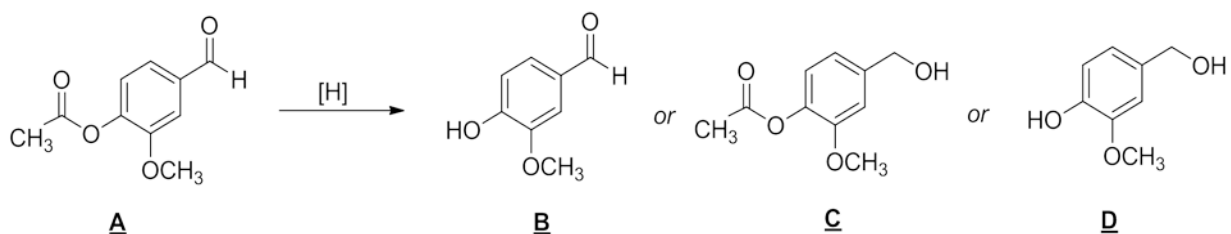# Selectivity in the Reduction of Vanillin Acetate Using Sodium Borohydride

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ABSTRACT

Scheme 1.

In this experiment, the reduction of vanillin acetate using sodium borohydride was explored. The reaction was monitored using thin-layer chromatography, and the product was identified using infrared, H-NMR, and C-MNR spectroscopies. The reducing selectivity of sodium borohydride was investigated to determine the three possible products of the reaction. The H-NMR data collected was the most convincing evidence for determining the product 4-(hydroxymethyl)-2-methoxyphenylacetate.
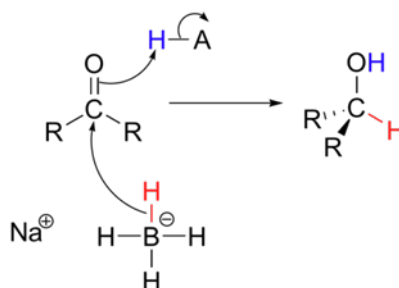
Introduction.

In chemistry, reduction refers to the gain of electrons. This is usually showed through the gain of hydrogen atoms or a loss of oxygen atoms, or both. For example, a carbonyl compound is reduced to an alcohol when its carbonyl group gains a hydride and a proton (3). Oxidation refers to a loss of electrons. In organic chemistry, oxidation can be refered to as an increase in oxygen content, or a decrease in hydrogen content (Figure 1). An oxidation may be indicated by an [O] above or below the reaction arrow. The reverse of an oxidation is a reduction reaction, and may also be indicated by an [H] above or below the reaction arrow.

Figure 1. Examples of redox reactions in organic chemistry

Sodium borohydride and lithium aluminum hydride (LAH) are two reagants commonly used to reduce carbonyl groups. Sodium borohydride is the milder of these two reagents. This reagent is easier to handle, and can be used with a simple alcohol such as methanol or ethanol as the solvent. LAH is more reactive and can only be used in ether solvents because it is more difficult to handle (1).

The functional group transformation of a carbonyl group to an alcohol can occur with the nucleophilic addition of hydride (H⁻) to the carbonyl carbon while successively pronating the carbonyl oxygen (Scheme 2). The hydride ion alone is not an effective nucleophile due to its basic properties. Sodium borohydride delivers the nucleophilic form of the hydride ion to the carbonyl carbon. The solvent of this reaction is usually and alcohol, and aids as a proton source (4).

Scheme 2. General mechanism for the borohydride reduction of a carbonyl compound

Thin-Layered Chromatography, infrared, H-NMR, and C-NMR spectroscopy techniques were all used to help determine the unknown product. Chromatography has changed the field of chemistry as well as biology because it can be used to separate proteins, nucleic acids, carbohydrates, and even viruses. Thin-Layered Chromatography (TLC) is a method used for separating mixtures of compounds based on differences in physical properties, such as polarity. This method tells if the reaction has gone to completion. Chromatography depends on the idea that each compound in a mixture will balance between two phases; one mobile and one stationary. The adsorbent in the TLC plates used contained silica gel (SiO_2) on the surface, making the stationary phase polar. More polar substances will be attached to the adsorbent and will not move as far as the less polar compounds. The movement of the compound over the silica gel occurs by capillary action. The retention factor (RF) of each compound can be calculated from the distance that each compound traveled relative to the initial position (2).

In the past, the structure of an organic compound was discovered in a time consuming and unreliable process. Modern organic spectrometric methods have changed how the structures of organic molecules are determined. These techniques are based off of spectroscopy, which is the absorption of radiation along the electromagnetic spectrum. Infrared spectroscopy (IR) techniques determine the structures of organic molecules. In an IR spectrum, energy is measured as wavelength and is plotted along the horizontal (x) axis and the intensity of the absorption is plotted along the vertical (y) axis. The three main characteristics of IR absorptions are location, intensity, and breadth. Location is the center of the absorption in wavenumbers (cm^{-1}) and is recorded as a range. Intensity is how strong the absorption is compared to the other absorptions along the spectra. Breadth is the width of the peak, and can be described as sharp ($<50cm^{-1}$), moderate ($50-150cm^{-1}$), or broad ($>150cm^{-1}$). IR identifies the presence or absence of functional groups using infrared energy. Specific bonds have absorptions that are at the same frequency regardless of the compound. O-H bonds in all alcohols appear at the same frequency range of $3650-2500cm^{-1}$. C=O vibrations of all carbonyl compounds also appear to have a similar frequency range of $1900-1500cm^{-1}$. The data collected from the IR spectra was an important indicator for the identification our unknown compound (2).

Therefore, the purpose of the experiment was to investigate the reducing selectivity of sodium borohydride by using these laboratory techniqes, to monitor the

reduction of the aldehyde functional group in vanillin acetate to a primary alcohol.

Results and Discussion

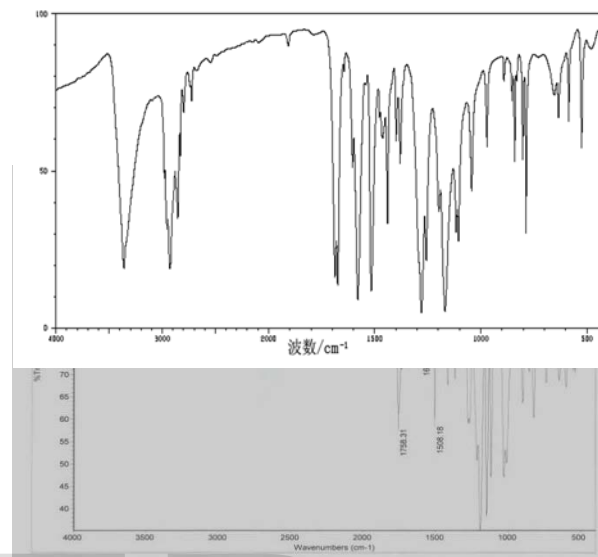**Figure 2.** IR spectrum of 4-(hydroxymethyl)-2-methoxyphenylacetate

Figure 3. IR spectrum of vanillin acetate

After the IR spectrum of the product was collected, a broad peak at around 3344 cm^{-1} was observed (Figure 2). This peak indicated the presence of a hydroxyl group. When compared to the IR spectrum of vanillin acetate (Figure 3), there was no indication of an alcohol in its structure. The presence of this hydroxyl group suggests that a carbonyl in the starting material had been reduced. The IR spectrum of the product also indicated the presence of a carbonyl carbon. This evidence eliminated the possibility of 4-(hydroxymethyl)-2-methoxyphenol to be the product, since this compound involved the reduction of both carbonyl carbons.

TLC was used to monitor the progress of the reaction, and determined if there was any starting material present in the reaction mixture. All three substances were dissolved in acetone before being spotted on the TLC plate. Since the product contained a hydroxyl group it was expected to be more polar and would have a slower mobile phase. Therefore, the expected R_f of the reaction mixture would be less than the starting material. This expectation was consistent with the calculated R_f values (See Table 2).

Although this evidence is important for the identification of the product, H-NMR and C-NMR spectroscopy techniques were necessary for the determination of the unknown compound. The carbonyl carbons of benzladehyde and phenyl acetate have the characteristics of a chemical shift at around 192 and 169 ppm resepectively. A benzyl alcohol carbinol carbon shows a chemical shift at 65 ppm, and the methyl carbon of methoxybenzene has a shift at 55 ppm. Although it was already determined that 4-(hydroxymethyl)-2-methoxyphenol was not the major product, the observed chemical shift at 170 ppm in the C-NMR data confirmed this assumption. This shift suggests that sodium borohydride did not reduce both carbonyl carbons. There was also an observed chemical shift at around 65 ppm (Figure 4). The data suggests that a carbinol carbon of benzyl alcohol is present as well as a carbonyl carbon of phenyl acetate. The H-NMR data provided by the instructor (Figure 5) was the most convincing evidence for determining the major organic product. The hydroxyl proton signal of an alcohol appears in the range of 0.5-6.0 ppm which was observed in the product's H-NMR spectrum (Figure 5). The spectrum did not indicate a singlet at around 9–10 ppm. Very few signals appeared far downdield in the collected H-NMR spectrum. The 9-10 ppm absorbance range is consistent with the aldehyde functional group. The absence of this functional group eliminated the possibility for 4-(hydroxymethyl)-3-methoxybenzaldehyde to be the major organic product.

In conclusion, the data suggests that the aldehyde functional group of vanillin acetate was reduced, forming a hydroxyl group. Thus, the product of the reaction was 4-(hydroxymethyl)-2-methoxyphenylacetate. From the results in this experiment, it was determined that sodium borohydride is able to reduce ketones and aldehydes. However, this reagent is not able to reduce ester functional groups.

A high percent yield of the product was recovered (See Table 2). The product was recovered in a high amount due to the separatory funnel extraction technique. The funnel was repeatedly washed with ether in order to extract as much of the organic material as possible.

Possible sources of error in this experiment could have been that water may have gotten into the reaction mixture when placed in the ice bath. Other sources of error could have been that not all of the ether was evaporated after the organic layer extraction. These possible experimental errors could have affected the collected IR spectrum. These errors could also have resulted in a smaller R_f value for the product than expected when using TLC. Water entering the reaction mixture would have caused the product to be more polar. This polarity would have resulted in the calculated R_f value to be lower.

Future research should investigate the use of sodium borohyide for reducing harmful chemicals from the environment. Since sodium borohydride is a much milder reducing agent than lithium aluminum hydride, it would be easier to handle in the environment. Therefore, this reducing agent may have the efficacy for creating a more economical and practical method for removing harmful oxidants from the environment.
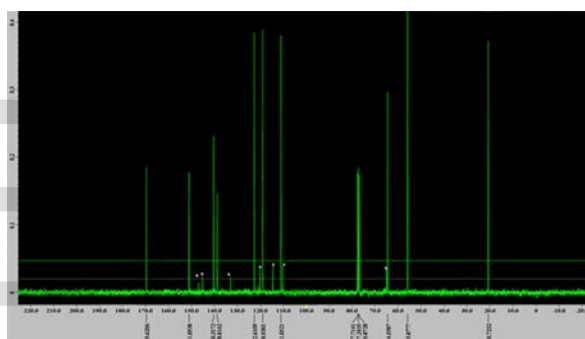

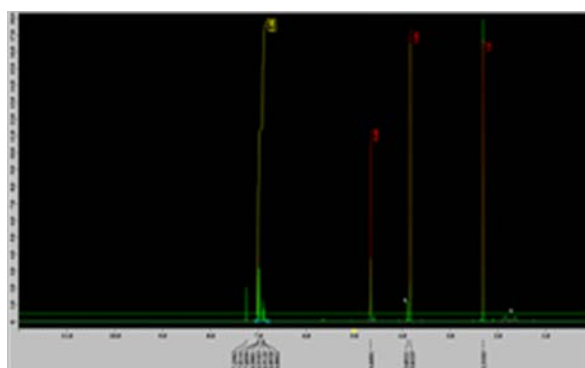**Figure 4.** C-NMR spectrum of the major organic product

Figure 5. H-NMR spectrum of the major organic product

Table 1. Reagent table for the selectivity in the reduction of vanillin acetate using sodium borohydride experiment

Chemical	FW (g/mol)	Mp (°C)	Bp (°C)	Mmol	Mass (g)	Density (g/mL)	Volume (mL)
vanillin acetate	194.18	79.0	N/A	2.60	0.51	N/A	N/A
Ethanol	46.07	N/A	78.3	51.40	2.37	0.79	3.00
sodium borohydride	37.83	N/A	N/A	7.80	0.30	N/A	N/A
ethyl acetate	88.11	N/A	77	N/A	N/A	N/A	N/A
hexanes	86.18	N/A	69	N/A	N/A	N/A	N/A
ether (diethyl)	74.12	N/A	34.6	N/A	N/A	N/A	30.00
saturated sodium chloride	58.44	N/A	N/A	N/A	N/A	N/A	15.00
4-(hydroxymethyl)-2-methoxyphenol	154.16	N/A	N/A	N/A	N/A	N/A	N/A
4-hydroxy-3-methoxybenzaldehyde	152.15	N/A	N/A	N/A	N/A	N/A	N/A
4-(hydroxymethyl)-2-methoxyphenylacetate	196.07	N/A	N/A	2.30	0.45	N/A	N/A

Table 2. Percent yield and R_f values for the starting material and product

Chemical	Final mass (g)	Theoretical yield (g)	Percent yield (%)	R_f (mm)
vanillin acetate	N/A	0.51	N/A	0.83
vanillin acetate with product	N/A	N/A	N/A	0.83
major organic product	0.45	N/A	87.3	0.57

Experimental Section.

A 25 mL Erlenmeyer flask was pre-weighed. 2.6 mmol (0.51 g) of vanillin acetate was added to the flask. A magnetic stir bar and 3.0 mL of ethanol were added to the flask. The reaction mixture was stirred to dissolve the vanillin acetate. While the flask was supported by a ring stand, the reaction mixture was cooled in an ice bath. 7.8 mmol of sodium borohydride was weighed. Over a period of 5 minutes the sodium borohydride was added in small portions to the vanillin acetate while it was kept in an ice bath. The reaction mixture was stirred in the ice bath for 15 minutes. After 15 minutes, the reaction was monitored using thin-layer chromatography. The TLC plate had three lanes, one for the starting material which was the vanillin acetate, one for the reaction mixture, and a co-spot in the middle. The co-spot contained both the reaction mixture and the starting material. A 2:3 ethyl acetate:hexane mixture was used as a mobile phase. The reaction was monitored under UV light to determine whether the reaction had gone to completion. If TLC indicated that some of the starting material remained in the reaction mixture, it was checked again after 5 minutes. This cycle continued until TLC indicated that all of the starting material was gone. 10.0 mL of deionized water was added to the reaction mixture. The reaction mixture was stirred in an

ice bath for 2 minutes. The reaction mixture was transferred into a small separatory funnel.

10.0 mL of ether was added to the separatory funnel to extract the reaction mixture. The separatory funnel was shaken. The stop cock was opened before shaking in order to vent the funnel. Venting the separatory funnel was done in a fume hood. The funnel was shaken and inverted, and the stopcock was opened before it was shook. If the funnel is not shaken, the stopper may pop out of the funnel and liquids and gases will be released. The funnel was inverted three to four times and was vented after each inversion. An additional 10.0 mL of ether was added each time the aqueous layer was drained from the separatory funnel. Once the inversion of the funnel was finished, the stopper was removed to prevent the buildup of pressure.

The organic ether layers from the separatory funnel were combined and washed with 10.0 mL of deionized water, and 15.0 mL of saturated sodium chloride (brine) solution. The organic layer was dried over sodium sulfate. The dried ether solution was decanted into a pre-weighed 125 mL Erlenmeyer flask. In a fume hood, the ether was evaporated under a stream of air.

The experimental and theoretical yields of the product were determined, and the percent yield was calculated. An IR spectrum of the product and starting material were collected**.**

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