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, sulphur dioxide and hydrogen chloride, are gases. This characteristic simplifies the isolation and purification of the reaction product.

In the laboratory component of this course, you will test a number 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 at room temperature. Thus, Lucas reagent can be used to help distinguish among primary, secondary and tertiary alcohols.

Content

When alcohols react with a hydrogen halide, a substitution takes place producing an alkyl halide and water:

\[
\text{Alcohol} + \text{Hydrogen Halide} \rightarrow \text{Alkyl Halide} + \text{Water}
\]

Figure

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 nonacidic 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:
Secondary, tertiary, allylic, and benzylic alcohols appear to react by a mechanism that involves the formation of a carbocation, in an $\text{(S}_\text{N1})$ reaction with the protonated alcohol acting as the substrate.

The $\text{(S}_\text{N1})$ mechanism is illustrated by the reaction tert-butyl alcohol and aqueous hydrochloric acid ($\text{H}_3\text{O}^+$, $\text{Cl}^-$). The first two steps in this $\text{(S}_\text{n1})$ substitution mechanism are protonation of the alcohol to form an oxonium ion. Although the oxonium ion is formed by protonation of the alcohol, it can also be viewed as a Lewis acid-base complex between the cation ($\text{(R}^+\text{)}$) and ($\text{H}_2\text{O}$). Protonation of the alcohol converts a poor leaving group ($\text{(OH}^-\text{)}$) to a good leaving group ($\text{(H}_2\text{O})$), which makes the dissociation step of the $\text{(S}_\text{N1})$ mechanism more favorable.

In step 3, the carbocation reacts with a nucleophile (a halide ion) to complete the substitution.

When we convert an alcohol to an alkyl halide, we carry out the reaction in the presence of acid and in the presence of halide ions, and not at elevated temperature. Halide ions are good nucleophiles (they are much stronger nucleophiles than water), and since halide ions are present in high concentration, most of the carbocations react with an electron pair of a halide ion to form a more stable species, the alkyl halide product. The overall result is an $\text{(S}_\text{n1})$ reaction.

### Primary Alcohols

Not all acid-catalyzed conversions of alcohols to alkyl halides proceed through the formation of carbocations. Primary alcohols and methanol react to form alkyl halides under acidic conditions by an $\text{SN2}$ mechanism.

In these reactions the function of the acid is to produce a protonated alcohol. The halide ion then displaces a molecule
of water (a good leaving group) from carbon; this produces an alkyl halide:

Figure

Again, acid is required. Although halide ions (particularly iodide and bromide ions) are strong nucleophiles, they are not strong enough to carry out substitution reactions with alcohols themselves. Direct displacement of the hydroxyl group does not occur because the leaving group would have to be a strongly basic hydroxide ion:

Figure

We can see now why the reactions of alcohols with hydrogen halides are acid-promoted.

Carbocation rearrangements are extremely common in organic chemistry reactions and are defined as the movement of a carbocation from an unstable state to a more stable state through the use of various structural reorganizational "shifts" within the molecule. Once the carbocation has shifted over to a different carbon, we can say that there is a structural isomer of the initial molecule. However, this phenomenon is not as simple as it sounds.

**Carbocation Rearrangement in the SN1 Reaction**

Whenever alcohols are subject to transformation into various carbocations, the carbocations are subject to a phenomenon known as carbocation rearrangement. A carbocation, in brief, holds the positive charge in the molecule that is attached to three other groups and bears a sextet rather than an octet. However, we do see carbocation rearrangements in reactions that do not contain alcohol as well. Those, on the other hand, require more difficult explanations than the two listed below. There are two types of rearrangements: hydride shift and alkyl shift. These rearrangements usually occur in many types of carbocations. Once rearranged, the molecules can also undergo further unimolecular substitution (SN1) or unimolecular elimination (E1). Though, most of the time we see either a simple or complex mixture of products. We can expect two products before undergoing carbocation rearrangement, but once undergoing this phenomenon, we see the major product.
Hydride Shift

Whenever a nucleophile attacks some molecules, we typically see two products. However, in most cases, we normally see both a major product and a minor product. The major product is typically the rearranged product that is more substituted (aka more stable). The minor product, in contrast, is typically the normal product that is less substituted (aka less stable).

The reaction: We see that the formed carbocations can undergo rearrangements called hydride shift. This means that the two electron hydrogen from the unimolecular substitution moves over to the neighboring carbon. We see the phenomenon of hydride shift typically with the reaction of an alcohol and hydrogen halides, which include HBr, HCl, and HI. HF is typically not used because of its instability and its fast reactivity rate. Below is an example of a reaction between an alcohol and hydrogen chloride:

The alcohol portion (-OH) has been substituted with the nucleophilic Cl atom. However, it is not a direct substitution of the OH atom as seen in Sn2 reactions. In this Sn1 reaction, we see that the leaving group, -OH, forms a carbocation on Carbon #3 after receiving a proton from the nucleophile to produce an alkylxonium ion. Before the Cl atom attacks, the hydrogen atom attached to the Carbon atom directly adjacent to the original Carbon (preferably the more stable Carbon), Carbon #2, can undergo hydride shift. The hydrogen and the carbocation formally switch positions. The Cl atom can now attack the carbocation, in which it forms the more stable structure because of hyperconjugation. The carbocation, in
this case, is most stable because it attaches to the tertiary carbon (being attached to 3 different carbons). However, we can still see small amounts of the minor, unstable product. The mechanism for hydride shift occurs in multiple steps that includes various intermediates and transition states. Below is the mechanism for the given reaction above:

Exercise


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