Mr Cole Science

Name: ______________________________ **Date:** ____________________

AQA A-LEVEL CHEMISTRY

CFCs and Ozone Depletion: Free Radical Substitution

Learn Pack

This pack is designed to be completed alongside the video to help you build a secure understanding of this topic before moving on to revision and exam practice.

How to use this Learn Pack:

1. Watch the video and complete the activities.
2. Answer the Fact Recall and Application questions.
3. Check your work using the Learn Pack Answers available at mrcolescience.co.uk.

WATCH THE LESSON

Chlorofluorocarbons

Chlorofluorocarbons, or CFCs, are halogenoalkane molecules in which all of the hydrogen atoms have been replaced with chlorine and fluorine atoms.

Lesson Objectives:

- Understand what CFCs are and how they are formed by free radical substitution reactions.
- Know why ozone is beneficial.
- Understand how CFCs have damaged the ozone.
- Recall the equations for the decomposition of ozone and explain how chlorine radicals catalyse this reaction.

Formation of CFCs

CFCs are formed by the free radical substitution of alkanes, chloroalkanes or fluoroalkanes. However, for this to happen an excess of chlorine and/or fluorine is needed.

Explain why an excess of chlorine and/or fluorine is needed for this reaction:

To help ensure that further substitution reactions occur so that all the hydrogen atoms are replaced.

Free Radical Substitution & Further Substitutions

Free radical substitution reactions occur in three stages; initiation, propagation and termination. During initiation the halogen-halogen covalent bond breaks homolytically to form two halogen free radicals:

$$Cl_2 \rightarrow 2Cl^\bullet$$

Identify the essential condition required for this reaction and explain why it is needed:

UV light is required to provide the energy needed to break the covalent bond between the halogen atoms.

During the first propagation step the halogen free radical produced during initiation reacts with your starting molecule, removing a hydrogen atom from it to form a hydrogen halide and an alkyl-based free radical:

$$C_2H_6 + Cl^\bullet \rightarrow {}^\bullet C_2H_5 + HCl$$

Then during the second propagation step the free radical formed during the first propagation step reacts with a halogen molecule to form a halogenoalkane and a halogen free radical:

$$\bullet C_2H_5 + Cl_2 \rightarrow C_2H_5Cl + Cl\bullet$$

However, if there is an excess of the halogen present, further substitution reactions can occur. The halogenoalkane formed during this initial propagation sequence can then undergo further substitution:

$$C_2H_5Cl + \bullet Cl \rightarrow \bullet C_2H_4Cl + HCl$$

$$\bullet C_2H_4Cl + F_2 \rightarrow C_2H_4ClF + F\bullet$$

If there is an excess of chlorine and/or fluorine available then these further substitution reactions can continue until all the hydrogen atoms have been replaced, eventually forming a chlorofluorocarbon.

The final stage of free radical substitution is termination. During this stage two free radicals react with one another to form a stable molecule, and this can occur in one of three ways:

1. Two halogen radicals reacting together.
2. An alkyl radical reacting with a halogen radical.
3. Two alkyl radicals reacting together.

CFCs and the Ozone Layer

CFCs are relatively unreactive, non-flammable and non-toxic substances and as such they were commonly used as fire extinguishers, propellants and coolants as well as being added to foam plastics for insulation.

However, in the 1970s it was discovered that CFCs were contributing to the decomposition of the ozone layer.

Explain why this is a problem:

Ozone absorbs harmful UV radiation from the Sun which can cause skin cancer.

When exposed to UV light in the upper atmosphere, carbon-chlorine bonds in CFCs can break, forming chlorine free radicals. These chlorine free radicals then go on to react with ozone, breaking it down into oxygen.

Give two equations to show how chlorine free radicals decompose ozone before explaining why the chlorine free radical is acting as a catalyst:

$Cl\cdot + O_3 \rightarrow O_2 + ClO\cdot$

$ClO\cdot + O_3 \rightarrow 2O_2 + Cl\cdot$

The chlorine radical is regenerated/reformed and so is not used up during the reaction.

Questions – Fact Recall

1. What is a chlorofluorocarbon?

   A halogenoalkane in which all the hydrogen atoms have been replaced with chlorine <ins>and</ins> fluorine atoms.

2. Why is an excess of chlorine and/or fluorine needed when forming CFCs?

   To help ensure further substitution occurs by increasing the chances of subsequent propagation stages.

3. Why is ozone in the upper atmosphere beneficial?

   It absorbs harmful UV radiation from the Sun.

4. Describe how chlorine free radicals are formed from CFCs in the upper atmosphere.

   In the presence of UV light high up in the atmosphere the C-Cl bonds break homolytically.

5. Write two equations to show how chlorine atoms catalyse the decomposition of ozone.

   $O_3 + Cl\cdot \rightarrow O_2 + ClO\cdot$

   $ClO\cdot + O_3 \rightarrow 2O_2 + Cl\cdot$

Questions – Application

1. A molecule of fluoroethane, C_2H_5F, is undergoing further free-radical substitution with chlorine. Write the equation for the propagation 1 step and the subsequent propagation 2 step.

$C_2H_5F + Cl\cdot \rightarrow \cdot C_2H_4F + HCl$

$\cdot C_2H_4F + Cl_2 \rightarrow C_2H_4FCl + Cl\cdot$

2. A molecule of C_2H_5Cl undergoes further free-radical substitution. Explain how this reaction could eventually contribute to the formation of a CFC.

If there is an excess of fluorine and chlorine present then furthe substitution reactions are likely to occur, eventually replacing all of the hydrogen atoms with fluorine and chlorine atoms.

3. Explain why a chlorine radical can continue to decompose ozone molecules without being used up overall.

Because during the reaction with ozone the chlorine radical is reformed and so is acting as a catalyst.

Next Steps

Check your work using the Learn Pack Answers: