

**Q1.** Halogens are used to make halogenated organic compounds.

(a) The refrigerant used in air conditioners is a mixture of fluorinated alkanes. These compounds are made by fluorination reactions. The mechanism for the reaction of fluorine with an alkane or with a fluoroalkane is a free-radical substitution similar to the reaction of chlorine with methane.

(i) Write the overall equation for the reaction of fluorine with methane to form trifluoromethane ( $\text{CHF}_3$ ).

.....

**(1)**

(ii) Write equations for the following steps in the mechanism for the reaction of fluorine with trifluoromethane ( $\text{CHF}_3$ ) to form tetrafluoromethane ( $\text{CF}_4$ ).

Initiation step

.....

First propagation step

.....

Second propagation step

.....

A termination step leading to the formation of hexafluoroethane.

.....

**(4)**

(b) Chlorofluorocarbons (CFCs) were used as refrigerants. In the upper atmosphere, ultra-violet radiation breaks bonds in the CFCs to produce a reactive intermediate that catalyses the decomposition of ozone.

(i) An example of a CFC is 1,1,1-trichloro-2,2-difluoroethane. Draw the displayed formula of this CFC.

(1)

- (ii) Identify a bond in a CFC that is broken by ultra-violet radiation to produce a reactive intermediate.  
Give the name of this reactive intermediate that catalyses the decomposition of ozone.  
Write an overall equation for this decomposition of ozone.

Bond broken .....

Name of the reactive intermediate .....

Overall equation

.....

(3)

(Total 9 marks)

**Q2.** Which molecule is **not** produced when ethane reacts with bromine in the presence of ultraviolet light?

A  $C_2H_4Br_2$

B HBr

C  $H_2$

D  $C_4H_{10}$

(Total 1 mark)

**Q3.** Chloromethanes, such as dichloromethane and trichloromethane, are produced in industry as they have many uses.

Trichloromethane has been used in the manufacture of the refrigerant chlorodifluoromethane.

(a) Chlorine can react with dichloromethane ( $CH_2Cl_2$ ) to form trichloromethane ( $CHCl_3$ ).

- (i) Write an equation for each of the following steps in the mechanism for this reaction.

Initiation step

.....

First propagation step

.....

Second propagation step

.....

(3)

- (ii) Give **one** essential condition for this reaction and name the type of mechanism.

Essential condition .....

Type of mechanism .....

(2)

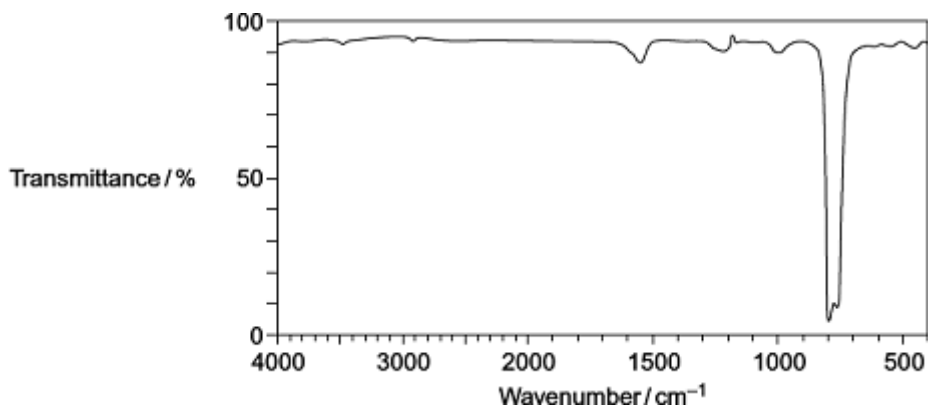
- (b) An organic product, **X**, with  $M_r = 154.0$  is obtained when chlorine reacts with trichloromethane.

- (i) Write an equation for the overall reaction of chlorine with trichloromethane to form **X**, by the same mechanism as that outlined in part (a)(i).

.....

(1)

- (ii) The following infrared spectrum was obtained for a sample of **X** produced in this reaction.



Use this infrared spectrum to explain why it is possible to deduce that this sample of **X** contains no trichloromethane.

You may find it helpful to refer to **Table 1** on the Data Sheet.

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(Extra space) .....

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(2)

- (c) Explain, with the aid of equations and the intermediates that form in the ozone layer, why the European Union has banned the use of chlorodifluoromethane ( $\text{CHClF}_2$ ) as a refrigerant.

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(Extra space) .....  
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(4)

(d) The compound 2,3,3,3-tetrafluoropropene is the refrigerant used in all new car air conditioners.

(i) Draw the displayed formula for 2,3,3,3-tetrafluoropropene.

(1)

(ii) Give **one** reason why 2,3,3,3-tetrafluoropropene is a more **environmentally** acceptable refrigerant than chlorodifluoromethane.

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(1)

(Total 14 marks)

**Q4.** The refrigerant R410A, used in air conditioners, is a mixture of two fluoroalkanes, pentafluoroethane and difluoromethane.

(a) (i) The mechanism for the reaction of fluorine with either an alkane or a fluoroalkane is similar to that for the reaction of chlorine with methane.

Name the type of mechanism for the reaction of chlorine with methane.

.....

(1)

- (ii) Write equations for the following steps in the mechanism for the reaction of fluorine with fluoromethane ( $\text{CH}_3\text{F}$ ) to form difluoromethane ( $\text{CH}_2\text{F}_2$ ).

Initiation step

.....

First propagation step

.....

Second propagation step

.....

A termination step leading to the formation of 1,2-difluoroethane.

.....

(4)

- (iii) Write an overall equation for the reaction of fluorine with ethane to form pentafluoroethane ( $\text{CF}_3\text{CHF}_2$ ) by this mechanism.

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(1)

- (b) The refrigerant R112A ( $\text{CCl}_3\text{CF}_2\text{Cl}$ ) has been banned because of concerns about ozone depletion.

Give the IUPAC name for  $\text{CCl}_3\text{CF}_2\text{Cl}$

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(1)

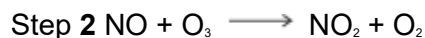
- (c) Nitrogen monoxide (NO) catalyses the decomposition of ozone into oxygen.

- (i) Write the overall equation for this decomposition.

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(1)

- (ii) Use the overall equation to deduce Step 3 in the following mechanism that shows how nitrogen monoxide catalyses this decomposition.



Step 3 .....

(1)

(Total 9 marks)

**Q5.** Chlorine can be used to make chlorinated alkanes such as dichloromethane.

- (a) Write an equation for each of the following steps in the mechanism for the reaction of chloromethane ( $CH_3Cl$ ) with chlorine to form dichloromethane ( $CH_2Cl_2$ ).

Initiation step

.....

First propagation step

.....

Second propagation step

.....

The termination step that forms a compound with empirical formula  $CH_2Cl$ .

.....

(4)

- (b) When chlorinated alkanes enter the upper atmosphere, carbon-chlorine bonds are broken. This process produces a reactive intermediate that catalyses the decomposition of ozone. The overall equation for this decomposition is



- (i) Name the type of reactive intermediate that acts as a catalyst in this reaction.

.....

(1)

- (ii) Write **two** equations to show how this intermediate is involved as a catalyst in the decomposition of ozone.

Equation 1.....

Equation 2.....

(2)

(Total 7 marks)

**Q6.** There are many uses of halogenated organic compounds despite environmental concerns.

- (a) Bromotrifluoromethane is used in fire extinguishers in aircraft.  
Bromotrifluoromethane is formed when trifluoromethane reacts with bromine.



The reaction is a free-radical substitution reaction similar to the reaction of methane with chlorine.

- (i) Write an equation for each of the following steps in the mechanism for the reaction of  $\text{CHF}_3$  with  $\text{Br}_2$

Initiation step

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First propagation step

.....

Second propagation step

.....

A termination step

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(4)

- (ii) State **one** condition necessary for the initiation of this reaction.

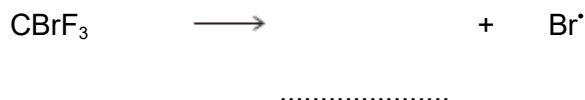
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(1)



(b) Bromine-containing and chlorine-containing organic compounds may have a role in the decomposition of ozone in the upper atmosphere.

(i) Draw an appropriate **displayed formula** in the space provided to complete the following equation to show how  $\text{CBrF}_3$  may produce bromine atoms in the upper atmosphere.



(1)

(ii) In the upper atmosphere, it is more likely for  $\text{CBrF}_3$  to produce bromine atoms than it is for  $\text{CClF}_3$  to produce chlorine atoms.

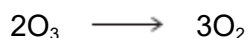
Suggest **one** reason for this.

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.....  
.....

(1)

(iii) Bromine atoms have a similar role to chlorine atoms in the decomposition of ozone.

The overall equation for the decomposition of ozone is



Write **two** equations to show how bromine atoms ( $\text{Br}^\bullet$ ) act as a catalyst in the decomposition of ozone.

Explain how these two decomposition equations show that bromine atoms behave as a catalyst.

Equation 1

.....

Equation 2

.....

Explanation .....

.....

.....

**Q7.**Trifluoromethane ( $\text{CHF}_3$ ) can be used to make the refrigerant chlorotrifluoromethane( $\text{CClF}_3$ ).

- (a) Chlorotrifluoromethane is formed when trifluoromethane reacts with chlorine.



The reaction is a free-radical substitution reaction similar to the reaction of methane with chlorine.

- (i) Write an equation for each of the following steps in the mechanism for the reaction of  $\text{CHF}_3$  with  $\text{Cl}_2$

Initiation step

.....

First propagation step

.....

Second propagation step

.....

Termination step to form hexafluoroethane

.....

(4)

- (ii) Give **one** essential condition for this reaction.

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(1)

- (b) In some refrigeration systems,  $\text{CHF}_3$  has replaced  $\text{CClF}_3$  because of concerns about ozone depletion.

- (i) Identify the species formed from  $\text{CClF}_3$  that is responsible for the catalytic decomposition of ozone in the upper atmosphere.

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(1)

(ii) Write an overall equation to represent the decomposition of ozone into oxygen.

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(1)  
(Total 7 marks)