



CANDIDATE  
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CENTRE  
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## 9701/22

February/March 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** The rate of chemical reactions is affected by changes in temperature and pressure.

- (a) (i)** Draw a curve on the axes to show the Boltzmann distribution of energy of particles in a sample of gaseous krypton atoms at a given temperature.

Label the curve **T1** and label the axes.



[2]

- (ii)** On the diagram in **(a)(i)**, draw a second curve to show the distribution of energies of the krypton atoms at a higher temperature.

Label the second curve **T2**.

[1]

**(b)** The Boltzmann distribution assumes that the particles behave as an ideal gas.

- (i)** State **two** assumptions of the kinetic theory as applied to an ideal gas.

1 .....

.....

2 .....

.....

[2]

- (ii)** 2.00 g of krypton gas, Kr(g), is placed in a sealed 5.00 dm<sup>3</sup> container at 120 °C.

Calculate the pressure, in Pa, of Kr(g) in the container.  
Assume Kr(g) behaves as an ideal gas.

Show your working.

pressure = ..... Pa [3]

- (iii) State and explain the conditions at which krypton behaves most like an ideal gas.

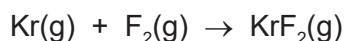
.....

.....

.....

..... [2]

- (c) Krypton reacts with fluorine in the presence of ultraviolet light to make krypton difluoride,  $\text{KrF}_2(\text{g})$ .

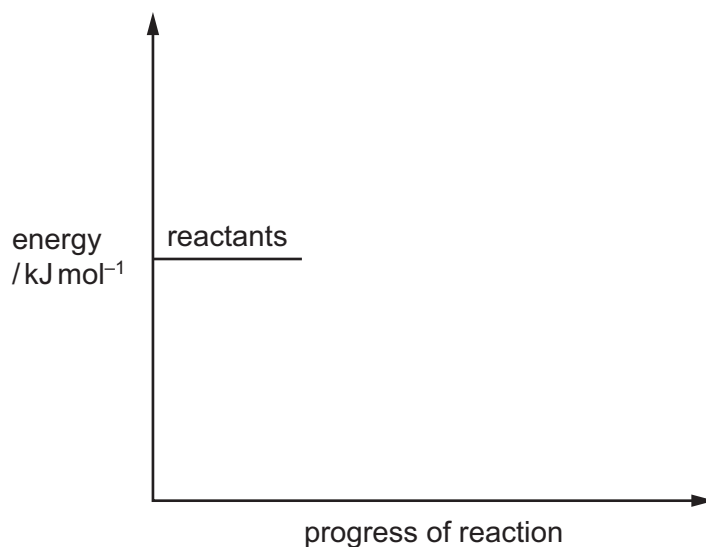


activation energy for the reaction,  $E_a = +385 \text{ kJ mol}^{-1}$

enthalpy change of formation of  $\text{KrF}_2$ ,  $\Delta H_f = +60.2 \text{ kJ mol}^{-1}$

- (i) Use this information to complete the reaction profile diagram for the formation of  $\text{KrF}_2$ . Label  $E_a$  and  $\Delta H_f$  on the diagram.

Assume the reaction proceeds in one step.



[2]

- (ii) Explain, in terms of activation energy,  $E_a$ , and the collision of particles, how an increase in temperature affects the rate of a chemical reaction.

.....

.....

.....

..... [2]

[Total: 14]

**2** 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,  $X^-$  (where  $X = Cl, Br, I$ ), show clear trends in their physical and chemical properties.

(i) State and explain the relative thermal stabilities of the hydrogen halides,  $HX$ .

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

The halide ions react easily with concentrated  $H_2SO_4$ .

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

| halide ion                                                             | $Cl^-$    | $Br^-$ | $I^-$  |
|------------------------------------------------------------------------|-----------|--------|--------|
| main sulfur-containing product of reaction with concentrated $H_2SO_4$ | $HSO_4^-$ | $SO_2$ | $H_2S$ |
| 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  $H_2SO_4$ .

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

(d)  $Cl_2$  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  $Cl_2$  with cold aqueous sodium hydroxide.

..... [1]

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

Aluminium chloride can exist as the gaseous molecule  $Al_2Cl_6(g)$ . This molecule contains coordinate bonds.

- (i) Draw a diagram that clearly shows all the types of bond present in  $Al_2Cl_6(g)$ .

[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]

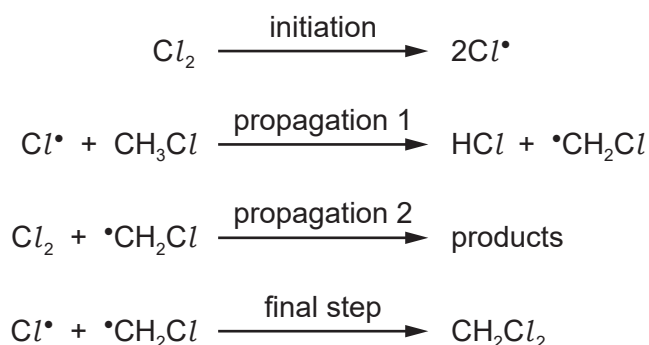
- (ii) Calculate the value of  $n$  in  $ZCl_n$ .

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

(g) Dichloromethane,  $\text{CH}_2\text{Cl}_2$ , is widely used as an organic solvent.

$\text{CH}_2\text{Cl}_2$  can be prepared by reacting  $\text{CH}_3\text{Cl}$  and  $\text{Cl}_2$  at room temperature.

The reaction proceeds via several steps, as shown.



(i) Give the name of the mechanism of this reaction.

..... [1]

(ii) State the essential condition required for the initiation step to take place.

..... [1]

(iii) Give the electronic configuration of  $\text{Cl}^\bullet$ .

$1s^2$  ..... [1]

(iv) Identify the products of the step labelled propagation 2.

..... [1]

(v) Name the type of reaction shown in the final step.

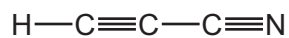
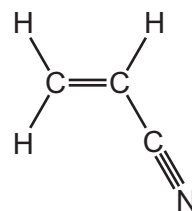
..... [1]

(vi) Suggest the identity of another organic molecule that is a product of the reaction of  $\text{CH}_3\text{Cl}$  and  $\text{Cl}_2$  under the same conditions.

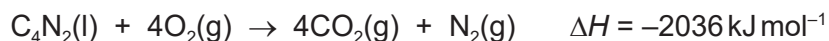
..... [1]

[Total: 23]

- 3 Compounds **P**, **Q** and **R** have all been found in the atmosphere of one of Saturn's moons.

**P****Q****R**

- (a) The equation for the complete combustion of **P**,  $\text{C}_4\text{N}_2(\text{l})$ , is shown.



- (i) The enthalpy change of formation,  $\Delta H_f$ , of  $\text{CO}_2(\text{g})$  is  $-384 \text{ kJ mol}^{-1}$ .

Calculate the enthalpy change of formation,  $\Delta H_f$ , of **P**, in  $\text{kJ mol}^{-1}$ .

$\Delta H_f$  of **P** = .....  $\text{kJ mol}^{-1}$  [2]

- (ii) One of the products of the complete combustion of **P** is nitrogen gas,  $\text{N}_2(\text{g})$ .

Explain the lack of reactivity of nitrogen.

..... [1]

(b) **Q** forms when HCN reacts with ethyne,  $\text{H}-\text{C}\equiv\text{C}-\text{H}$ .

(i) Ethyne, HCN and **Q** are all weak Brønsted–Lowry acids.

Explain what is meant by the term *weak Brønsted–Lowry acid*.

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

(ii) Ethyne, HCN and **Q** all contain triple bonds between two atoms.

A triple bond consists of one sigma ( $\sigma$ ) and two pi ( $\pi$ ) bonds.

Draw a labelled diagram to show the formation of one pi ( $\pi$ ) bond.

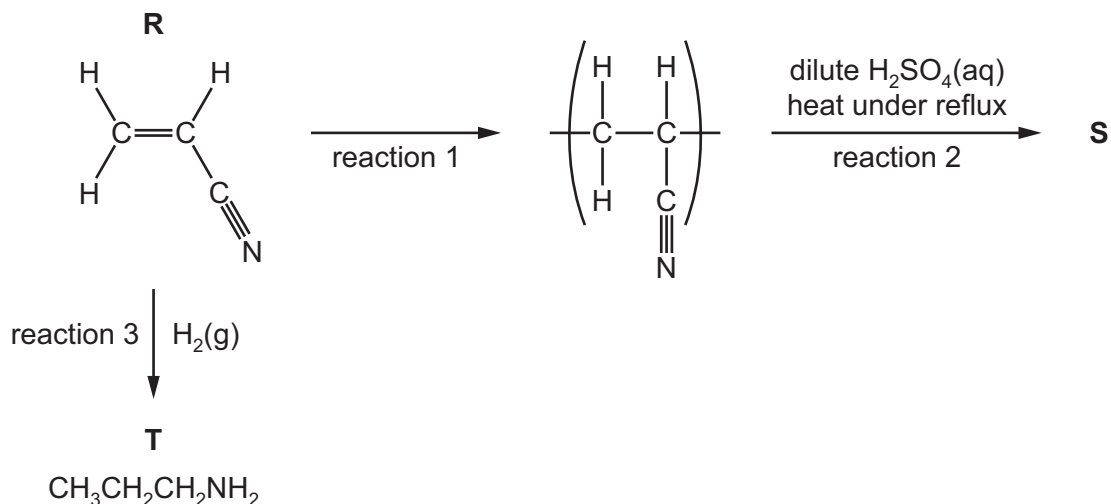
[2]

(c) **P** and **Q** can be detected in the atmosphere by infrared spectroscopy.

Identify **two** absorptions, and the bonds that correspond to these absorptions, that will appear in the infrared spectra of both **P** and **Q**.

1 .....  
 .....  
 2 .....  
 ..... [2]

(d) The flow chart shows some reactions of **R**.



(i) Name the type of reaction shown in reaction 1.

..... [1]

(ii) Draw the structure of **S**, the organic product of reaction 2.

[1]

(iii) Name **T**.

..... [1]

(iv) **T** can also be formed by the reaction of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$  with ammonia.

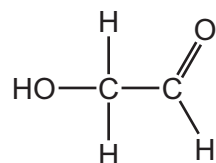
State the necessary conditions of this reaction.

..... [1]

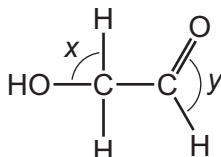
[Total: 13]

- 4 Hydroxyethanal,  $\text{HOCH}_2\text{CHO}$ , has been observed in dust clouds near the centre of our galaxy.

hydroxyethanal



- (a) Predict the bond angles labelled  $x$  and  $y$  in the diagram of hydroxyethanal.



$x = \dots\dots\dots^\circ$

$y = \dots\dots\dots^\circ$

[2]

- (b) Hydroxyethanal reacts separately with 2,4-dinitrophenylhydrazine (2,4-DNPH) and with Tollens' reagent.

State what you would observe in each reaction.

reaction with 2,4-DNPH .....

reaction with Tollens' reagent .....

[2]

- (c) Hydroxyethanal is converted to ethanedioic acid,  $(\text{CO}_2\text{H})_2$ , when it reacts with excess acidified dichromate(VI) ions,  $\text{Cr}_2\text{O}_7^{2-}$ .

- (i) State the role of acidified  $\text{Cr}_2\text{O}_7^{2-}$  in this reaction.

..... [1]

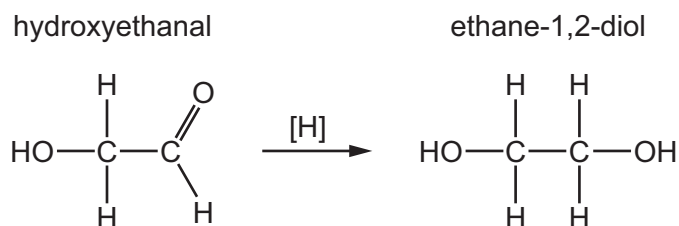
- (ii) State and explain any other necessary conditions for this reaction to be successful.

.....

.....

..... [2]

(d) Hydroxyethanal can be reduced to ethane-1,2-diol,  $(\text{CH}_2\text{OH})_2$ , as shown.



(i) Write an equation for the reduction of hydroxyethanal to  $(\text{CH}_2\text{OH})_2$ .

Use  $[\text{H}]$  to represent an atom of hydrogen from the reducing agent.

..... [1]

(ii) Identify a reagent for this reduction reaction.

..... [1]

(iii)  $(\text{CH}_2\text{OH})_2$  also forms when an alkene **A** reacts with cold, dilute, acidified manganate(VII) ions.

Name **A**.

..... [1]

[Total: 10]

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