

Candidate Name

Candidate Number

Centre Name

Centre Number

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**Paper 2: Chemistry**

For Examination December 2023

(2 hours)

It is necessary to respond on the answer sheets provided alongside this question paper. Additionally, you must have a soft pencil (preferably of type B or HB), a clean eraser and a dark blue or black pen.

**INSTRUCTIONS:**

- You must write your name, candidate number, centre name and centre number on the answer sheets in the designated spaces.
- Attempt all the questions from using a dark blue or black pen.
- It is important to follow the instructions provided on the answer sheets.
- Do not use correction fluid.
- Avoid writing on any bar codes.

**INFORMATION:**

The number of marks assigned for every question or its parts is indicated within brackets [ ]

## Question 1

Chlorine,  $\text{Cl}_2$ , is a reactive yellow-green gas. It is a strong oxidising agent.

- (a) State how  $\text{Cl}_2$  is used in water purification.

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

- (b) Chlorine has the highest first ionisation energy of the Period 3 elements Na to Cl.

- (i) Construct an equation for the first ionisation energy of chlorine.

Include state symbols.

..... [1]

- (ii) Explain the general increase in the first ionisation energies of the Period 3 elements.

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

- (c) The halide ions,  $\text{X}^-$  (where  $\text{X} = \text{Cl}, \text{Br}, \text{I}$ ), show clear trends in their physical and chemical properties.

- (i) State and explain the relative thermal stabilities of the hydrogen halides,  $\text{HX}$ .

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

The halide ions react easily with concentrated  $\text{H}_2\text{SO}_4$ .

The main sulfur-containing product of each reaction is shown in the table.

| halide ion   | $\text{Cl}^-$    | $\text{Br}^-$ | $\text{I}^-$         |
|--|------------------|---------------|----------------------|
| main sulfur-containing product of reaction with concentrated $\text{H}_2\text{SO}_4$ | $\text{HSO}_4^-$ | $\text{SO}_2$ | $\text{H}_2\text{S}$ |
| oxidation number of sulfur   |                  |               |                      |

(ii) Complete the table to show the oxidation number of sulfur in each of the sulfur-containing products. [1]

(iii) Explain why different sulfur-containing products are produced when each of these halide ions reacts with concentrated  $\text{H}_2\text{SO}_4$ .

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

(d)  $\text{Cl}_2$  reacts with aqueous sodium hydroxide in a disproportionation reaction.

(i) State what is meant by *disproportionation*.

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

(ii) Write an equation for the reaction of  $\text{Cl}_2$  with cold aqueous sodium hydroxide.

..... [1]

(e) Aluminium reacts with chlorine to form aluminium chloride.

Aluminium chloride can exist as the gaseous molecule  $\text{Al}_2\text{Cl}_6$  (g). This molecule contains coordinate bonds.

(i) Draw a diagram that clearly shows all the types of bond present in  $\text{Al}_2\text{Cl}_6$  (g).

[2]

(ii) Describe what you would see when solid aluminium chloride reacts with water. Name the type of reaction that occurs.

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

- (f) 0.020 mol of element **Z** reacts with excess  $Cl_2$  to form 0.020 mol of a liquid chloride.

The liquid chloride has formula  $ZCl_n$ , where  $n$  is an integer.

$ZCl_n$  reacts vigorously with water at room temperature to give an acidic solution and a white solid.

When excess  $AgNO_3(aq)$  is added to the solution, 11.54 g of  $AgCl(s)$  forms.

- (i) Suggest the type of bonding and structure shown by  $ZCl_n$ .  
..... [1]
- (ii) Calculate the value of  $n$  in  $ZCl_n$ .  
..... [2]

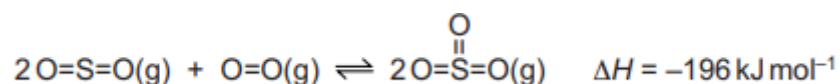
$n =$  ..... [2]

[Total: 17]

## Question 2

Sulfuric acid is manufactured by the Contact process.

One stage in this process is the conversion of sulfur dioxide into sulfur trioxide in the presence of a heterogeneous catalyst of vanadium(V) oxide,  $V_2O_5$ .



- (a) (i) State the effect of a catalyst on a reaction.  
Explain how a catalyst causes this effect.

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

- (ii) State the meaning of the term *heterogeneous* as applied to catalysts.

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

**(b)** Some bond energies are given.

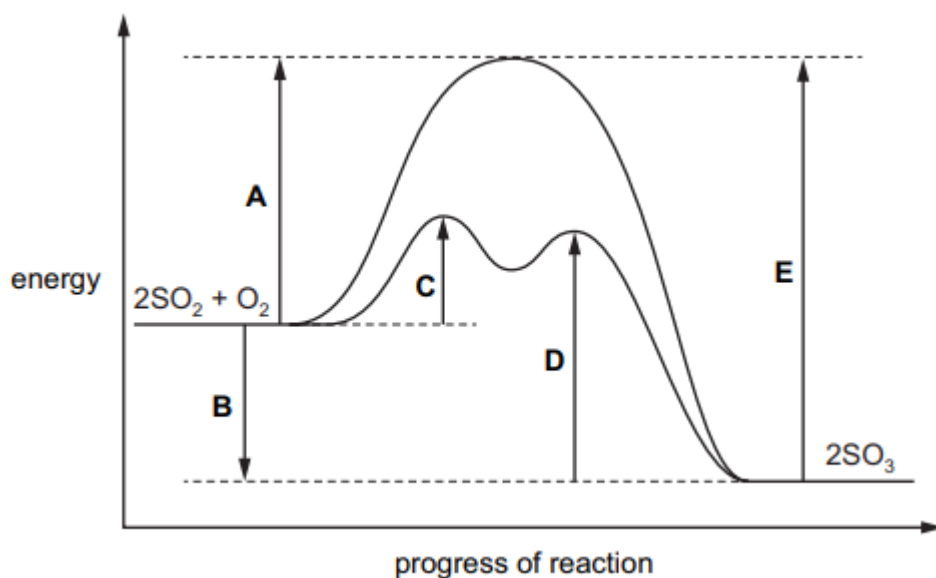
| bond                      | bond energy / kJ mol <sup>-1</sup> |
|---------------------------|------------------------------------|
| S=O (in SO <sub>2</sub> ) | 534                                |
| O=O                       | 496                                |

Use the data, and the enthalpy change for the conversion of sulfur dioxide into sulfur trioxide, to calculate a value for the S=O bond energy in SO<sub>3</sub>.

S=O bond energy in SO<sub>3</sub> = ..... kJ mol<sup>-1</sup> [2]

The Contact process is usually carried out at a temperature of about 400 °C and a pressure just above atmospheric pressure. Using a higher or lower temperature and pressure would affect both the rate of production of sulfur trioxide and the yield of sulfur trioxide.

- (c) A reaction pathway diagram for both the catalysed and uncatalysed reactions between  $\text{SO}_2$  and  $\text{O}_2$  is shown.



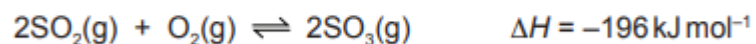
The letters **A–E** represent energy changes.

Complete the table by stating which letter, **A–E**, represents the energy change described.

| energy change   | letter |
|---|--------|
| the energy change for the production of $\text{SO}_3$   |        |
| the activation energy for the production of $\text{SO}_3$ in the absence of a catalyst                              |        |
| the activation energy for the first step in the <b>decomposition</b> of $\text{SO}_3$ in the presence of a catalyst |        |

[3]

The equation for this stage of the Contact Process is shown.



**(d) (i)** State and explain the effect of increasing temperature on the rate of production of  $\text{SO}_3$ .

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

**(ii)** State and explain the effect of increasing temperature on the yield of  $\text{SO}_3$ .

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

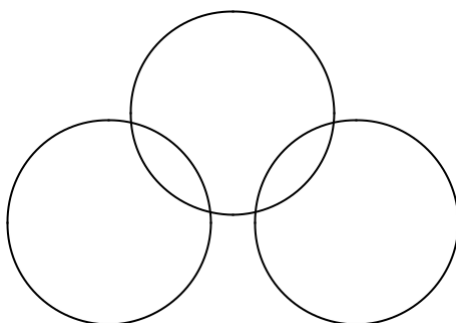
**(e)** The  $\text{SO}_3$  produced is converted to sulfuric acid in two stages. In the first stage the  $\text{SO}_3$  is reacted with concentrated sulfuric acid to produce oleum,  $\text{H}_2\text{S}_2\text{O}_7$ . The oleum is then reacted with water to form sulfuric acid.

Suggest an equation for the reaction of oleum,  $\text{H}_2\text{S}_2\text{O}_7$ , with water to form sulfuric acid.

..... [1]

**(f)**  $\text{SO}_2$  reacts with water to form sulfurous acid. Sulfurous acid is a weak Brønsted-Lowry acid, while sulfuric acid is a strong Brønsted-Lowry acid.

**(i)** Complete the 'dot-and-cross' diagram to show the bonding in a molecule of  $\text{SO}_2$ . Show outer electrons only.



[1]

(ii) State the meaning of the term **strong Brønsted-Lowry acid**.

.....

.....

..... [2]

(iii) Write an equation to show the acid-base behaviour of sulfuric acid with water. Include state symbols.

..... [2]

[Total: 20]

### Question 3

Crude oil is a complex mixture of hydrocarbon molecules.

The hydrocarbon molecules in crude oil are separated by fractional distillation. Fractional distillation is used because the different hydrocarbon molecules in crude oil have different boiling points.

i) Explain why the hydrocarbon molecules in crude oil have different boiling points.

.....

.....

.....

.....

.....

.....

..... [2]

ii) Some of the hydrocarbon molecules obtained from crude oil are processed further by cracking. Suggest why some hydrocarbon molecules are processed further by cracking.

.....

.....

..... [1]



- b) Cracking one mole of dodecane,  $C_{12}H_{26}$ , produces two moles of ethene and one mole of another hydrocarbon molecule.

(j) Write the equation for this cracking reaction.

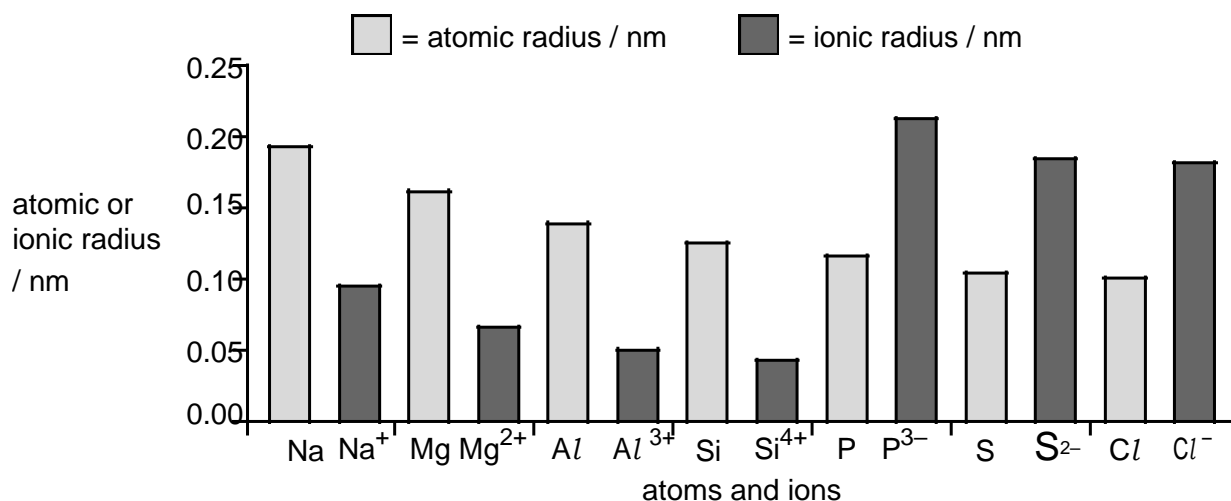
..... [1]

[Total: 4]

#### Question 4

The elements in the third period exhibit periodicity in both their chemical and physical properties.

A graph of the atomic and ionic radii across the third period is shown.



(i) Explain the decrease in atomic radius across the third period.

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

(ii) Explain why, for sodium to silicon, the ionic radii are less than the atomic radii.

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

(iii) Explain why, for phosphorus to chlorine, the ionic radii are greater than the atomic radii.

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

**(b)** The first ionisation energies of the elements across the third period show a general increase.

Aluminium and sulfur do **not** follow this general trend.

**(i)** Explain why aluminium has a lower first ionisation energy than magnesium.

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

**(ii)** Explain why sulfur has a lower first ionisation energy than phosphorus.

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

**(c)** The elements in the third period, from sodium to silicon, can react with chlorine to form chlorides.

**(i)** State and explain the pattern of change of oxidation number which occurs to both chlorine and the different Period 3 elements when they react together.

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

**(ii)** Give the equations to show the reactions of sodium chloride and silicon(IV) chloride when separately added to water.

sodium chloride .....  
silicon(IV) chloride .....  
[2]

**(iii)** Complete the table to describe the structure and bonding in sodium chloride and silicon(IV) chloride.

|                      | structure | bonding |
|----------------------|-----------|---------|
| sodium chloride      |           |         |
| silicon(IV) chloride |           |         |

[2]

[Total: 16]

### Question 5

**X** is  $\text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{CH}_3$ .

(a) The reaction between **X** and alkaline aqueous iodine produces a yellow precipitate.

(i) Give the name of the compound formed as a yellow precipitate in this reaction.

..... [1]

(ii) Give the name of **X**.

..... [1]

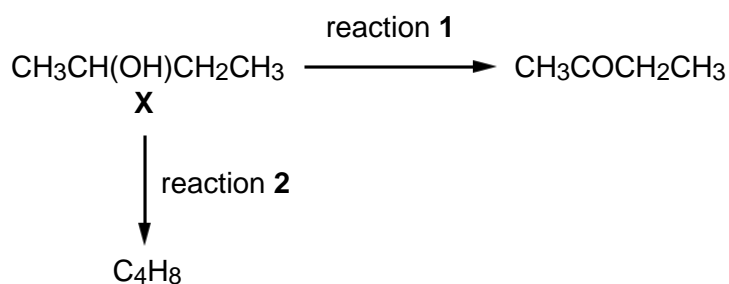
(b) There are three structural isomers of **X** that are alcohols.

Draw the structures of these three isomers of **X**.

|  |  |
|--|--|
|  |  |
|  |  |

[3]

(c) Two reactions of **X** are shown.



(i) Identify the type of reaction involved in reaction 1.

..... [1]

(ii) Identify the reagents for reaction 1.

..... [1]

- (iii) Reaction **2** can be carried out by passing the vapour of **X** over hot aluminium oxide. The product of reaction **2**, C<sub>4</sub>H<sub>8</sub>, is actually a mixture of three isomers.

Give the full names of the three isomers formed by reaction **2**.

- 1 .....
- 2 .....
- 3 .....

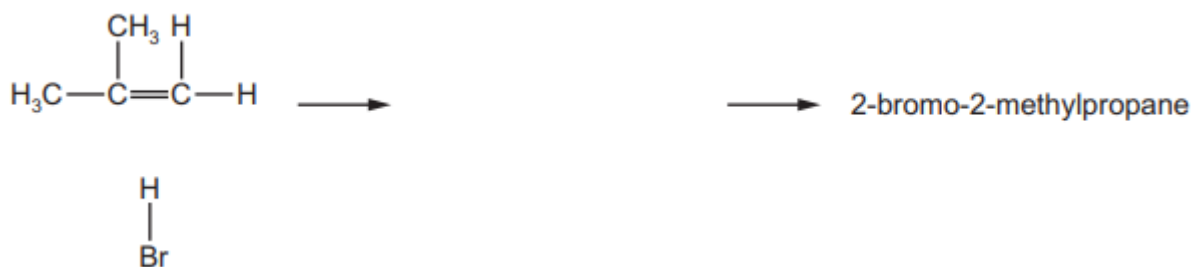
[3]

- (d) The reaction of methylpropene, (CH<sub>3</sub>)<sub>2</sub>CCH<sub>2</sub>, with hydrogen bromide, HBr, produces a mixture of two halogenoalkanes.

One of the halogenoalkanes, 2-bromo-2-methylpropane, is formed as the major product while 1-bromo-2-methylpropane is formed in small quantities.

- (i) Complete the mechanism to show the reaction of methylpropene with HBr to form the **major** product.

Include the structure of the intermediate and all necessary charges, dipoles, lone pairs and curly arrows. The structure of 2-bromo-2-methylpropane is not required.



[4]

- (ii) Explain why 2-bromo-2-methylpropane is the major product of this reaction.

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.....

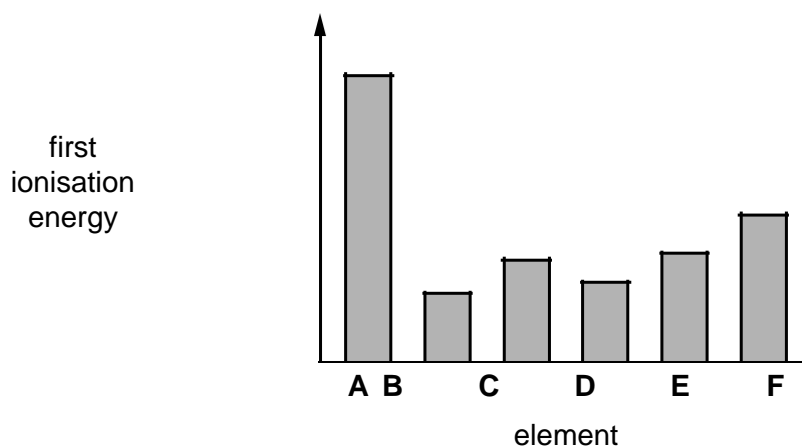
..... [2]

[Total: 16]

### Question 6

The graph shows a sketch of the first ionisation energies of six successive elements in the Periodic Table.

The letters are **not** the symbols of the elements.



(b) Explain what is meant by the term *first ionisation energy*.

.....

.....

.....

..... [3]

(iii) Suggest why the first ionisation energy of **B** is much less than that of **A**.

.....

.....

.....

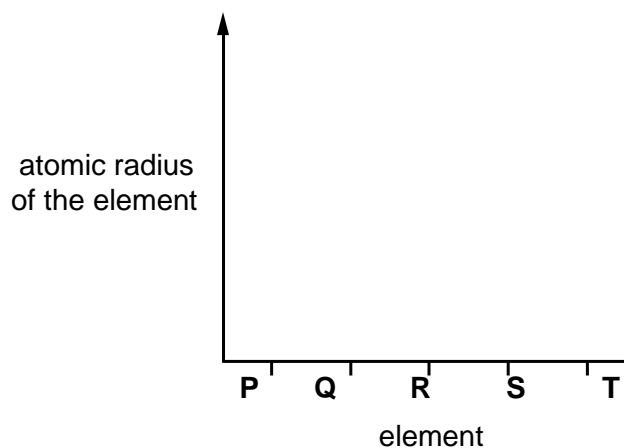
.....

..... [3]

(d) **P–T** are successive elements in Period 3 of the Periodic Table. The letters are **not** the symbols of the elements.

On the axes, sketch a graph to show the trend in the atomic radius of the elements **P–T**.

Explain your answer.



explanation .....

.....

.....

.....

.....

[3]

[Total: 9]

### Question 7

(a) Carbon and silicon are elements in Group 14.

$C_{60}$  and diamond are allotropes of carbon.

Describe the lattice structure of solid  $C_{60}$ .

.....

.....

.....

..... [2]

- (b)  $C_{60}$  sublimes (turns directly from solid to gas) at about 800 K. Diamond also sublimes but only above 3800 K.

Explain why  $C_{60}$  and diamond sublime at such different temperatures.

.....

.....

.....

.....

.....

.....

..... [3]

- (c)  $C_{60}$  forms hydrocarbons with similar chemical properties to those of alkenes. One such **hydrocarbon** is  $C_{60}H_{18}$ .

- i. State what is meant by the term *hydrocarbon*.

.....

..... [1]

- ii. Describe a test to indicate the presence of double bonds between carbon atoms in  $C_{60}H_{18}$ . Give the result of the test.

**test** .....

.....

**result** .....

..... [2]

[Total: 8]

**End of Paper**