



CANDIDATE
NAME

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CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/22

October/November 2021

1 hour 15 minutes

You must answer on the question paper.

You will need: Data booklet

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working, use appropriate units and use an appropriate number of significant figures.

- The total mark for this paper is 60.
- The number of marks for each question or part question is shown in brackets [].

This document has **12** pages.

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

1 Hydrogen iodide, HI, is a colourless gas at room temperature.

(a) (i) Explain why HI has a higher boiling point than HCl and HBr.

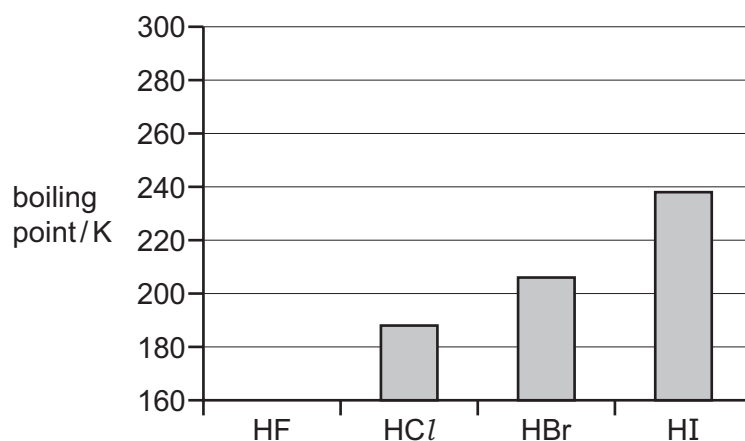
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.....

.....

..... [2]

(ii) The bar chart shows the boiling points of HCl, HBr and HI. The boiling point of HF is not shown.



Hydrogen bonds form between HF molecules.

Draw a bar on the bar chart to predict the boiling point of HF.

Explain your answer.

.....

..... [2]

(b) The standard enthalpy change of formation, $\Delta H_f^\ominus$, of HI(g) is $+26.5 \text{ kJ mol}^{-1}$.

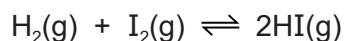
Define the term *standard enthalpy change of formation*.

.....

.....

..... [2]

- (c) HI(g) can be formed by reacting H₂(g) with I₂(g). The reaction is reversible, and an equilibrium forms quickly at high temperatures.



- (i) Construct an expression for the equilibrium constant, K_p , for the reaction of H₂(g) and I₂(g) to form HI(g).

$K_p =$

[1]

- (ii) The equilibrium partial pressures of the gases at 200 °C are as follows.

$$p_{\text{H}_2(\text{g})} = 895 \text{ Pa}$$

$$p_{\text{I}_2(\text{g})} = 895 \text{ Pa}$$

$$p_{\text{HI}(\text{g})} = 4800 \text{ Pa}$$

Calculate K_p for this reaction.

$K_p = \dots\dots\dots$ [1]

- (iii) State how the value of K_p would change, if at all, if the reaction were carried out at 100 °C rather than 200 °C.

Explain your answer.

.....

 [2]

(d) HI reacts with oxygen to form iodine and water.

(i) Construct an equation for the reaction of HI with oxygen.

..... [1]

(ii) Explain, with reference to oxidation numbers, why this reaction is a redox reaction.

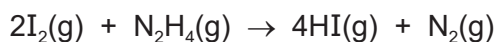
.....

.....

.....

..... [2]

(e) HI(g) can also be formed by the reaction of I₂(g) with hydrazine, N₂H₄(g).



State the change in pressure that would occur when 2 mol I₂(g) fully reacts with 1 mol N₂H₄(g) in a sealed container at constant temperature. Explain your answer.

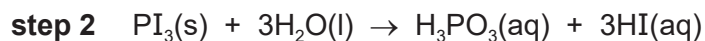
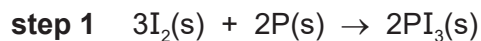
.....

.....

.....

..... [2]

(f) In the laboratory, HI(aq) can be formed in a two-step process.



(i) Draw a 'dot-and-cross' diagram of a PI_3 molecule.

[2]

(ii) Name the type of reaction in **step 2**.

..... [1]

(iii) $\text{H}_3\text{PO}_3(\text{aq})$ and $\text{HI}(\text{aq})$ are both strong Brønsted–Lowry acids.

Give the meaning of the term *strong Brønsted–Lowry acid*.

.....

 [2]

(iv) Give the formula of the conjugate base of H_3PO_3 .

..... [1]

(g) HI(g) reacts with propene, $\text{CH}_3\text{CH}=\text{CH}_2(\text{g})$ to form a mixture of 1-iodopropane and 2-iodopropane.

(i) Identify which of 1-iodopropane and 2-iodopropane is the major product of this reaction.

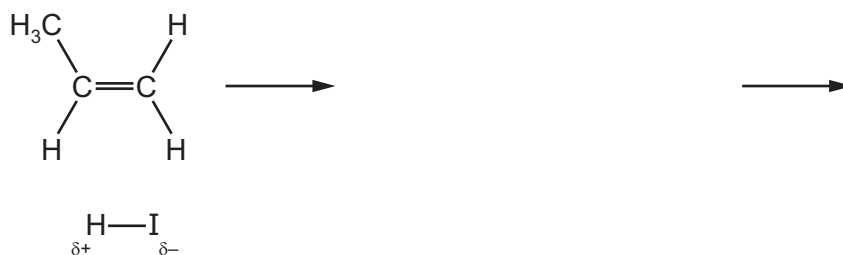
Explain your answer.

.....

 [2]

(ii) Complete the diagram to show the mechanism of the reaction between HI and $\text{CH}_3\text{CH}=\text{CH}_2$ that forms the major product identified in (g)(i).

Include curly arrows, lone pairs of electrons and charges as necessary.



[3]

[Total: 26]

- 2 (a) Table 1 gives physical data for some of the Period 3 elements.

Table 1

atomic number, Z	11	12	13	14	15	16	17
bonding present in element	M						C
first ionisation energy / kJ mol ⁻¹	494	736	577	786	1060	1000	1260
maximum oxidation number							+7
anionic radius / nm	–	–	–	0.271	0.212	0.184	0.181

- (i) Complete the row in the table labelled 'bonding present in element'.

Use C = covalent, I = ionic, M = metallic, as appropriate.

[1]

- (ii) Explain the difference between the first ionisation energies of the elements with atomic numbers 11 and 17.

.....

 [2]

- (iii) Explain the difference between the first ionisation energies of the elements with atomic numbers 15 and 16.

.....

 [2]

- (iv) Complete the row in the table labelled 'maximum oxidation number'.

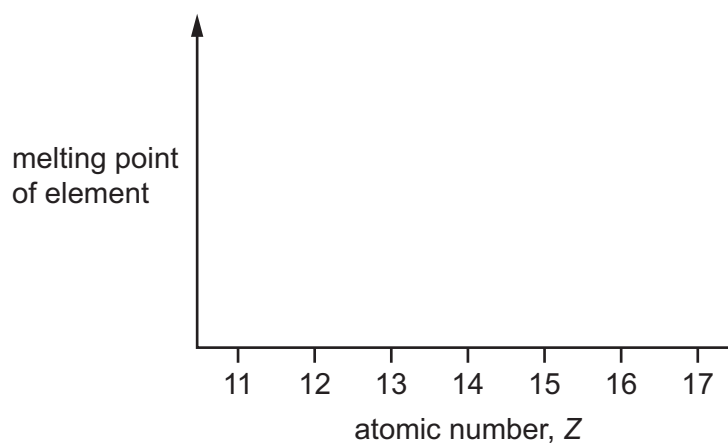
[1]

- (v) Explain the variation in anionic radius for the elements with atomic numbers 14 to 17.

.....

 [2]

- (b) Use the axes to sketch a graph that shows the trend in melting points of the elements with atomic numbers 11 to 17.



[2]

- (c) Dmitri Mendeleev published the first Periodic Table in 1869.

Mendeleev used his knowledge of chemical periodicity to propose the properties of gallium, ${}_{31}\text{Ga}$, a Group 13 element.

Table 2 gives some chemical and physical data of elements in Group 13.

Table 2

element	density / g cm^{-3}	boiling point /K	cationic radius /nm
${}_5\text{B}$	2.34	3930	0.020
${}_{13}\text{Al}$		2470	0.050
${}_{31}\text{Ga}$	5.91	2400	
${}_{49}\text{In}$	7.30		0.081
${}_{81}\text{Tl}$	11.8	1460	0.095

Complete the table by predicting values for the missing data.

[3]

(d) Indium and aluminium are elements in Group 13 of the Periodic Table.

Indium has very similar chemical properties to aluminium.

- Indium reacts vigorously with hydrochloric acid to form a colourless gas and a salt in solution.
- Indium oxide, In_2O_3 , is amphoteric.
- Gaseous indium bromide has the formula In_2Br_6 . This molecule contains coordinate bonds.

(i) Identify the formula of the salt formed when indium reacts with hydrochloric acid.

..... [1]

(ii) Construct an equation for the reaction of In_2O_3 with excess aqueous NaOH .

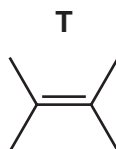
..... [1]

(iii) Draw a diagram that clearly shows the types of bond present in $\text{In}_2\text{Br}_6(\text{g})$.

[2]

[Total: 17]

- 3 Compound **T** is an isomer of C_6H_{12} .



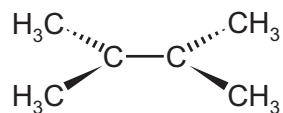
- (a) Name **T**.

..... [1]

- (b) Draw the skeletal formula of a structural isomer of **T** that shows *cis-trans* (geometrical) isomerism.

[1]

- (c) Each carbon atom in **T** forms a sigma (σ) bond to at least one other carbon atom, as shown.

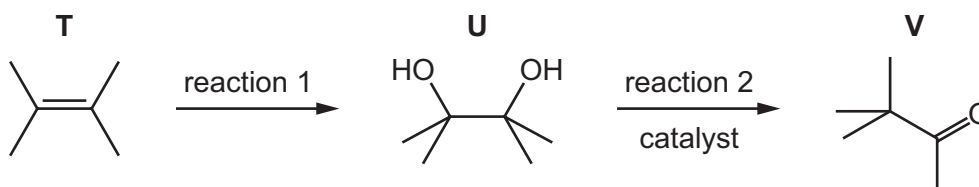


- (i) On the diagram, draw the orbitals that represent the pi (π) bond that is also present in **T**. [1]

- (ii) State the hybridisation of the two carbon atoms between which the pi (π) bond forms.

..... [1]

- (d) A reaction scheme starting with **T** is shown. Reaction 2 occurs in the presence of a catalyst; knowledge of the mechanism for this reaction is not required.



- (i) Give the reagent(s) and conditions for reaction 1.

..... [1]

- (ii) State and explain how 2,4-dinitrophenylhydrazine (2,4-DNPH) can be used to detect the presence of **V** as a product of reaction 2.

.....

 [2]

- (iii) The progress of reaction 2 can be monitored by infrared spectroscopy.

The absorption caused by O–H bonds is always present because water is used as a solvent.

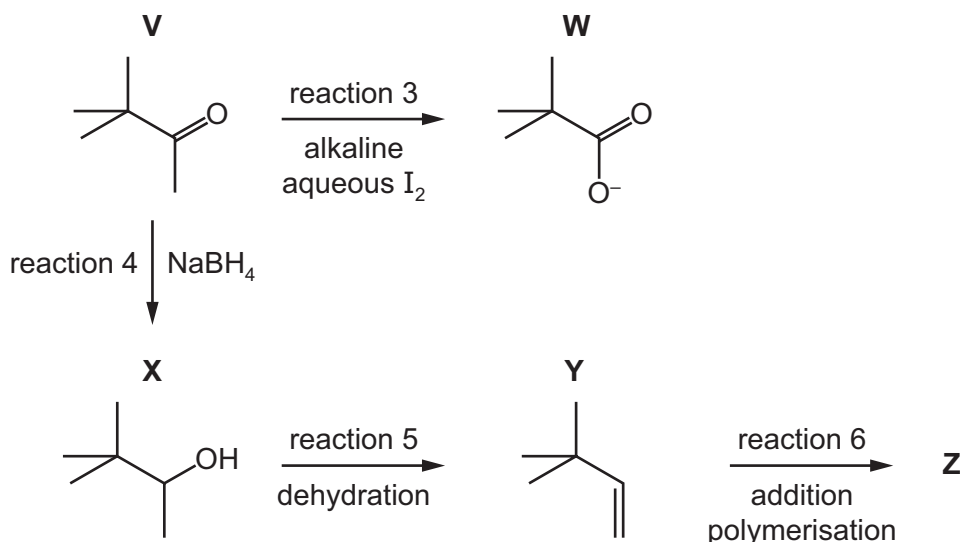
Identify two absorptions, and the bonds responsible for these absorptions, whose appearance will change significantly during the reaction.

1

 2
 [2]

- (e) **V** is used in a wide range of organic reactions.

Some reactions of **V** are shown.



- (i) **V** and **W** are colourless and soluble in water.

State what you would observe in reaction 3.

..... [1]

- (ii) Reaction 3 is a redox reaction.

Identify which of the **reactants** is reduced in this reaction.

..... [1]

- (iii) Construct an equation for reaction 4.

Use [H] in the equation to represent an atom of hydrogen from NaBH_4 .

$\text{C}_6\text{H}_{12}\text{O} + \dots\dots\dots$ [1]

- (iv) **X** is a mixture of two optical isomers.

Draw the two optical isomers in the boxes provided.



[2]

- (v) Both optical isomers of **X** can be dehydrated to form a single product, **Y**.
Give the reagent(s) and conditions required for reaction 5.

..... [1]

- (vi) **Y** can form an addition polymer **Z**.

Draw one repeat unit of **Z**.

[1]

- (vii) Reaction 6 does not proceed quickly at room temperature.

Suggest why this is the case.

.....

..... [1]

[Total: 17]

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