe(OH)_3(s) + e^- \rightleftharpoons Fe(OH)_2(s) + OH^-(aq)$	–0.56 V
2	$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40 V

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..... **[4]**

TURN OVER FOR QUESTION 22(c)

(c)* This question is about copper and copper compounds.

Experiment 1
Hydrochloric acid, HCl(aq), is added to an aqueous solution containing $[Cu(H_2O)_6]^{2+}$ complex ions.
A yellow-green solution forms containing complex ion **B**.

Experiment 2
A piece of copper metal is heated with concentrated sulfuric acid.
A reaction takes place forming a pale blue solution **C** and 45 cm^3 of a gas **D**, measured at RTP. The mass of gas **D** is 0.12 g.

Experiment 3
An excess of copper(II) oxide is heated with dilute nitric acid. The resulting mixture is filtered. The filtrate is a blue solution **E**.
Aqueous potassium iodide, KI(aq), is added to the blue solution **E**.
A white precipitate **F** and a brown solution **G** form.

Determine the formulae of **B**–**G**.
Construct equations for the reactions taking place, include any changes in oxidation number, and show your working where appropriate. **[6]**

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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).