Objectives

After completing this section, you should be able to

1. write an equation for the conversion of an alcohol to an alkyl halide.
2. list a given series of alcohols in increasing or decreasing order of reactivity with hydrogen halides.
3. identify the alkyl halide formed when a given alcohol reacts with thionyl chloride, phosphorus tribromide, or a hydrogen halide.
4. identify the alcohol which should be used to prepare a given alkyl halide using one of the reagents specified in Objective 3.
5. select the most appropriate reagent for converting a given alcohol to a given alkyl halide.

Study Notes

The use of thionyl chloride for converting alcohols to alkyl chlorides has the added benefit that both of the by-products, sulfur dioxide and hydrogen chloride, are gases. This characteristic simplifies the isolation and purification of the reaction product.

In the laboratory, one can test for the presence of alcohols with Lucas reagent (a mixture of concentrated hydrochloric acid and zinc chloride). Lucas reagent converts alcohols to alkyl chlorides: tertiary alcohols give an immediate reaction, indicated when the alcohol solution turns cloudy; secondary alcohols usually show evidence of reacting within five minutes; primary alcohols do not react to any significant extent. Thus, Lucas reagent can help distinguish among primary, secondary and tertiary alcohols.

This page looks at reactions in which the -OH group in an alcohol is replaced by a halogen such as chlorine or bromine. It also includes a simple test for an -OH group using phosphorus(V) chloride. The general reaction looks like this:

\[ \text{ROH} + \text{HX} \rightarrow \text{RX} + \text{H}_2\text{O} \]

**Reaction with hydrogen chloride**

Tertiary alcohols react reasonably rapidly with concentrated hydrochloric acid, but for primary or secondary alcohols the reaction rates are too slow for the reaction to be of much importance. A tertiary alcohol reacts if it is shaken with concentrated hydrochloric acid at room temperature. A tertiary halogenoalkane (haloalkane or alkyl halide) is formed.

\[
\begin{align*}
\text{CH}_3 & \quad \text{CH}_3 \\
\text{H}_3\text{C} & + \text{HCl} \quad \rightarrow \quad \text{H}_3\text{C} & + \text{H}_2\text{O}
\end{align*}
\]

**Replacing -OH by bromine**

Rather than using hydrobromic acid, the alcohol is typically treated with a mixture of sodium or potassium bromide and concentrated sulfuric acid. This produces hydrogen bromide, which reacts with the alcohol. The mixture is warmed to distil off the bromoalkane.
Replacing -OH by iodine

In this case, the alcohol is reacted with a mixture of sodium or potassium iodide and concentrated phosphoric(V) acid, $\text{H}_3\text{PO}_4$, and the iodoalkane is distilled off. The mixture of the iodide and phosphoric(V) acid produces hydrogen iodide, which reacts with the alcohol.

$$\text{CH}_3\text{CH}_2\text{OH} + \text{HI} \rightarrow \text{CH}_3\text{CH}_2\text{I} + \text{H}_2\text{O} \quad \text{(1.1.3)}$$

Phosphoric(V) acid is used instead of concentrated sulfuric acid because sulfuric acid oxidizes iodide ions to iodine and produces hardly any hydrogen iodide. A similar phenomenon occurs to some extent with bromide ions in the preparation of bromoalkanes but not enough to interfere with the main reaction. There is no reason why you could not use phosphoric(V) acid in the bromide case instead of sulfuric acid if desired.

As seen with each of these examples, when alcohols react with a hydrogen halide, a substitution takes place producing an alkyl halide and water.

Scope of Reaction

- The order of reactivity of alcohols is $3^\circ > 2^\circ > 1^\circ$ methyl.
- The order of reactivity of the hydrogen halides is $\text{HI} > \text{HBr} > \text{HCl}$ (HF is generally unreactive).

The reaction is acid catalyzed. Alcohols react with the strongly acidic hydrogen halides HCl, HBr, and HI, but they do not react with non-acidic NaCl, NaBr, or NaI. Primary and secondary alcohols can be converted to alkyl chlorides and bromides by allowing them to react with a mixture of a sodium halide and sulfuric acid:

\[
\text{OH} + \text{NaX, H}_2\text{SO}_4 \rightarrow \text{X} + \text{H}_2\text{O} \\
\text{OH} + \text{NaX, H}_2\text{SO}_4 \rightarrow \text{X} + \text{H}_2\text{O}
\]

Reacting Alcohols with Phosphorus Halides

Alcohols react with liquid phosphorus(III) chloride (also called phosphorus trichloride) to yield chloroalkanes.

$$\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} + \text{PCl}_3 \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl} + \text{H}_3\text{PO}_3 \quad \text{(1.1.3a)}$$

Alcohols also violently react with solid phosphorus(V) chloride (phosphorus pentachloride) at room temperature, producing clouds of hydrogen chloride gas. While it is not a good approach to make chloroalkanes, it is a good test for the presence of -OH groups. To show that a substance was an alcohol, you would first have to eliminate all the other
groups that also react with phosphorus(V) chloride. For example, carboxylic acids (containing the -COOH group) also react with it (because of the -OH in -COOH) as does water (H-OH).

If you have a neutral liquid not contaminated with water, and clouds of hydrogen chloride are produced when you add phosphorus(V) chloride, then you have an alcohol group present.

\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} + \text{PCl}_5 \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl} + \text{POCl}_3 + \text{HCl} \label{1.1.4} \]

There are also side reactions involving the \(\text{POCl}_3\) reacting with the alcohol.

Other reactions involving phosphorus halides

Instead of using phosphorus(III) bromide or iodide, the alcohol is usually heated under reflux with a mixture of red phosphorus and either bromine or iodine. The phosphorus first reacts with the bromine or iodine to give the phosphorus(III) halide.

\[ 2\text{P}_{(s)} + 3\text{Br}_2 \rightarrow 2\text{PBr}_3 \label{1.1.5} \]
\[ 2\text{P}_{(s)} + 3\text{I}_2 \rightarrow 2\text{PI}_3 \label{1.1.6} \]

These then react with the alcohol to give the corresponding halogenoalkane, which can be distilled off.

\[ 3\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} + \text{PBr}_3 \rightarrow 3\text{CH}_3\text{CH}_2\text{CH}_2\text{Br} + \text{H}_3\text{PO}_3 \label{1.1.7} \]
\[ 3\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} + \text{PI}_3 \rightarrow 3\text{CH}_3\text{CH}_2\text{CH}_2\text{I} + \text{H}_3\text{PO}_3 \label{1.1.8} \]

Reacting alcohols with Thionyl Chloride

Sulfur dichloride oxide (thionyl chloride) has the formula SOCl \(_2\). Traditionally, the formula is written as shown, despite the fact that the modern name writes the chlorine before the oxygen (alphabetical order). The sulfur dichloride oxide reacts with alcohols at room temperature to produce a chloroalkane. Sulfur dioxide and hydrogen chloride are given off. Care would have to be taken because both of these are poisonous.

\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} + \text{SOCl}_2 \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl} + \text{SO}_2 + \text{HCl} \label{1.1.9} \]

The advantage that this reaction has over the use of either of the phosphorus chlorides is that the two other products of the reaction (sulfur dioxide and HCl) are both gases. That means that they separate themselves from the reaction mixture.

Exercises

Questions

Q10.5.1
Predict the alcohol required for the synthesis of the following halides:

Solutions

S10.5.1

\[
\begin{align*}
\text{Cl} & \quad \Rightarrow \quad \text{OH} \\
\text{Br} & \quad \Rightarrow \quad \text{OH} \\
\text{Ph} & \quad \Rightarrow \quad \text{OH}
\end{align*}
\]

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