Surname	Centre Number	Candidate Number
First name(s)		2

GCE A LEVEL

A410U10-1

O21-A410U10-1

TUESDAY, 5 OCTOBER 2021 – AFTERNOON

CHEMISTRY – A level component 1
Physical and Inorganic Chemistry

2 hours 30 minutes

ADDITIONAL MATERIALS

In addition to this examination paper, you will need a:
- calculator;
- **Data Booklet** supplied by WJEC.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen or correction fluid. You may use pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Section A Answer **all** questions.
Section B Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1. to 8.**	**15**	
Section B	**9.**	**12**	
	10.	**14**	
	11.	**15**	
	12.	**20**	
	13.	**17**	
	14.	**17**	
	15.	**10**	
	Total	**120**	

A410U101
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Candidates are advised to allocate their time appropriately between **Section A (15 marks)** and **Section B (105 marks)**.

INFORMATION FOR CANDIDATES

The number of marks is given in brackets at the end of each question or part-question.

The maximum mark for this paper is 120.

Your answers must be relevant and must make full use of the information given to be awarded full marks for a question.

The assessment of the quality of extended response (QER) will take place in **Q.13***(c)*(i) and **Q.15***(b)*.

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SECTION A

Answer **all** *questions in the spaces provided.*

1. Give a reason why chlorine is used in the treatment of domestic water supplies. [1]

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2. Explain why graphite is able to conduct electricity. [1]

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3. The strengths of many acids are recorded using their pK_a values, where pK_a = –log K_a.

The pK_a values of several acids are given below. State, giving a reason, which of these acids is the weakest. [1]

Acid	pK_a
methanoic acid	3.75
ethanoic acid	4.76
hydrofluoric acid	3.20

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4. In the gas phase phosphorus(V) chloride dissociates according to the equation below.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

A sample of pure PCl_5 is allowed to dissociate in a sealed vessel. At equilibrium the total pressure is 240 kPa, with the partial pressure of the PCl_5 being 100 kPa. Find the value of K_p. [3]

K_p = ... Pa

5. The rate of reaction between aqueous sodium hydrogencarbonate and hydrochloric acid was studied at different concentrations. The relative rates of reaction are given in the table.

Concentration of $NaHCO_3$ / mol dm^{-3}	Concentration of HCl / mol dm^{-3}	Relative rate
1.0	1.0	1.00
1.0	0.5	0.50
0.5	1.0	0.50
0.5	0.5	0.25

(a) Suggest a method of measuring the rate of this reaction. [1]

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(b) Find the orders of reaction with respect to $NaHCO_3$ and HCl and hence write the rate equation. [2]

rate = ...

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6. Write an equation to show the reaction that represents the standard enthalpy change of formation of ethanol, $\Delta_f H^\theta$ (C_2H_5OH). You should include state symbols. [2]

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7. A chemical reaction occurs at a temperature of 300 K with an activation energy of 54 000 J mol^{-1}. The frequency factor, *A*, is $1.27 \times 10^9 s^{-1}$.

Write the Arrhenius equation and use it to calculate the value of the rate constant. [2]

Arrhenius equation .....

k = ... s^{-1}

8. Oxygen difluoride, OF_2, is a highly oxidising gas with a foul smell.

(a) Give a reason why the bond angle in OF_2 is less than 109° despite the oxygen having four electron pairs in its outer shell. [1]

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(b) Sulfur is able to form a range of fluorides including SF_2 and SF_6 but oxygen can only form fluorides containing two fluorine atoms. Give a reason for this difference between the chemistry of oxygen and sulfur. [1]

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SECTION B

Answer **all** *questions in the spaces provided.*

9. Caesium is a Group 1 element and it is the most reactive of all naturally occurring metals.

(a) The reactivity of Group 1 elements increases down the group as the first ionisation energy decreases.

Explain why the first ionisation energy of Group 1 elements decreases down the group. [2]

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(b) Caesium is extracted from the mineral pollucite.

A sample of pollucite contains 24.16 % caesium by mass, with each formula unit containing one caesium ion. Find the relative formula mass of this sample of pollucite. [2]

M_r = ...

(c) Caesium chloride has a different crystal structure from sodium chloride.

(i) Draw the crystal structure of caesium chloride. Label your diagram clearly. [1]

(ii) Explain why caesium chloride has a different crystal structure from sodium chloride. [1]

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(d) Caesium-137 was one of the main isotopes released during the Chernobyl nuclear accident in 1986. Another was iodine-131. Some data on these two radioisotopes is given in the table.

Isotope	Half-life	Radiation emitted	Level of radioactivity following the accident / Bq
caesium-137	30 years	β^-, γ	1.8×10^{16}
iodine-131	8 days	β^-, γ	8.5×10^{16}

1 Bq = decay of one nucleus per second

(i) Iodine-131 decays by emission of a β^- particle. Identify the isotope formed. [1]

Element ..... Mass Number .....

(ii) State what is meant by β^- radiation. [1]

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A410U101
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(iii) Calculate the level of radioactivity due to iodine-131 after 32 days. [2]

Level of radioactivity due to iodine-131 = ... Bq

(iv) Suggest which of the two isotopes was released in greater amounts during the accident. Use the data in the table to justify your answer. [2]

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12

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10. A biochemistry handbook suggests using a mixture of propanoic acid, CH_3CH_2COOH, and sodium propanoate, CH_3CH_2COONa, as a buffer solution.

(a) State what is meant by a buffer solution. [1]

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(b) Give a use for a buffer. [1]

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A410U101
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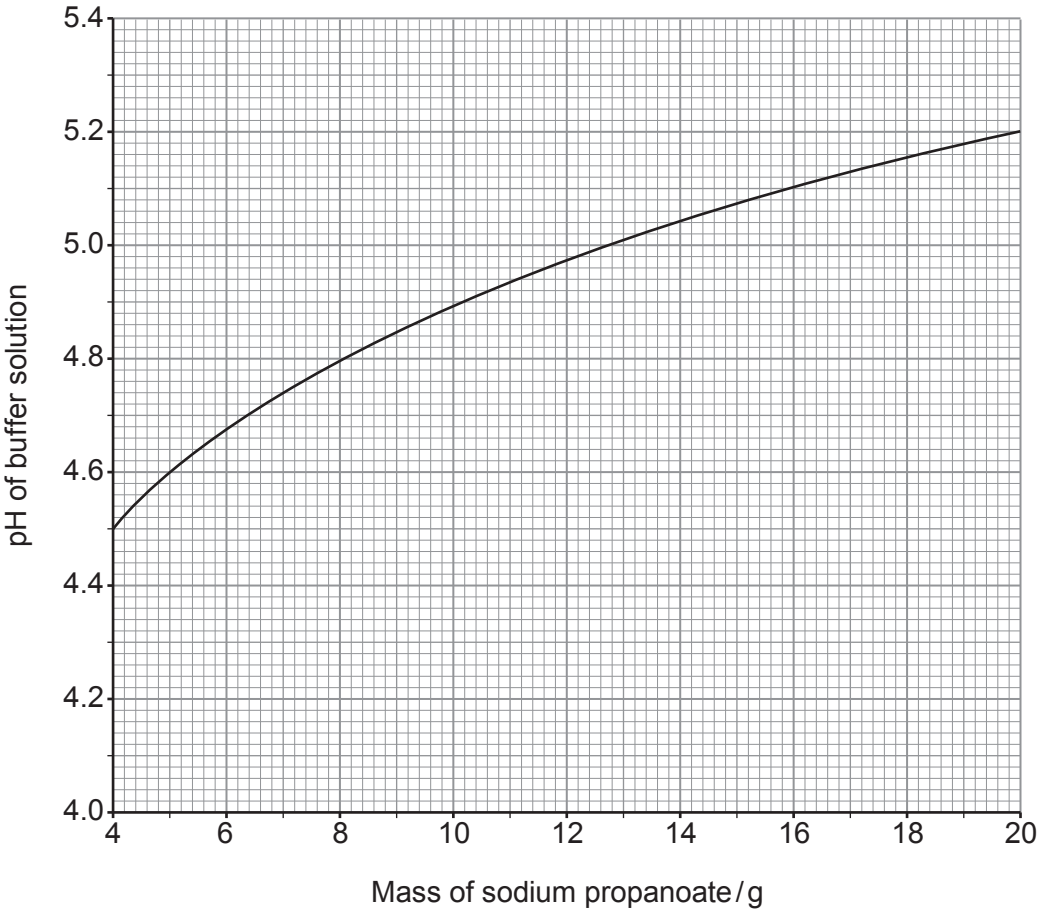
(c) The handbook suggests using $100\,cm^3$ of $1.00\,mol\,dm^{-3}$ aqueous propanoic acid and dissolving an appropriate mass of sodium propanoate in the acid at 298 K to form a buffer.

The mass of sodium propanoate needed for different pH values is given in the chart below.



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(i) Find the pH of the buffer when the concentration of the sodium propanoate is equal to the concentration of the propanoic acid. [4]

pH = ...

(ii) Find the value of K_a for propanoic acid. [2]

K_a = ...

(iii) At a higher temperature a greater mass of sodium propanoate must be added to the propanoic acid to achieve the same pH.

Explain what information this provides about the effect of temperature on K_a and hence the energy change during the dissociation of propanoic acid. [3]

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(d) Propanoic acid reacts with calcium oxide to form calcium propanoate and water.

(i) Write an equation for this reaction. [1]

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(ii) Calculate the mass of calcium propanoate formed by addition of 1.20 g of calcium oxide to excess propanoic acid. [2]

Mass = ... g

14

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11. Copper has two stable oxidation states in its compounds, +1 and +2.

(a) Give the electronic structure of a copper atom. [1]

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(b) Copper(I) compounds are generally white solids. Explain why copper(I) compounds are not coloured. [1]

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(c) Copper(II) oxide reacts with a range of acids to produce salts.

(i) Copper(II) oxide reacts with concentrated hydrochloric acid to give a green solution.

Draw the structure of the copper-containing ion present in this solution. [1]

(ii) Copper(II) oxide reacts with dilute sulfuric acid to give a solution containing aqueous Cu^{2+} ions.

Aqueous Cu^{2+} ions are blue, but a white solid is formed when the solution is heated to complete dryness. Explain why Cu^{2+} ions lose their colour. [2]

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(d) Copper(II) chloride, $CuCl_2$, and copper(I) chloride, CuCl, are the two chlorides of copper. Some thermodynamic data is given in the table.

Substance	Standard enthalpy change of formation / kJ mol^{-1}	Standard entropy / J K^{-1} mol^{-1}
CuCl(s)	–138	87
$CuCl_2$(s)	–206	108
Cu(s)	0	33
Cl_2(g)	0	233

A student states that since copper(II) chloride is more stable than copper(I) chloride, the copper(I) chloride will disproportionate according to the following equation.

$$2CuCl \longrightarrow CuCl_2 + Cu$$

(i) Using the data, give a reason why the student states that $CuCl_2$ is more stable than CuCl. [1]

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(ii) State why the standard enthalpy changes of formation for copper and chlorine are zero. [1]

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(iii) Give a reason why the standard entropy of chlorine is the greatest of all four substances listed. [1]

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(iv) Use the values in the table to show that the student is incorrect and that the disproportionation reaction will not occur at any temperature for the substances in their standard states. [4]

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(v) The data in the table suggests that copper should react with chlorine at room temperature, however heating is usually needed for efficient reaction. Suggest why heating is beneficial. [1]

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A410U101
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(e) The table below lists the standard electrode potentials for some redox systems.

	Standard electrode potential, E^{θ}/V
$H_3PO_3 + 2H^+ + 2e^- \rightleftharpoons H_3PO_2 + H_2O$	–0.50
$Cu^{2+} + e^- \rightleftharpoons Cu^+$	+0.16
$SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons SO_2 + 2H_2O$	+0.17
$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+0.33
$VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$	+0.34
$Cu^+ + e^- \rightleftharpoons Cu$	+0.52
$H_2MoO_4 + 2H^+ + 2e^- \rightleftharpoons MoO_2 + 2H_2O$	+0.65

Copper(I) compounds can be produced by reduction of copper(II) compounds in solution. Identify any suitable reducing agent(s) from the table, explaining your choice(s). [2]

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12. There are many common acids and these can be classified as weak acids such as ethanoic acid, or strong acids such as nitric acid and sulfuric acid.

(a) Nitric acid can be prepared from ammonia in a three-step process.

(i) In step 1 of the process, ammonia is oxidised by oxygen to give nitric oxide, NO, and water.

Write an equation for this step. [1]

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(ii) In the second step, nitric oxide is converted into nitrogen dioxide, NO_2.

$$2NO(g) + O_2(g) \longrightarrow 2NO_2(g) \qquad \Delta H^{\theta} = -114\,kJ\,mol^{-1}$$

The standard enthalpy change of formation of nitric oxide, NO, is $91\,kJ\,mol^{-1}$.

Calculate the standard enthalpy change of formation of nitrogen dioxide, NO_2. [2]

$\Delta_f H^{\theta}$ = ... $kJ\,mol^{-1}$

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(iii) The final step is shown below.

$$3NO_2(g) + H_2O(l) \longrightarrow 2HNO_3(aq) + NO(g) \qquad \Delta H^{\theta} = -117\,kJ\,mol^{-1}$$

I. Use oxidation states to show that this is a disproportionation reaction. [2]

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II. 1.85 g of NO_2 was added to 120 cm^3 of water at a temperature of 19.7 °C. Calculate the final temperature of the water. [4]

Final temperature = ... °C

III. Find the pH of the solution formed in part II. [2]

pH = ...

IV. Nitric oxide, NO, is produced as a side product in step 3. Suggest a way of improving the process to avoid this NO being wasted. [1]

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(b) One method of making ethanoic acid is by the carbonylation of methanol.

$$CH_3OH(l) + CO(g) \longrightarrow CH_3COOH(l) \qquad \Delta G^{\theta} = -88\,kJ\,mol^{-1}$$

$$\Delta H^{\theta} = -137\,kJ\,mol^{-1}$$

Calculate the standard entropy change for this reaction. [3]

ΔS^{θ} = ... $J\,K^{-1}\,mol^{-1}$

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(c) Acids are neutralised by metal carbonates.

(i) Write the ionic equation for the reaction of a carbonate ion with acid. [1]

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(ii) Equal volumes of 1.0 mol dm^{-3} solutions of HNO_3, CH_3COOH and H_2SO_4 were added to separate samples of 1 g of powdered magnesium carbonate.

State and explain any differences in the rates observed for each reaction. [3]

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(iii) The experiment in part (ii) is repeated using barium carbonate in the place of magnesium carbonate.

State and explain any differences in the observations for this experiment. [1]

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13. *(a)* Aluminium chloride exists as the dimer Al_2Cl_6. This includes both covalent and coordinate bonds.

State what is meant by the term coordinate bond, indicating clearly how a coordinate bond differs from a covalent bond. [2]

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(b) Aluminium chloride dimers can break up in the gas phase to form $AlCl_3$ molecules.

The mass spectrum of these molecules contains several molecular ion peaks with m/z in the range 125-150. All the molecular ions contain the isotope aluminium-27.

Find the masses of the heaviest and lightest molecular ions giving peaks in this range and the ratios of their abundances. [4]

Mass of lightest molecular ion peak .....

Mass of heaviest molecular ion peak .....

Ratio of abundance of heaviest molecular ion to lightest molecular ion

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(c) (i) Hydrogen bonding can affect the physical properties of a range of substances.

Explain what is meant by hydrogen bonding and how it affects physical properties. [6 QER]

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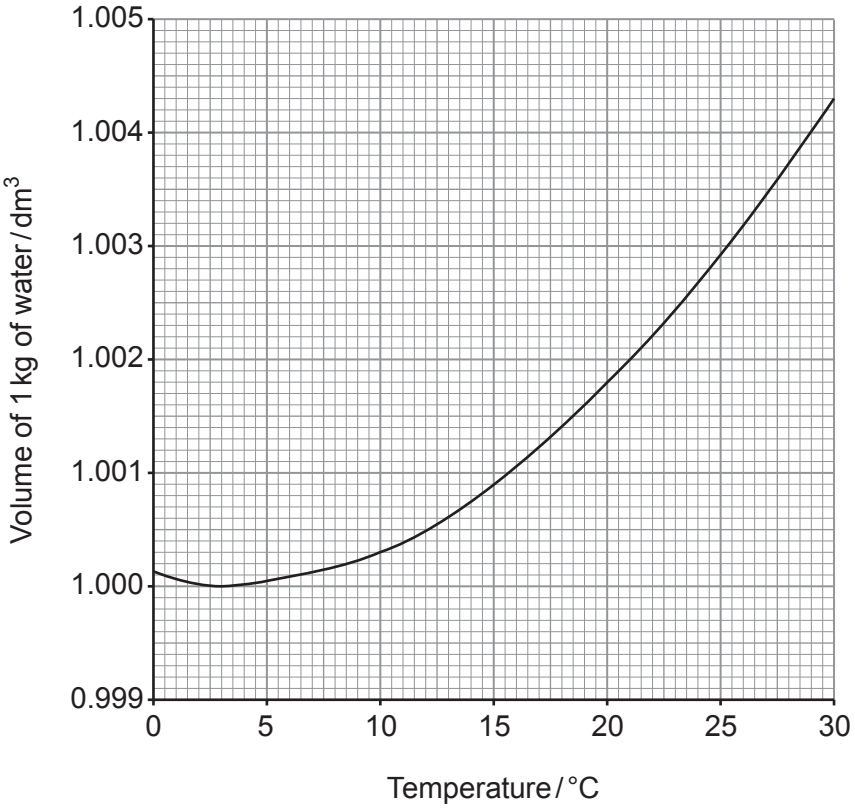
(ii) The volume of 1.000 kg of liquid water was measured at a range of temperatures. The results are shown in the graph.



I. Describe how the **density** of the water changes over this temperature range. [2]

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II. Find the concentration of the water at 20 °C, giving your answer to four significant figures. [3]

Concentration of water = ... mol dm^{-3}

17

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14. Limestone is a common rock which consists mainly of calcium carbonate, but often contains dolomite [$CaMg(CO_3)_2$] as well as insoluble, inert impurities such as sand grains.

A group of students planned to investigate the composition of a sample of limestone found in the Peak District National Park. Their teacher told them to start by crushing the rock into a powder and mixing it thoroughly before taking a sample.

Two students attempted to find the percentage by mass of carbonate ions in the sample, and hence find the percentage of dolomite. The methods used by the two students, and their results, are shown below.

Anne's method: Back titration	*Jack's method: Gas volume*
• Measure precisely a mass of approximately 1.5 g of the powdered limestone and place in a conical flask. • Add 25.0 cm^3 of hydrochloric acid of concentration 2.00 mol dm^{-3} to the powder and mix thoroughly. • Add a few drops of phenolphthalein indicator and titrate using sodium hydroxide solution of concentration 1.00 mol dm^{-3} until a permanent pink colouration is seen.	• Measure precisely a mass of approximately 0.5 g of the powdered limestone and place in a conical flask. • Add 25.0 cm^3 of hydrochloric acid of concentration 2.00 mol dm^{-3} to the powder and immediately place a bung in the mouth of the flask connected to a gas syringe. Mix thoroughly and measure the volume of gas released.
Anne's results Mass of limestone used = 1.510 g Volume of aqueous sodium hydroxide used in titration = 20.65 cm^3	*Jack's results* Mass of limestone used = 0.41 g Volume of carbon dioxide gas measured at 16 °C and 1 atm pressure = 96 cm^3

(a) Give **two** reasons why the teacher recommended "crushing the rock into a powder and mixing it thoroughly". [2]

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(b) Anne initially intended to use sulfuric acid in her method, but her teacher said that hydrochloric acid would be better. Suggest why sulfuric acid would not be appropriate for this method. [1]

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(c) (i) State, giving a reason, which of the two methods gives the more accurate value for the percentage by mass of carbonate ions in the sample. [2]

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(ii) Use the results of the method you have chosen to find the percentage by mass of carbonate ions in the sample. Give your answer to an **appropriate** number of significant figures. [4]

Percentage by mass of carbonate ions = ... %

(iii) The students performed other experiments and found that the sample contained 3.00 % by mass of inert impurities and 37.66 % of calcium ions.

Find the percentage by mass of dolomite. [2]

Percentage by mass of dolomite = ... %

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(d) One major use of limestone is in the production of calcium oxide, CaO, by heating calcium carbonate to approximately 1000 K.

$$CaCO_3 \longrightarrow CaO + CO_2$$

(i) Calculate the atom economy of this method of producing calcium oxide. [2]

Atom economy = ... %

(ii) Suggest why this method does not meet the principles of green chemistry. [2]

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(iii) Suggest, giving a reason, an appropriate temperature for converting barium carbonate to barium oxide in a similar reaction. [2]

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15. A student is provided with four solutions labelled **A**, **B**, **C** and **D**. All four solutions contain ionic compounds made up of familiar cations and anions. All the ions are different.

The student performed flame tests and saw several different flame colours. Two of the flame colours were lilac and golden yellow.

Three of the solutions were colourless and one was pale blue.

To find out the identities of the compounds the student mixed pairs of solutions and his results are given in the table.

	Solution **A**	Solution **B**	Solution **C**
Solution **D**	white precipitate in a pale blue solution	white solid in a brown solution	pale blue precipitate in a colourless solution
Solution **C**	white precipitate in a colourless solution, precipitate dissolves when more solution **C** is added	no visible change	
Solution **B**	bright yellow precipitate in a colourless solution		

(a) The concentration of all four solutions was 0.10 mol dm^{-3}, however the solutions were labelled with concentrations in g dm^{-3}.

Complete the table by finding the relative formula masses of the ionic compounds dissolved in solutions **A**-**D**. [2]

Solution	Concentration / g dm^{-3}	Relative formula mass (M_r)
A	33.10	.....
B	15.00	.....
C	5.611	.....
D	15.95	.....

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(b) Identify the ionic compounds dissolved in solutions **A**-**D**. You should explain clearly how you have reached your conclusions. [6 QER]

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Identities of compounds

A .....

B .....

C .....

D .....

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(c) The lilac colour of the flame test is caused by the emission spectrum of an ion.

Describe how the emission spectrum of hydrogen atoms can be used to find the first ionisation energy of hydrogen. [2]

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END OF PAPER

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Question number	Additional page, if required. Write the question number(s) in the left-hand margin.

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