

Candidate Name

Candidate Number

Centre Name

Centre Number


**Paper 2: Chemistry**

For Examination June 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

Magnesium silicide,  $\text{Mg}_2\text{Si}$ , is a compound that is made by heating magnesium with sand.

- (a) Draw a 'dot-and-cross' diagram to show the arrangement of outer electrons present in a formula unit of  $\text{Mg}_2\text{Si}$ . Assume magnesium silicide is an ionic compound.

[2]

- (b) When solid  $\text{Mg}_2\text{Si}$  is added to water, silane gas,  $\text{SiH}_4$ , and a solution of magnesium hydroxide are produced.

Construct the equation for this reaction. Include state symbols.

..... [2]

- (c) Suggest, with reference to structure and bonding, why  $\text{SiH}_4$  is a gas at room temperature.

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..... [2]

- (d) The table shows the electronegativity values of carbon, hydrogen and silicon.

element	carbon	hydrogen	silicon
electronegativity	2.5	2.1	1.8

- (i) C–H and Si–H bonds have weak dipoles.

Use the electronegativity values in the table to show the polarity of the C–H and Si–H bonds.

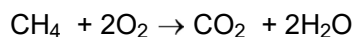
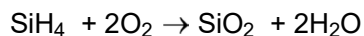


[2]

(ii) Explain why methane, CH<sub>4</sub>, has no overall dipole moment.

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(e) SiH<sub>4</sub> reacts in air without heating but CH<sub>4</sub> must be ignited before combustion occurs.



Suggest, with reference to bond energies from the *Data Booklet*, why SiH<sub>4</sub> reacts in air without heating but CH<sub>4</sub> must be ignited.

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..... [2]

(f) Silicon dioxide reacts with hot, concentrated sodium hydroxide.

(i) Identify the **two** products formed during this reaction.

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..... [2]

(ii) Describe the behaviour of the silicon dioxide during this reaction.

..... [1]

[Total: 15]

## Question 2

Magnesium nitrate,  $\text{Mg}(\text{NO}_3)_2$ , when heated decomposes into different products. One product is a brown gas, nitrogen dioxide.

- (a) (i) Write an equation that describes this reaction. You are not required to include state symbols.

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[2]

- (ii) Calcium nitrate decomposes in a similar way to magnesium nitrate, but at a higher temperature.

Explain why the two different nitrates have different stability to heat.

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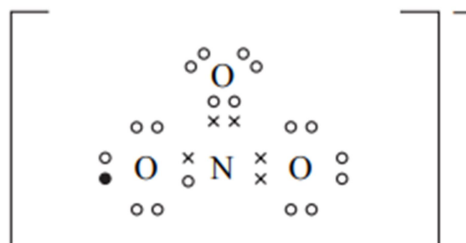
[2]

- (b) Sodium nitrate also decomposes when exposed to heat. However, it gives different products to magnesium nitrate. State the equation for the decomposition of sodium nitrate. State symbols are not required.

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[1]

A student suggest to their classmates that the structure of the nitrate ion,  $\text{NO}_3^-$ , is as follows:



Scientists have reported that the bonds in the nitrate ion,  $\text{NO}_3^-$ , between the nitrogen and oxygen atoms, are all of the same length. Is the student's suggestion supported by this evidence? Explain your answer in detail.

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[2]

The compound, nitrogen dioxide gas is able to dimerize to form nitrogen tetroxide,  $\text{N}_2\text{O}_4$ , a very pale yellow gas, as shown in the below equation.



- (i) What would you expect to see if any equilibrium mixture of these specific gases were warmed up gently? Explain your answer.

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[3]

- (ii) Explain why an equilibrium mixture of these gases when the pressure on it is increased, result in a paler colour.

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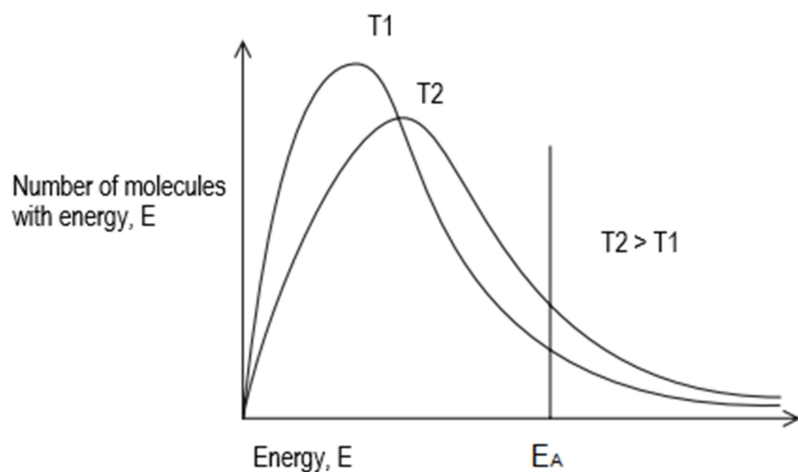
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[2]

Shown below are two Maxwell-Boltzmann distributions showing the energy of gas particles at different temperatures,  $T_1$  and  $T_2$ , are shown below. The activation energy for the reaction is labelled  $E_A$ .



Explain why gas particles react faster when the temperature is increase. Use the distributions in your answer.

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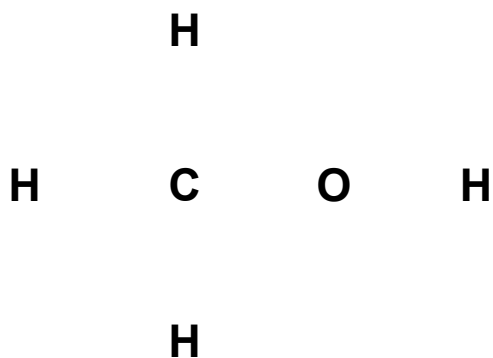
[2]

[Total = 14 marks]

### Question 3

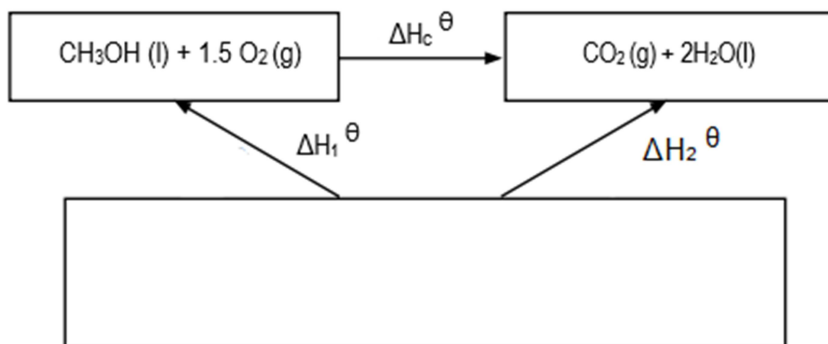
This question is about methanol and specifically, the energy changes that accompany some of its reactions.

- (a) Complete the diagrams (using crosses and dots) to illustrate the bonding in methanol,  $\text{CH}_3\text{OH}$ . Outer electrons should be shown only.



[2]

- (b) The Hess cycle shown below, can be used to calculate the standard enthalpy change of combustion of methanol, using standard enthalpy changes of formation.



- (i) Complete the cycle by filling in the empty box.

[2]

- (ii) Define the term **standard enthalpy change of formation** of a compound, making clear the meaning of **standard** in this situation.

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[3]

- (iii) Use the above cycle and the information below to calculate the standard enthalpy change of combustion of methanol,  $\Delta H_c^\theta$ .

	$\Delta H_f^\theta / \text{kJ mol}^{-1}$
$\text{CO}_2 (\text{g})$	- 393.5
$\text{H}_2\text{O} (\text{l})$	- 285.8
$\text{CH}_3\text{OH} (\text{l})$	- 239.1

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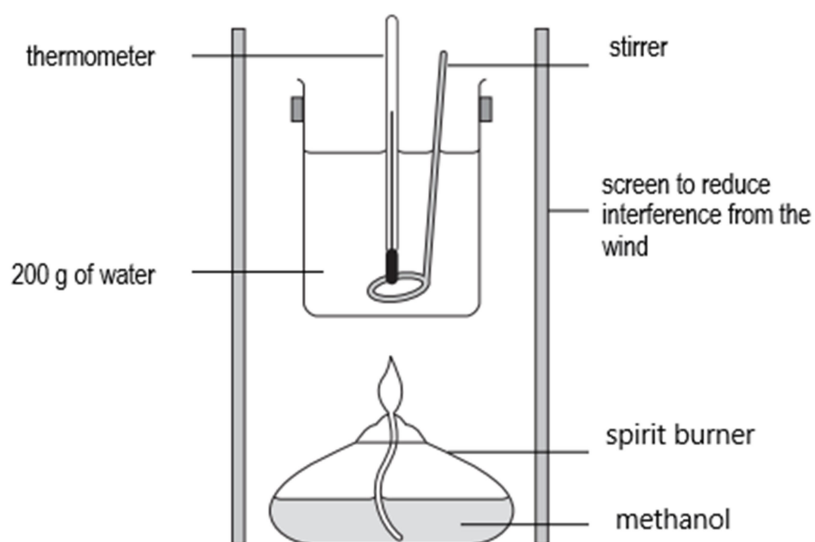
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[2]



A student performs an experiment, to estimate the standard enthalpy change of combustion of methanol.



After burning the methanol for a couple of minutes, the water in the beaker starts to rise in temperature by  $20.7^{\circ}\text{C}$ . The mass of the ethanol that was burnt weighed 0.848 g.

- (i) Determine the amount of energy that was transferred to the water.

Energy transferred (J) = mass of water  $\times$  4.18  $\times$  temperature change

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[2]

- (ii) Calculate the number of moles of methanol,  $\text{CH}_3\text{OH}$ , which was burnt during the experiment.

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[2]

- (iii) Use your answers to (c)(i) and (ii) to determine the experimental value for the standard enthalpy change of combustion. Your answer should include a sign and units, which should be given to three significant figures.

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[3]

- (iv) Compare your answers to (b)(iii) and (c)(iii) and provide TWO reasons to explain any differences between them.

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[2]

**[Total: 18 marks]**

#### Question 4

Vinegar is used as a food preservative. It is an acidic solution consisting of ethanoic acid,  $\text{CH}_3\text{COOH}$ .

(a) A titration was carried out to measure the concentration of ethanoic acid in a sample of vinegar. A solution of vinegar ( $25.0 \text{ cm}^3$ ) was titrated with a solution of sodium hydroxide, with a concentration of  $0.250 \text{ mol dm}^{-3}$ . The concentration of the ethanoic acid in the vinegar solution was found to be  $0.125 \text{ mol dm}^{-3}$ .

(i) Calculate the pH of  $0.250 \text{ mol dm}^{-3}$  sodium hydroxide at 298 K.  
[ $K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$  at 298 K.]

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[2]

(ii) Write the **expression** for the acid dissociation constant,  $K_A$ , for ethanoic acid.

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[2]

- (iii) Calculate the pH of  $0.125 \text{ mol dm}^{-3}$  ethanoic acid at 298 K.  
[ $K_a$  for ethanoic acid is  $1.7 \times 10^{-5} \text{ mol dm}^{-3}$  at 298 K.]

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[3]

- (iv) At the point where half of the ethanoic acid is neutralized, the remaining concentration of ethanoic acid is equal to the concentration of the sodium ethanoate that has formed. Determine what the pH of the mixture is at this point. Justify your answer.

[3]

pH .....

Justification .....

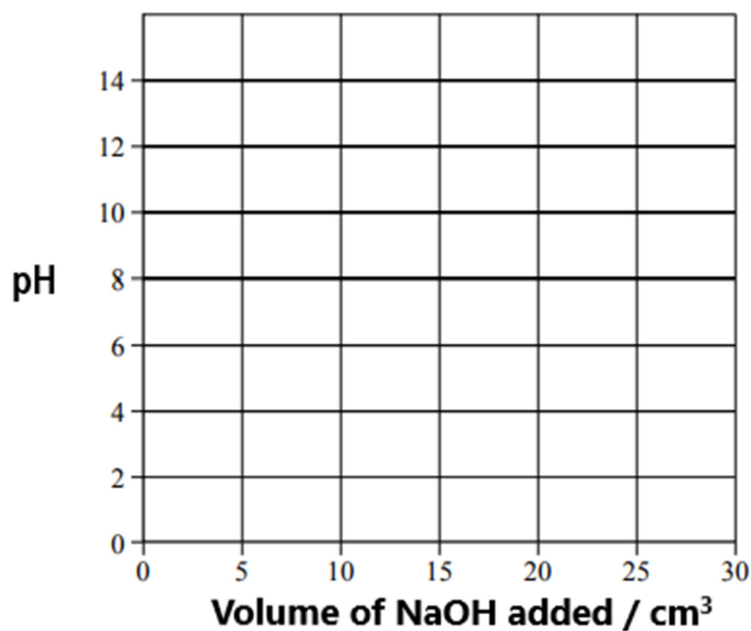
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v) On the graph below, draw the titration curve for this reaction when 30.0 cm<sup>3</sup> of sodium hydroxide is added to 25.0 cm<sup>3</sup> of the vinegar solution.



vi) In the food industry, ethanoic acid is described as a regulator of acidity, additive number (E260).

Ethanoic acid can neutralize alkalis. What substance can you suggest that could be mixed with ethanoic acid so that it regulates pH as a buffer in foodstuffs? Provide a reason for your suggestion.

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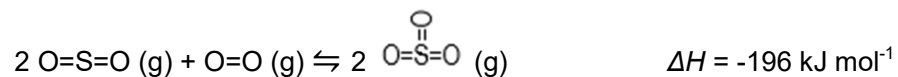
[1]

[Total: 11 marks]

### Question 5

Sulfuric acid is produced industrially by the Contact process.

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



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

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[2]

- (ii) Define the term **heterogeneous** as applied to catalysts.

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[1]

(b) Two bond energies are given in the table below.

Bond	Bond energy / $\text{kJ mol}^{-1}$
S=O (in $\text{SO}_2$ )	534
O=O	496

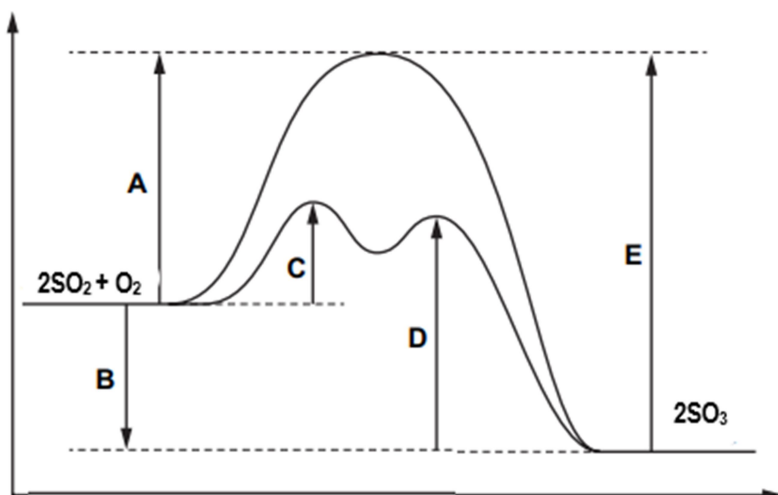
Using the data in the table above, and the enthalpy change for the conversion of sulfur dioxide into sulfur trioxide, calculate a value for the S=O energy bond in  $\text{SO}_3$ .

S=O bond energy in  $\text{SO}_3$  = .....  $\text{kJ mol}^{-1}$

[2]

The Contact process is typically carried out at a high temperature of approximately  $400^\circ\text{C}$  and a pressure just above atmospheric pressure. By using a higher or lower pressure and temperature, would result in affecting both of the rate of production of sulfur trioxide and the yield of sulfur trioxide.

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



The letters A-E in the diagram represent energy changes.

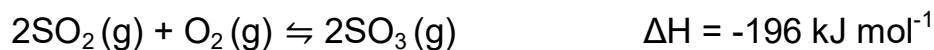


Complete the following table by naming which letter, A-E, represents the energy change described.

Energy Change	Letter
The energy change for the production of SO <sub>3</sub>	
The activation energy for the production of SO <sub>3</sub> in the absence of a catalyst	
The activation energy for the first step in the decomposition of SO <sub>3</sub> in the presence of a catalyst	

[3]

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



- (d) (i) State and give reasons on the effect of increasing the temperature on the rate of SO<sub>3</sub> production.

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[3]

- (ii) State and explain the effect of increasing temperature on the yield of SO<sub>3</sub>.

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[3]

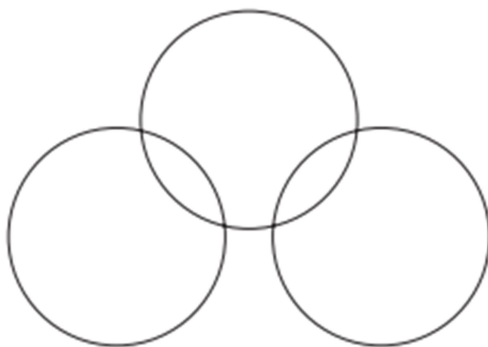
(e) The  $\text{SO}_3$  produced is converted to sulfuric acid in two stages. During the first stage, the  $\text{SO}_3$  reacts with the concentrated sulfuric acid to produce oleum,  $\text{H}_2\text{S}_2\text{O}_7$ . The oleum then reacts with water to form sulfuric acid.

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

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[1]

f)  $\text{SO}_2$  further reacts with water to form sulfurous acid. Sulfurous acid is a weak Bronsted-Lowry acid.

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



[1]

- (iii) Define the term strong Bronsted-Lowry acid.

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[2]

- (iv) State an equation that shows the acid-base behaviour of sulfuric acid with water.  
Include state symbols.

..... [2]

[Total: 20 marks]

### Question 6

Carbon and silicon are elements that are found in Group 14.

- (a)  $C_{60}$  and diamond are common allotropes of carbon.

- (i) Describe the lattice structure of solid  $C_{60}$ .

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..... [2]

$C_{60}$  undergoes sublimation (turns directly from a solid to a gas) at about 800 K.  
Diamond also sublimates but only above 3800K.

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

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[4]

b)  $C_{60}$  forms hydrocarbons with similar chemical properties to those of alkenes. One example of a hydrocarbon is  $C_{60}H_{18}$ .

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

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[1]

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

Test.....

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Result. ....

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[2]

c) Crude oil is a complex mixture containing hydrocarbon molecules.

These hydrocarbon molecules can be separated by a process called fractional distillation. Fractional distillation can be used because the different hydrocarbon molecules in crude oil have different boiling points.

- i) Explain why these different hydrocarbon molecules (in crude oil) have different boiling points.

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[2]

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

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[1]

[Total: 12 marks]