Multistep Synthesis of Benzilic Acid from Benzaldehyde

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**Abstract:**

In this experiment, a multistep synthesis was carried out to produce benzylic acid, which was further analyzed and verified through IR spectroscopy and melting point analysis. Benzoin formed through the benzoin condensation reaction, which occurred as benzaldehyde reacted with thiamine and sodium hydroxide. The benzoin was combined with ammonium nitrate and copper (II) acetate, which, through an oxidation reaction, produced benzil. The benzil product reacted with potassium hydroxide to form potassium benzilate. This potassium benzilate underwent molecular rearrangement as it reacted with hydrochloric acid to form the final product, benzylic acid. A good experimental product yield was obtained, and a melting point analysis was performed to further confirm the identity of the product and the absence of the starting material(s) in the final products.

**Introduction:**

Forming complex molecules can sometimes require many steps and expensive (and potentially dangerous) chemicals. However, some of these multistep synthesis reactions can be maximized at the cost of either time or money. The multistep synthesis of benzilic acid is a cost-effective reaction which utilizes a fairly “inexpensive starting material, benzaldehyde” [1]. The overall production of the benzilic acid occurs in three separate stages. The first reaction involved the conversion of our starting material to benzoin through a benzoin condensation. This was then converted to benzil in the second reaction through an oxidation step. In the final reaction, the benzil was converted to our predicted product through a molecular rearrangement. The two intermediates produced were integral to the completion of the full synthesis. All reactions and products involved, such as the starting materials, intermediate products, and the final product, were analyzed via melting point analysis and IR spectroscopy to further confirm their identities. As stated before, this synthesis requires three steps. The amount of steps in a reaction has a great impact on the overall yield. Due to factors like these, the cost of chemicals can sometimes be based on the availability or complexity of the creation of these molecules. Luckily, through the said analytical methods, we were able to get an accurate measurement of our yields and their purities to better help us predict our final yield.

**Results:**

**Part A:**

**Theoretical Yield**

15.5 mL Benzaldehyde x ( ) x ( ) x ( ) x ( ) = 16.119 g Benzoin

**Actual Yield Percent Yield Melting Point Range of Product**

7.217 g benzoin x 100 = 44.77% 120⁰C – 130⁰C

**Reaction Mechanism**

A picture containing diagram

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**Part B:**

**Theoretical Yield**

7.217 g Benzoin x ( ) x ( ) x ( ) = 7.149 g Benzil

**Actual Yield Percent Yield Melting Point Range of Product**

6.581 g Benzil x 100 = 92.1% 93 ⁰C – 95 ⁰C

Diagram

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**Part C:**

**Theoretical Yield**

6.581 g benzil x ( ) x ( ) x ( ) = 7.144 g benzilic acid

**Actual Yield Percent Yield**

9.39 g benzilic acid x 100 = 131.44%

**Diagram

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**Materials and Methods:**

**Part A:**

To begin, 2.626 g of thiamine hydrochloride was collected along with 8 mL of deionized water. These were both added to a 125 mL Erlenmeyer flask. 30 mL of 95% ethanol was then collected and added as well. The Erlenmeyer flask was then left in an ice bath to let cool. A stirring rod was used to make sure the solution was well mixed. While continually stirring, 5 mL of 3M NaOH was added dropwise to the solution. The temperature of the solution was always kept below 20 ⁰C. After all the NaOH was added, 15.5 mL if benzaldehyde was added to this solution with continuous mixing. While the benzaldehyde was being added, a hot water bath was prepared and maintained at around 60 ⁰C. After all the benzaldehyde was added to the solution, the Erlenmeyer flask was added to the hot water bath. The temperature was kept withing a 10 ⁰C buffer range while the solution was stirred for 1 hour and 13 minutes. Following this, the solution was taken off the heat, and then later kept back in an ice bath to let crystallization occur. The crystallized mixture was then vacuum filtrated and washed twice with ice-cold deionized water, and then twice with 10 mL portions of ice-cold methanol. The residue was then left in a pre-weighed beaker to let dry for a week. The dried product was then weighed and analyzed via melting point and IR.

**Part B:**

7.217 g of benzoin was added to a round bottom flask along with 3.608 g of ammonium nitrate, 36 mL of acetic acid, and 0.16 g of copper (II) acetate. The round bottom flask was then heated and stirred using a heating mantle. A water-cooled reflux condenser was additionally attached to the flask. The solution was then gently brought to a boil, where it was allowed to reflux for 1 hour and 30 minutes. Following this, the reaction mixture was allowed to cool to 50 ⁰C, where it was then poured over a beaker filled with crushed ice. The crystallized benzil was then collected via vacuum filtration, along with two washes of ice-cold water. The product was then left to dry for a week, whereafter a melting point analysis and an IR analysis were taken.

**Part C:**

16.5 mL of potassium hydroxide was obtained along with 19.7 mL of 95 % ethanol. These two chemicals were added into a 100 mL RBF with the benzil produced in the reaction before. A heating mantle was used to heat the round bottom flask and produce reflux for the contents in the flask. The solution was allowed to reflux for 15 minutes. After this, the reaction was poured into 250 mL beaker containing 100 mL of deionized water and allowed to chill. The solution was then brought to a temperature of 50° C using a hot plate. 0.5 g of decolorizing carbon and 0.5 g of celite were stirred into the solution for two minutes. The solution was then strained using gravity filtration. 15ml of hydrochloric acid was added to 100 ml of crushed ice in a beaker. 14.5 ml of potassium benzilate solution was initially added into beaker along with the filtered solution and stirred. Upon dissolving, the rest of the potassium benzilate solution was added. The pH at this step of the reaction was around 1, so additional hydrochloric acid was not necessary. The solution was then vacuum filtrated and washed with cold water. The residue was collected, weighed, and used for a melting point analysis and an IR analysis.

**Discussion:**

**Part A:**

The synthesis of benzoin was initiated by combining the benzaldehyde to a cold solution of water, thiamine hydrochloride, sodium hydroxide, and 95% ethanol. The mixture was cooled as the sodium hydroxide was added slowly to prevent an exothermic reaction exceeding 20 ⁰C. Additionally, the thiamine hydrochloride would decompose if it was placed in a warm environment, which was also the reason the solution was allowed to sit for 5 – 10 minutes after the addition of the sodium hydroxide. While adding the sodium hydroxide, it was noted that the solution initially turned yellow, but became more dilute as the solution was mixed. After a majority of the sodium hydroxide was added to the solution, a more vibrant color change was noticeable as the solution had maintained a bright yellow color, even through the mixing process. The thiamine, formed by the deprotonation of thiamine hydrochloride, served as the nucleophile which attacked the electrophilic carbon found on the benzaldehyde, which was added to the solution soon after. Following the addition of the benzaldehyde, the solution was then heated to 60 ⁰C. This temperature was maintained with a 10 ⁰C buffer zone for 1 hour and 13 minutes. Within 20 minutes of the heating, the consistency and color had changed to that of a mango slushy. Once the mixture was heated for the set time, the reaction mixture was cooled down in an ice bath in order to induce crystallization which led to the formation of benzoin. The benzoin was vacuum filtrated in order to separate the product from the remaining solution. The solids remaining in the Buchner funnel were washed twice with ice-cold water and ice-cold methanol. This turned the residue from a yellow solid to a white solid. This, however, was still very moist, so it would not have been prudent for us to have taken a melting point or an IR analysis because it would have given us a false reading. Letting the product dry for a week, an white powder was used for a melting point and IR analysis. The low percent yield was most likely due to unreacted starting material still in the product, and the loss of product due to various minor difficulties experienced throughout the procedure. The melting point range was from 120 ⁰C – 130 ⁰C. This range was broad and lower than expected 137 ⁰C, showing us that our product was most likely impure due to impurities collected throughout the experiment. The IR analysis revealed that we had indeed produced our expected product as indicated by the sharp peak at 3376.94 -1cm. This peak indicated the presence of an OH bond, which is not on our starting material of benzaldehyde, but is on our expected product of benzoin. The other notable stretches were those for aromatic rings and carbonyl groups. The IR analysis showed the presence of aromatic groups through the peak seen at 1677.18 -1cm. Another notable factor of the aromatic stretch was also the overtones seen right above this range. This range also most likely masked the stretches of our expected carbonyl group as they both lie in the same range. A comparison between our IR analysis and the expected IR analysis also supports the conclusion that our product was produced as both contained many similar characteristics.

**Part B:**

The synthesis of benzil from benzoin was achieved by mixing the remaining benzoin sample with copper (II) acetate, acetic acid, and ammonium nitrate. The ammonium nitrate acted as a mild oxidizing agent in the presence of the copper (II) acetate which derives the conversion of the benzoin to benzil. The mixture was slowly heated and stirred till its boiling point, at which it was left to reflux. The reaction mixture turned from a brown slush to a opaque green withing 2 minutes of refluxing. This was most likely due to copper ions forming in the mixture. The reaction mixture then turned to a beautiful emerald green, which may have happened due to the reformation of copper (II) ions remaining in the solution. Once reflux was completed for an hour and a half, the reaction mixture was cooled to 50 ⁰C and then poured into crushed ice. The ice allowed the maximization of our product’s crystallization. The benzil product was dried and collected through vacuum filtration, though the light-yellow solid had the consistency of sponge. After the precipitate was washed with water, the solid was then left to dry for a week. The solid was then weighed and used for a melting point analysis and an IR analysis. By the end of this procedure, we had 6.581 g of benzil with a high percent yield of 92.1%. The melting point range was narrow and was around our expected melting point of 94 ⁰C. This indicated that we had a high possibility of a very pure product. The IR spectra confirmed that the expected product was formed and that the starting material was absent. This was indicated by the loss of a hydroxyl stretch, which would have been indicated by a narrow peak at around the 3400 -1cm range. The aromatic stretch we anticipated were shown, as indicated by the narrow peak above the 1500 -1cm range.

**Part C:**

Benzilic Acid was produced in the third part of the lab using the benzil that was produced from the previous lab along with potassium hydroxide, 95% ethanol, deionized water, carbon, celite, hydrochloric acid, and potassium benzilate. Initially, at the beginning of this lab potassium hydroxide, benzil, and ethanol were combined in a round bottom flask. Ethanol was the third chemical that was introduced into the flask, when this occurred an immediate color change was observed to a dark purple shade. The solution was then refluxed and stirred for 15 minutes. After this, the solution was transferred into a beaker containing 100ml of deionized water. The hydroxide from the potassium hydroxide attacked a carbonyl, resulting in a benzilate salt (after the electrons were pushed). When the solution was heated to 50°C another color change was observed to a coffee color shade of brown, most likely from the dissolving of the salt. 0.5g of carbon and 0.5g of celite were added to the solution to remove impurities, and the solution was allowed to stir for two minutes. During this time the decolorizing carbon changed the color of the solution from a coffee brown to a clear black liquid. The solution was then gravity-filtered, where another color change was occurred to a clear orange solution. This was most likely due to the black carbon being removed during filtration. 15ml of hydrochloric acid and 100 ml of ice were combined in a beaker along with the filtered portion of the solution. The addition of the hydrochloric acid to the potassium benzilate salt allowed the salt to be protonated and caused a molecular rearrangement that ultimately produced benzilic acid. The contents were allowed to crystalize and then transferred to a vacuum filtration where a white slightly moist powdery substance was left on the top of the Buchner funnel. This substance was analyzed using IR spectroscopy, but not using melting point do to its inconvenient moist state. Reading the chart, we were able to prove that the final product created was Benzilic Acid. This was seen by the O-H stretches in the 3400 -1cm range. The ever-present aromatic ring stretch still remained, and the sharp peak at the 1712 -1cm range accounted for the carbonyl found on benzilic acid. In total, the IR proved that benzilic acid was formed, also proving that this lab was successful.

**Conclusion:**

The multistep synthesis of benzylic acid was carried out through 3 different reactions. The first reaction was the formation of benzoin from benzaldehyde through benzoin condensation. The second reaction involved the benzoin reacting with copper (II) acetate, ammonium nitrate, and acetic acid to form benzil and nitrogen gas. The third reaction allowed the benzil product to react with potassium hydroxide to form a salt, that was protonated and rearranged to form the final product, benzylic acid. An experimental yield of the final product, Benzilic acid, was 9.39 g which was a 131.44% yield of the 7.144 g theoretical yield. The yield was large because the product was not dried enough. The melting point range was not taken due to the likelihood of a very broad range because our product was not dried as much as needed. The IR spectra of the product determined that the product was in fact the desired product of benzilic acid.

**References:**

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(3) Lehman, John W., and John W Lehman. *Multiscale Operational Organic Chemistry: A Problem-Solving Approach to the Laboratory Course*, 3rd ed., Pearson Prentice Hall, Upper Saddle River, NJ, 2009, pp. 117–124.