Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Standard level
Paper 2

9 May 2024

Zone A morning | **Zone B** morning | **Zone C** morning

Candidate session number

1 hour 15 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[50 marks]**.

2224 – 6211

Answer **all** questions. Answers must be written within the answer boxes provided.

1. An organic compound, **A**, has the following composition by mass when its only combustion products, carbon dioxide and water, are analysed.

C / %	H / %
71.93	12.10

(a) Outline why this compound is **not** a hydrocarbon. [1]

. . . . . .

. . . . . .

. . . . . .

(b) Determine the empirical formula of **A**. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) A sample of the vapour of **A** at 200.0 °C and 1.00×10^5 Pa has a density of 2.544×10^3 g m^{-3}.

Determine the molar mass and the molecular formula of **A**. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

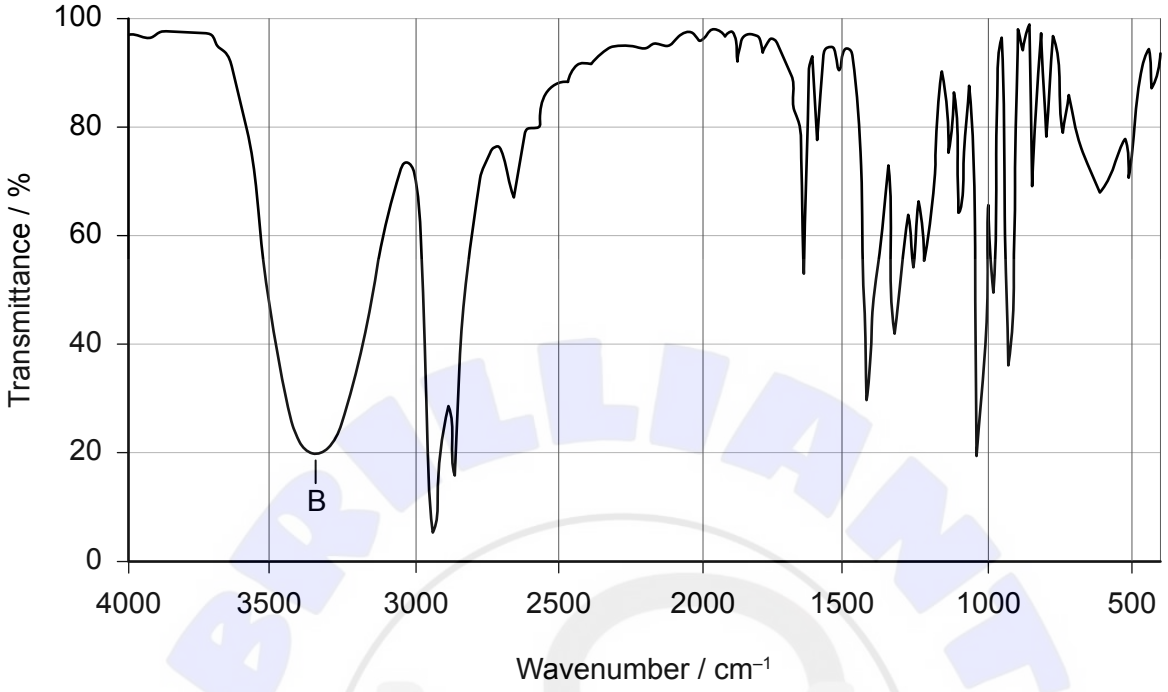
. . . . . .

. . . . . .

(This question continues on the following page)

(Question 1 continued)

(d) The infrared (IR) spectrum of **A** is shown below.



Identify the bond responsible for the absorption labelled **B** in the IR spectrum. Use section 26 of the data booklet. [1]

. . . . . .

(e) **A** can be converted to compound **E**, which has a higher molecular mass, by heating it under reflux with acidified potassium dichromate(VI), $K_2Cr_2O_7$.

Identify **one** functional group present in **E**, based on this information only. [1]

. . . . . .

. . . . . .

2. In the stratosphere, ozone is decomposed by ultraviolet radiation.

$$O_3(g) \rightarrow O_2(g) + O(g)$$

(a) State the full electron configuration of an oxygen atom and the number of unpaired electrons in that atom. [2]

Electron configuration: . . . . . .

Unpaired electrons: . . . . . .

(b) (i) Draw a Lewis (electron dot) structure for the ozone molecule. [1]

(ii) Predict the shape and bond angle of the ozone molecule. [2]

. . . . . .

. . . . . .

. . . . . .

(c) Suggest a value, in pm, for the bond lengths in the ozone molecule and explain your answer. Use section 10 of the data booklet. [2]

. . . . . .

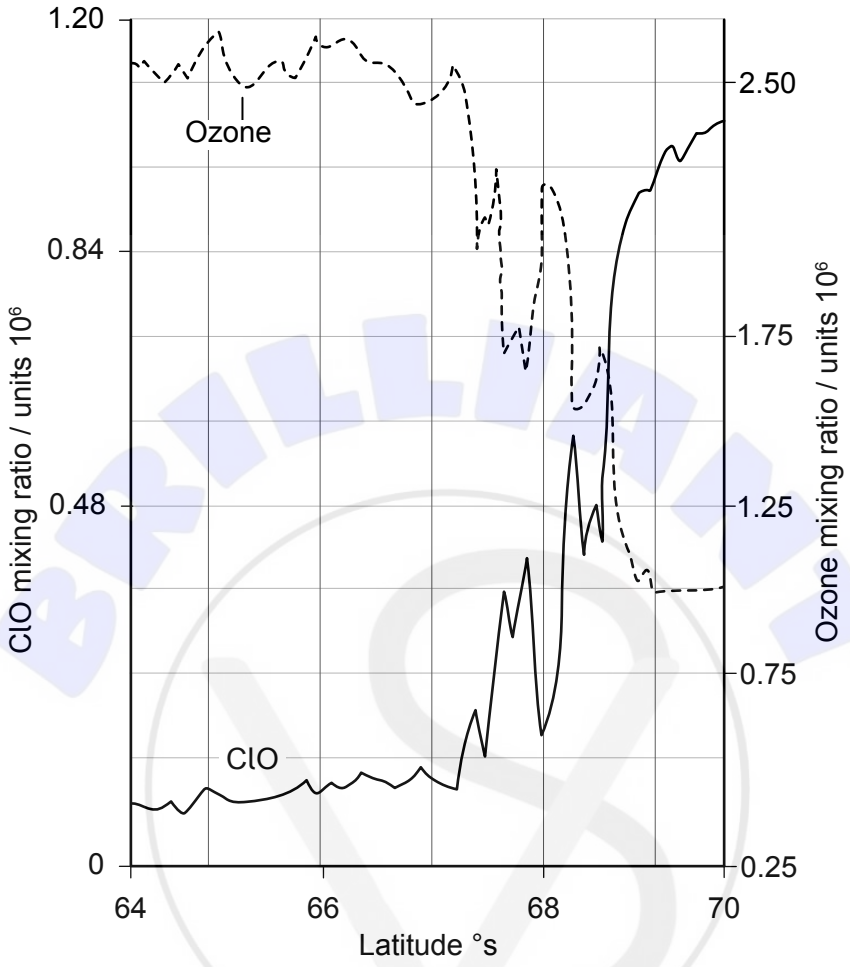
. . . . . .

. . . . . .

(This question continues on the following page)

(Question 2 continued)

(d) The concentrations of ozone molecules and chlorine monoxide, ClO, free radicals were measured.



(i) Outline the relationship between the concentrations of ozone and ClO, free radicals. [1]

. . . . . .

. . . . . .

(ii) Comment, based on this graph, on the conclusion that the hole in the ozone layer is caused by ClO free radicals. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

3. The acid–base character of the oxides of elements depends on their position in the periodic table.

(a) (i) State **one** environmental problem caused by sulfur dioxide, SO_2. [1]

. . . . . .

. . . . . .

(ii) Write an equation to show how sulfur dioxide reacts in the atmosphere to produce a secondary pollutant. [1]

. . . . . .

. . . . . .

(b) A solution was prepared by dissolving 0.100 mol of sodium oxide in distilled water and making the total volume up to 1.00 dm^3.

(i) Write the equation for the reaction between sodium oxide and water. [1]

. . . . . .

. . . . . .

(ii) Calculate the pH of the solution. [2]

. . . . . .

. . . . . .

(This question continues on the following page)

(Question 3 continued)

(c) Phosphoric acid, H_3PO_4, also reacts with water.

$$H_3PO_4(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + H_2PO_4^-(aq)$$

(i) State an expression for the equilibrium constant, K_c, for this equation. [1]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) State, with a reason, the effect of an increase in temperature on the position of this equilibrium, assuming $\Delta H^{\ominus} < 0$. [1]

. . . . . .

. . . . . .

. . . . . .

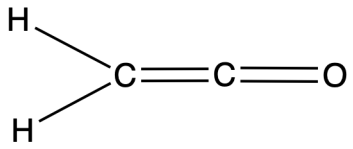
(d) Outline why the ionic radius of the phosphide ion, P^{3-}, is greater than that of the sulfide ion, S^{2-}. [1]

. . . . . .

. . . . . .

. . . . . .

4. Ethenone, CH_2CO, is used in the synthesis of pharmaceutical compounds.



(a) Suggest why the compound is given this IUPAC name. [2]

. . . . . .

. . . . . .

. . . . . .

(b) Compare and contrast the intermolecular forces that result in ethenone being less volatile than carbon dioxide. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) Ethenone can be made by the thermal decomposition of propanone.

$$CH_3COCH_3\ (l) \rightarrow CH_2CO\ (g) + CH_4\ (g)$$

(i) Calculate the standard enthalpy change for this reaction.
Use $\Delta H^{\ominus}_f$ ethenone $= -87.2\,kJ\ mol^{-1}$ and section 12 of the data booklet. [2]

. . . . . .

. . . . . .

. . . . . .

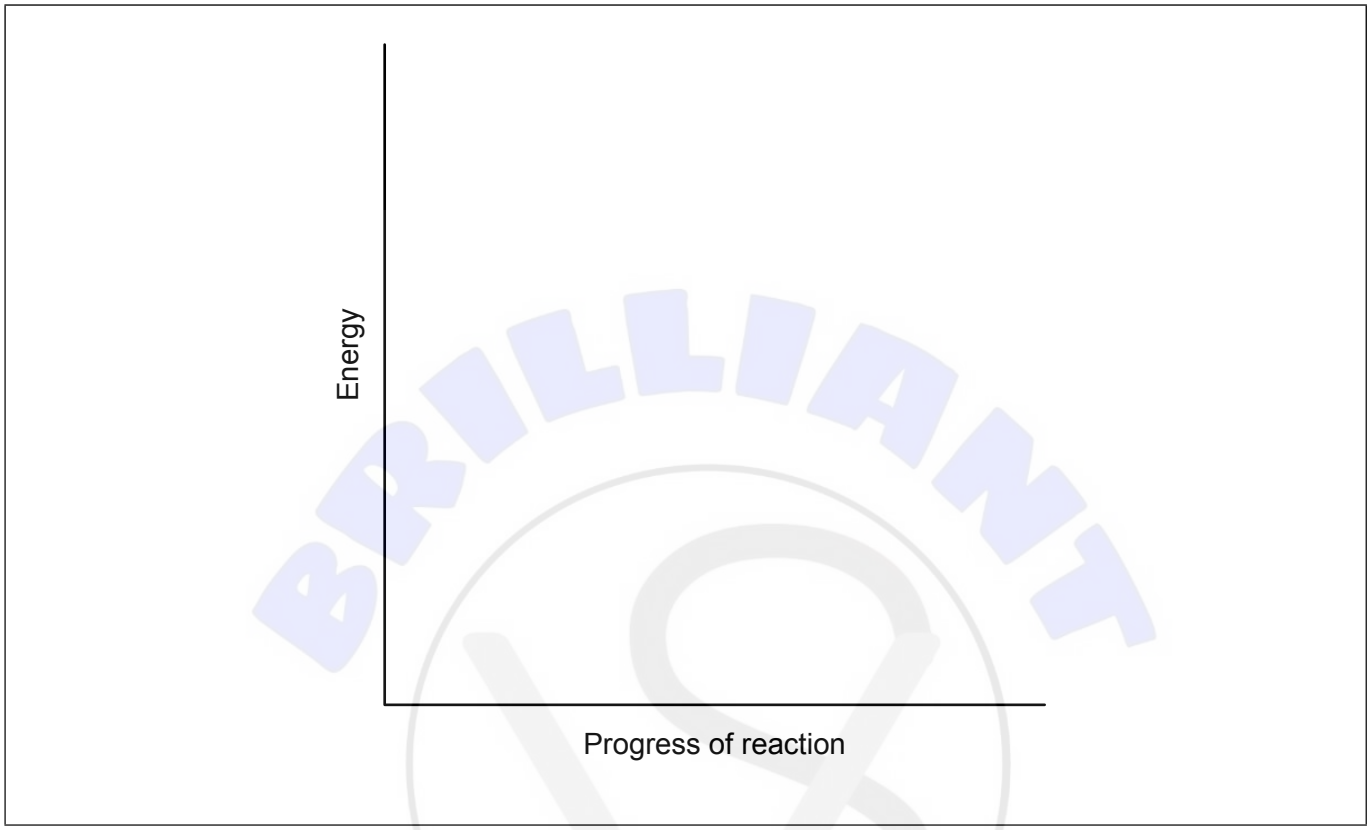
. . . . . .

. . . . . .

(This question continues on the following page)

(Question 4 continued)

(ii) Sketch the potential energy diagram for the thermal decomposition of propanone from (c)(i). Use the axes given and indicate both the enthalpy of reaction and the activation energy. [2]

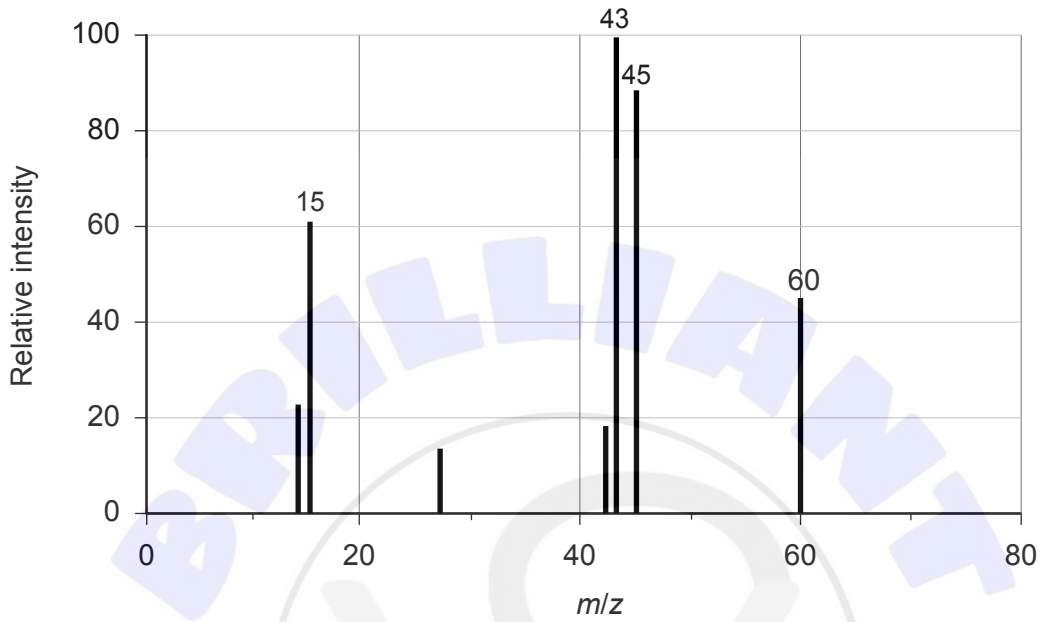


(This question continues on the following page)

(Question 4 continued)

(d) Ethenone can be converted to compound **G**, which reacts slowly with metal oxides when in aqueous solution.

The mass spectrum of **G** is shown.



[Source: Used with permission. © United States of America as represented by the Secretary of Commerce.]

Deduce the identity of **G**, giving **two** reasons based on the spectrum. [3]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question 4 continued)

(e) 10.0 cm^3 of ethenone is mixed with 100 cm^3 of oxygen and burnt completely.

$$CH_2CO\ (g) + 2O_2\ (g) \rightarrow 2CO_2\ (g) + H_2O\ (l)$$

Determine the final volume of the gaseous mixture after the reaction mixture has returned to the original temperature and pressure. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

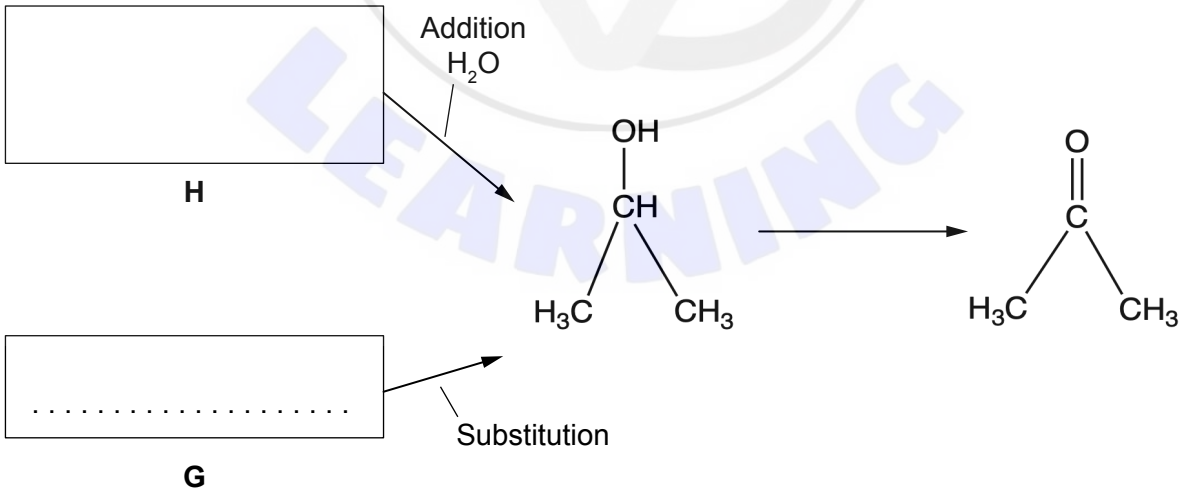
(f) Calculations often assume that real gases behave like ideal gases.

State **one** reason why gases such as carbon dioxide and ethenone become less ideal at higher pressures. [1]

. . . . . .

. . . . . .

(g) Propanone can be synthesised by the oxidation of propan-2-ol. Propan-2-ol can be synthesised in **two** ways, from **H** by addition of water or from **G** by a substitution reaction.



Draw the **structure** of **H** and state the **name** of **G**, applying IUPAC rules. [2]

5. A student investigated the kinetics of the reaction between a dye, RCl, and aqueous sodium hydroxide. The dye has an intense blue colour that fades during the reaction.

The reaction can be represented by the following equation.

$$RCl\ (aq) + OH^-\ (aq) \rightarrow ROH\ (aq) + Cl^-\ (aq)$$

Blue Colourless

In a trial investigation, the student mixed the solutions and measured the time for the colour to disappear in the reaction mixture shown in the table. The student calculated the rate of reaction using the following equation.

Calculated rate = [RCl] / time for colour to disappear

Initial concentration / mol dm^{-3}		**Time for colour to disappear / s**	**Calculated rate / mol dm^{-3} s^{-1}**
[RCl]	[OH^-]		
3.00×10^{-6}	2.00×10^{-2}	110	2.73×10^{-8}

(a) Outline why the calculated rate **does not** correspond to the initial rate of reaction. [1]

. . . . . .

. . . . . .

. . . . . .

(b) The student modified the procedure to measure the concentration of the dye using a spectrophotometer.

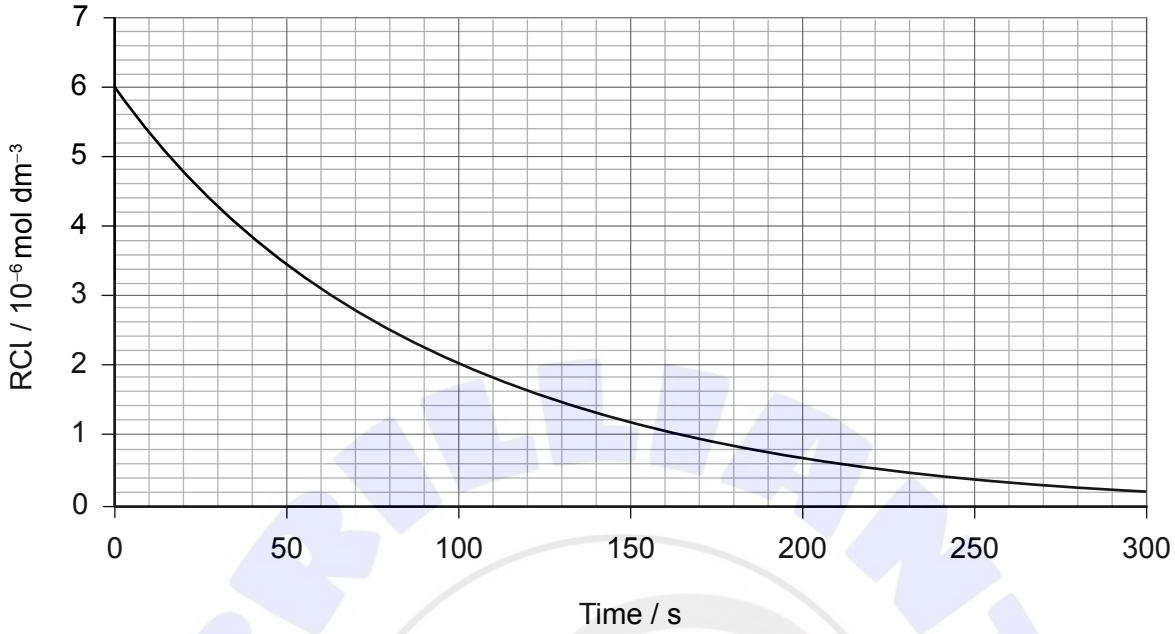
The concentration of the dye was measured continually by monitoring the light absorbed by the reaction mixture.

Experiment	**Initial concentration / mol dm^{-3}**		**Initial rate / mol dm^{-3} s^{-1}**
	[RCl]	**[OH^-]**	
1	3.00×10^{-6}	2.00×10^{-2}	3.20×10^{-8}
2	1.50×10^{-6}	1.00×10^{-2}	8.00×10^{-9}
3		2.00×10^{-2}	

(This question continues on the following page)

(Question 5 continued)

A graph of [RCl] versus time for experiment 3 is shown.



(i) Using the graph, determine the missing values from the table for **experiment 3**.

Justify your answer. [3]

Initial [RCl]: . . . . . .

. . . . . .

Initial rate: . . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Outline, on a molecular level, why the rate decreases with time. [1]

. . . . . .

. . . . . .

6. Compounds are often identified as oxidizing and reducing agents.

(a) Write the half-equations for the formation of the products at the positive electrode (anode) and negative electrode (cathode) when molten sodium bromide is electrolysed. [2]

Positive electrode (anode): . . . . . .

. . . . . .

Negative electrode (cathode): . . . . . .

. . . . . .

(b) Identify the species oxidized and the number of electrons transferred in the following equation. [2]

$$2MnO_4^-(aq) + SO_3^{2-}(aq) + 2OH^-(aq) \rightarrow 2MnO_4^{2-}(aq) + SO_4^{2-}(aq) + H_2O(l)$$

Species oxidized: . . . . . .

Number of electrons transferred: . . . . . .

References:

1.(d) Irina Doroshenko et al. Infrared Absorption Spectra of Monohydric Alcohols. Open access article distributed under the Creative Commons Attribution License https://creativecommons.org/licenses/by/4.0/. Image adapted.

2.(d) Rowland, F.S., 2006. Stratospheric ozone depletion. *Philos Trans R Soc Lond B Biol Sci* 361(1469), pp. 769–790. [e-journal] Available at: https://pubmed.ncbi.nlm.nih.gov/16627294/ [Accessed 12 April 2023]. Source adapted.

4.(d) Used with permission. © United States of America as represented by the Secretary of Commerce.

Please **do not** write on this page.

Answers written on this page
will not be marked.