

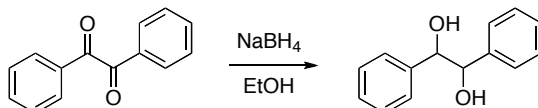
Stereochemical Analysis of the Reduction of Benzyl

Intro:

Background

- Oxidation - Reduction reactions

Oxidation-reduction reactions (or redox) reactions, are a type of chemical reaction that involves a transfer of electrons between two species. An oxidation-reduction reaction is any chemical reaction in which the oxidation number of a molecule, atom, or ion changes by gaining or losing an e⁻.¹ In this lab, we will be carrying out a reaction to reduce the two carbonyl groups on benzyl:



- Re-crystallization

Recrystallization is the primary method for purifying solid organic compounds. Compounds obtained from natural sources or from reaction mixtures almost always contain impurities. The impurities may include some combination of insoluble, soluble, and coloured impurities. To obtain a pure compound these impurities must be removed. Each is removed in a separate step in the recrystallization procedure.¹

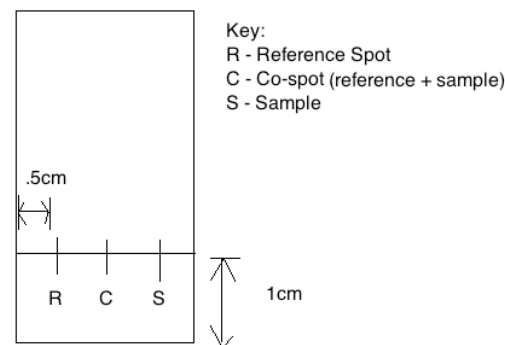
- Suction Filtration

Crystals may be collected from a solution by filtration on a Büchner funnel. A partial vacuum is created in the filter flask by a water aspirator. (Water flowing past a small hole in a pipe draws in gas from the hose to the filter flask. This reduces the pressure creating the partial vacuum.¹

Procedure:

1. 0.97 g of benzil was measured and placed in a 100ml round bottom flask
2. A magnetic stir bar and 10.0ml of ethanol were added to the flask
3. The flask was clamped over top of a magnetic stirrer, an ice bath was then placed on the magnetic stirrer, under the flask. The solution in the flask was mixed for approximately 5 minutes.
4. 0.20g of sodium borohydride was measured, and a third of this sample was added to the flask. Each of the reaming thirds of the sample were added, waiting approximately 2 minutes between subsequent additions. The solution was then allowed to mix for approximately 10 minutes.
5. The ice bath was removed, and the solution was allowed to mix for approximately 10 minutes.
6. A TLC was prepared, see figure 1. The reaction mixture was used to spot the TLC plate.
7. Approximately 10.0mL of warm water were added to the flask. The flask was clamped within a heating mantle above a magnetic mixer, and the solution was allowed to mix and heat for approximately 10 minutes.
8. Approximately 20.0mL of warm water were added to the flask, the solution was continuously heated and mixed for approximately 10 minutes.
9. The flask was removed from the hotplate and allowed to cool until it had reached approximately room temperature.
10. Using suction filtration, the crystals that formed in the reaction mixture were collected. The crystals were washed with cold water, and the suction filtration was allowed to continue for approximately 5 minutes.
11. A TLC plate was prepared see figure 1. The collected crystals were dissolved in acetone and the mixture was used to spot the TLC plate.
12. 330mg of the crystal product were placed in a 25.0mL round bottom flask. Approximately 25.0mL of CH_2Cl_2 and a stirring bar were added to the flask.
13. approximately 1.0mL of 2-methoxypropene and 50 mg of p-toluenesulfonic acid were added to the flask. The mixture was allowed to stir for approximately 20 minutes.
14. A TLC plate was prepared, see figure 1. The reaction mixture was used to spot the TLC plate.
15. Two TLC plates were prepared, see figure 1. The reaction mixture was used to spot both plates. One plat was referenced with syn acetone, while the other was referenced by anti acetone.

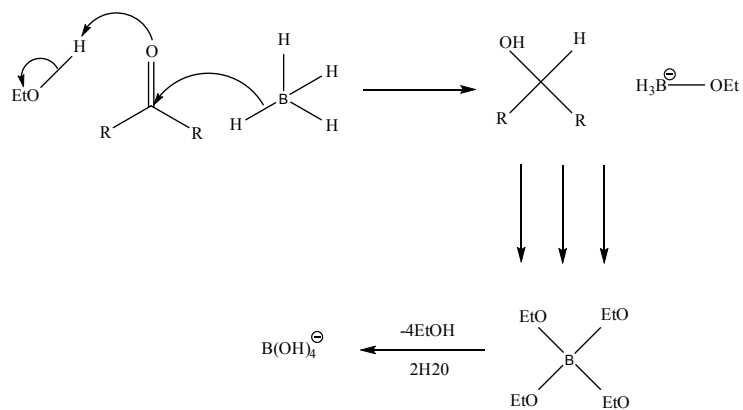
Figure 1.



Observations/Data:

Mechanisms

- Reduction of carbonyl with NaBH_4



- Addition of protecting group to diol

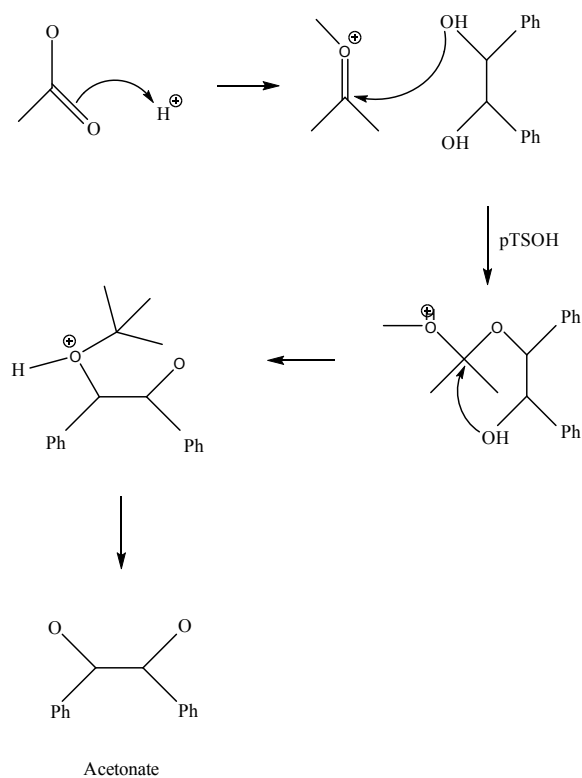


Table of reagents

- Table 1: Reduction of Benzil with Sodium borohydride

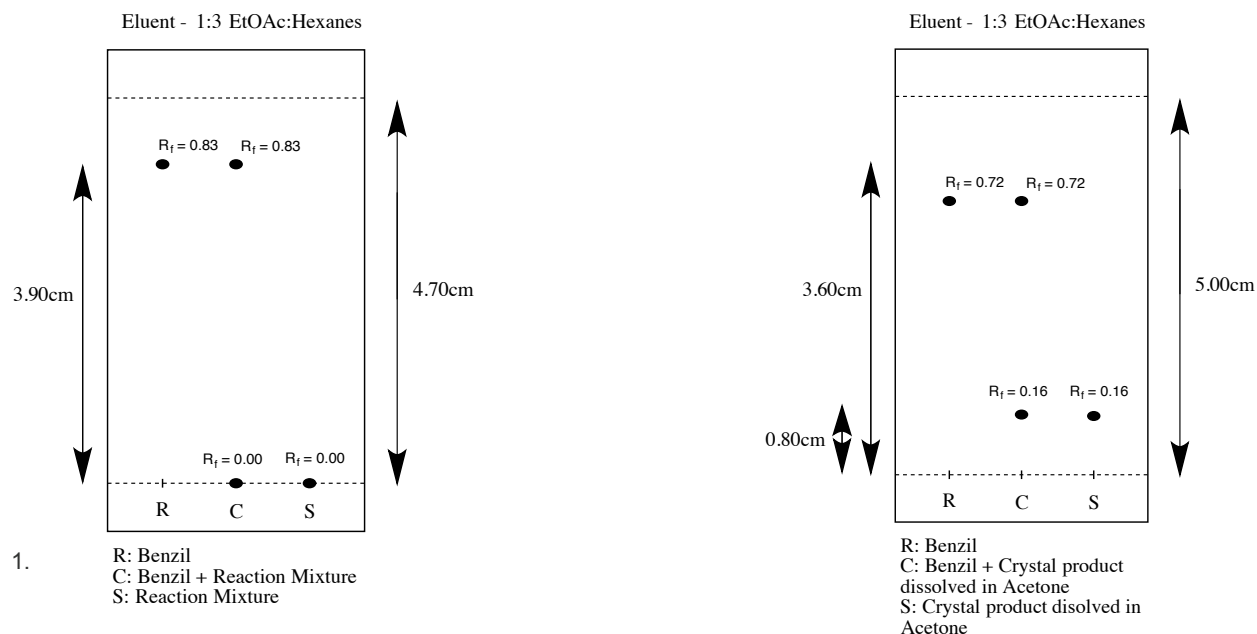
Compound	Molar Mass (g/mol)	Density (g/mL)	Amount(g)	mol	Equivalents
Benzil	210.23	1.23	0.97	4.61E-03	1.00
Sodium borohydride	37.83	1.07	0.2	5.29E-03	0.500

- Table 2: Protection of diol

Compound	Molar Mass (g/mol)	Density (g/mL)	Amount(g)	mol	Equivalents
2-methoxypropane	72.11	0.753	0.753	1.04E-02	0.258
p-toluenesulfonic acid	172.2	1.24	0.050	2.90E-04	1.00

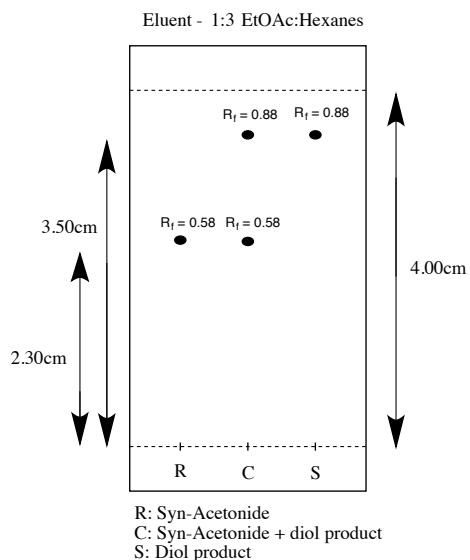
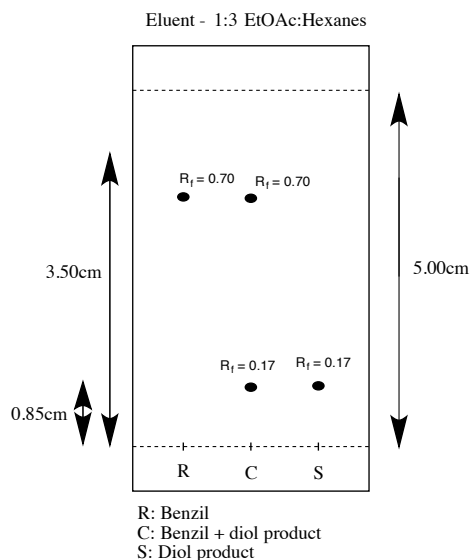
TLC Plates

TLC Plate #1 - Verification of Reaction Completion (see procedural step #6) TLC Plate #2 - Crystal Product Yield (see procedural step #11)

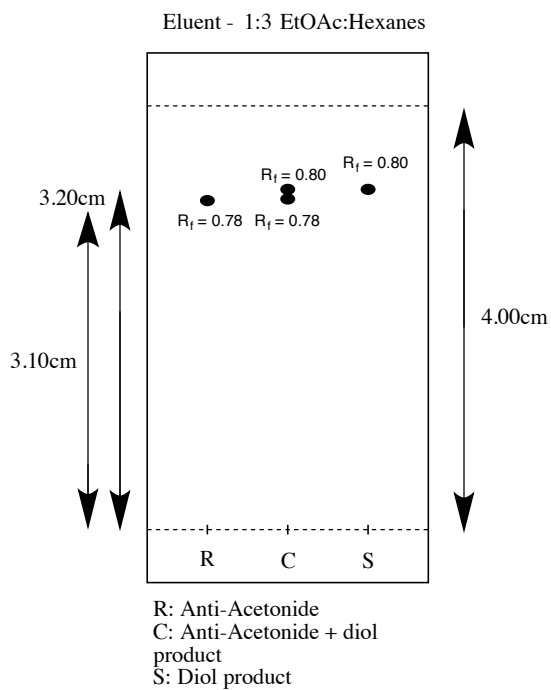


TLC Plate #3 - Verification of Reaction Completion
(Diol Product, see procedural step #14)

TLC Plate #4 - Final Diol Product Spotted Against Syn-Acetonide (see procedural step #15)

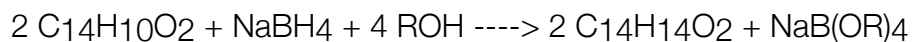


TLC Plate #5 - Final Diol Product Spotted Against Anti-Acetonide (see procedural step #15)



Yield of Benzoin Crystals

Reaction is given by:



*Note that benzil is the limiting reagent

Theor. Yield = number of moles of benzil*[mols of Benzoin/mols of Benzil] * molar mass of Benzoin

$$\begin{aligned} &= 0.00461 * [2\text{mol}/2\text{mol}] * 214.28\text{g/mol} \\ &= 0.988\text{g} \end{aligned}$$

Actual Yield = 0.310g

Percent yield = Actual yield/theoretical x 100%
= 0.310g/0.988g x 100%
= 31.4%

*See Error Discussion for explanation regarding the very low percent yield.

Qualitative Observations

- Solid benzil was a pale yellow fine powder.
- Mixture loses its pale colour when sodium borohydride is added
- Reaction mixture begins to bubble, and loses its yellowish colour when hot water is added
- Crystals begin to form as the reaction mixture is allowed to cool
- The crystals obtained by suction filtration were white and plate-like

Discussion:

Discussion Questions

1. Solubility @ 20.0°C = 1g/100mL = 0.01g/mL
Solubility @ 60.0°C = 16g/100mL = 0.16g/mL
Mass of compound A = 3.5g
Mass of compound B = 10.0g

While at 100.0°C

The solubility of the compound mixture that will dissolve is 0.16g/mL, so, if all of the 13.5g mixture is to dissolve, it will require:

$$13.5\text{g}/0.16\text{g/ml} = 84.375\text{mL}$$

of solution.

While at 20.0°C

The solubility of the compound mixture is 0.01g/mL, and we have 84.75mL of solution, so the amount of the compound mixture that dissolves:

$$0.01\text{g/mL} * 84.375\text{mL} = 0.84375\text{g}$$

This leaves us with $13.5\text{g} - 0.84375\text{g} = 12.65625\text{g}$ of compound mixture that is not dissolved.

The percent of A in the initial compound mixture is $3.5\text{g}/13.5\text{g} = 0.26$

So the amount of A in the crystals is given by:

$$12.65625\text{g} * 0.26 = 3.29\text{g of compound A}$$

Following the same procedure for compound B

$$10.0\text{g}/13.5\text{g} = 0.74$$

$$12.65625\text{g} * 0.74 = 9.37\text{g of compound B}$$

$$\% \text{ yield of A} = 3.29/3.5\text{g} * 100 = 94\% \text{ of compound A}$$

$$\% \text{ yield of B} = 9.37\text{g}/10.0\text{g} * 100 = 94\% \text{ of compound B}$$

The mother liquor contains 0.84375g of a dissolved mixture of compound A and B, as determined above. Assuming that the mother liquor ONLY contains dissolved compounds A and B (this is obviously an ideal situation) then,

$$0.84375\text{g} * 26\% \text{ compound A} = 0.22\text{g of compound A}$$

$$0.84375\text{g} * 74\% \text{ compound B} = 0.62\text{g of compound B}$$

2.

While at 20.0°C

The solubility of the compound mixture is 0.01g/mL, and we have 100mL of solution, so the amount of the compound mixture that dissolves:

$$0.01\text{g/mL} * 100\text{mL} = 1\text{g}$$

This leaves us with (3.29g of compound A + 9.37g of compound B) - 1g = 11.66g of compound mixture that is not dissolved.

The percent of A in the initial compound mixture is $3.29\text{g}/12.66\text{g} = 0.26$

So the amount of A in the crystals is given by:

$$11.66\text{g} * 0.26 = 3.03\text{g of compound A}$$

Following the same procedure for compound B

$$9.37\text{g}/12.66\text{g} = 0.74$$

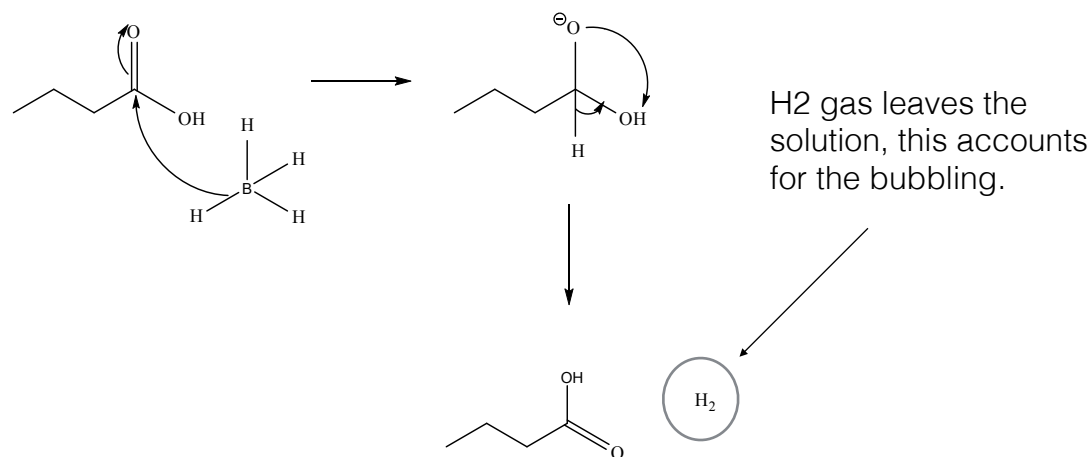
$$11.66 * 0.74 = 8.63\text{ of compound B}$$

$$\% \text{ yield of A} = 3.03/3.29 * 100 = 92\% \text{ of compound A}$$

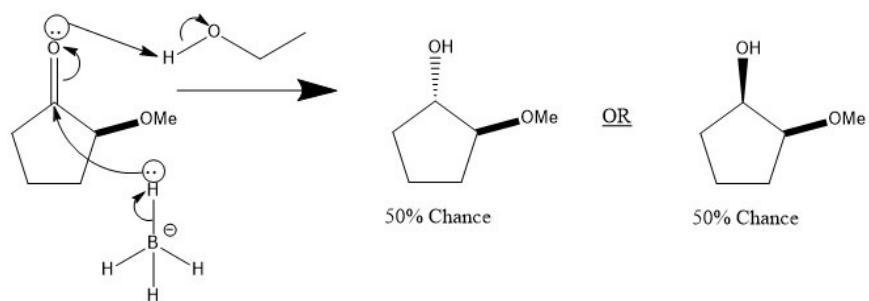
$$\% \text{ yield of B} = 8.63/9.37 * 100 = 92\% \text{ of compound B}$$

3. It is possible that the solution is in fact too soluble in methanol. This would explain why the recovery was so poor, as a high solubility in methanol would mean that more of the crystals remained dissolved, even after cooling it to roughly 0 degrees Celsius. Thus, when suction filtration is performed much of the crystals will remain dissolved in methanol and not in crystal form. In order to improve the recovery, the student could choose a more suitable solvent, particularly, one in which the solubility of the compound she is trying to crystal out is high in the solvent at high temperatures and low in the solvent at low temperatures. Furthermore, it would also likely improve her yield if she were to allow the mixture of dissolved crystals in the solvent to cool more slowly, perhaps using cold water as apposed to an ice bath. In absence of changing the solvent, cooling the reaction mixture to a lower temperature - perhaps sum value below 0 degrees Celsius - may also help to decrease the solubility of the desired compound in methanol, thus increasing the amount of crystallization and therefore, the yield.

4. Sodium borohydride, NaBH_4 , is not a powerful enough reducing agent to reduce a carboxylic acid; however, hydrogen is liberated from the -OH group of the butanoic acid and form hydrogen gas with a donated hydrogen from the borohydride.. The net reaction of the hydrogen gas formation and its escape ($\text{H}^+ + \text{H}^- \rightarrow \text{H}_2$) is the reason why bubbling is observed. Along with the production of hydrogen gas, this reaction would produce salts of the acid, in this case, sodium butanoic acid.



5. The nucleophilic hydride ions from the sodium borohydride can attack the double bonded carbon from either the “front” or the “back”. There will be a 50/50 chance that either will occur, resulting in the formation of two equally possible isomers. Consequently, we would obtain the following racemic mixture:

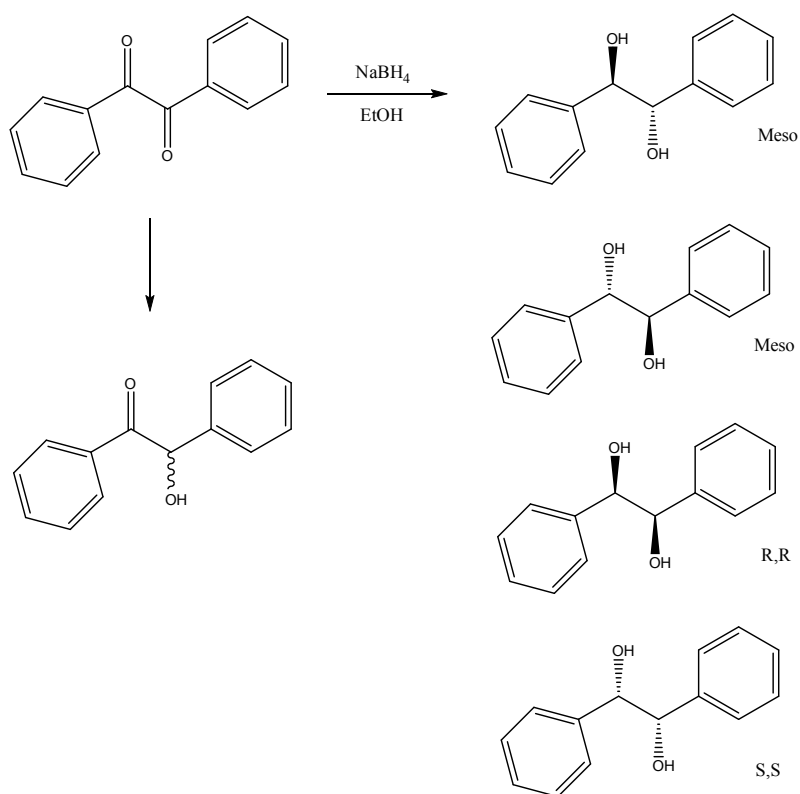


General Discussion:

During the early procedural steps of the experiment, a benzil and ethanol mixture was cooled in an ice bath. This served to bring down the temperature of the mixture before the addition of sodium borohydride. The reaction between sodium borohydride and benzil highly favours the formation of a B-O bond, and large amounts of energy are released when this bond is formed. The aforementioned reaction is

exothermic (bubbling was observed). Hot water was then added, and this served the purpose of replacing the ethyl groups with hydrogen, in order to prevent the formation of a product with ethyl groups present. A product with ethyl group present would form a stick solid in the flask.

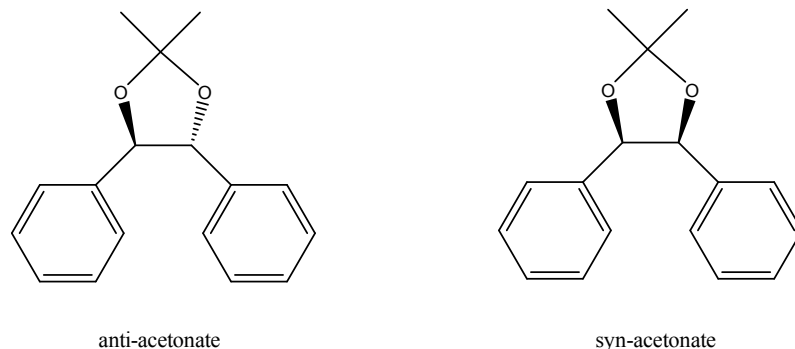
The reaction between benzil and sodium borohydride is given by the following mechanism, note the production of 4 stereoisomers:



It should be noted that the first two stereoisomers are meso, and therefore are the same compound. The likelihood that the reaction will yield any of the aforementioned stereoisomers is equal; however, there is a 50% chance that the reaction will favour the production of a meso. We can then conclude that, statistically speaking, the reaction will favour the production of the meso isomer - this accounts for the stereoselectivity of the reaction. As expected, the TLC plates demonstrates that all three of the distinct stereoisomers were formed.

The reaction was then cooled slowly to room temperature, so that the maximum purity of the crystals would be obtained. This step is worth special mention, as rapid cooling would have resulted in both the desired product, and the impurities, to crash out of the solution. To explain this effect, we must realize that when a molecule recrystallizes slowly, the pieces have enough time to form in a tight crystal lattice reducing the chance of impurities forming within them. Rapid cooling increases the chance that all molecules (including impurities) to pack together as they solidify out of the solution.

2-methoxypropene was used in order to protect the diol. It is important to note that since we produced three distinct isomers of hydrobenzoin, we will produce two different acetates, namely: anti and syn isomers:



Anti-acetate forms from the racemic hydrobenzoin while syn-acetate forms from meso hydrobenzoin. As expected, the TLC plates #4 and #5 demonstrate that both isomers of the acetate were, in fact, formed.

By examining TLC plates #4 and #5, we can easily observe that our produced mixture of acetate contains mostly the anti-acetate isomer, as the R_f values of the reference (anti-acetate) and the sample (our acetate mixture) on TLC plate #4 are closer than that of TLC plate #5 (which was spotted with the syn-acetate isomer).

Error Discussion:

Our %yield for hydrobenzoin crystals was notably low, at only 31.4%. The likely reason for this extremely low yield becomes obvious when we examine TLC plate #1. The purpose of this plate was to check if the reaction between sodium borohydride and benzin had gone to completion (see first mechanism mentioned in **Observations/Data**.) We see that the dot on the sample lane, and its corresponding dot on the co-spot lane both have R_f values of 0.0. Thus, we know that the aforementioned reaction did not go to completion - this explains the low crystal yield, as we continued the lab with very little hydrobenzoin dissolved within our reaction mixture before recrystallization and collection of the hydrobenzoin crystals.

We continued on with the lab even with the knowledge that the reaction had not gone to completion simply due to time constraints, as we decided it was more important to have a low yield yet finish all procedural steps, than have a high yield and not finish all the procedural steps.

Conclusion:

The percent yield of the hydrobenzoin was found to be 31.4%. Furthermore, we conclude that our acetone mixture predominately contains the anti isomer of acetone, *anti-acetone*.