Synthesis and Resolution of a Substituted Dioxolane from Glycerol

A Thesis

Presented to the Department of Chemistry

College of Liberal Arts and Sciences

and

The Honors Program

of

Butler University

In Partial Fulfillment

of the Requirements for Graduation Honors

Susannah Dawn Cox

May 5, 2014

Synthesis and Resolution of a Substituted Dioxolane from Glycerol

Susannah D. Cox

Abstract

Glycerol (Figure 1) is one of the major byproducts in the manufacturing of biofuels. As the interest in biodiesel grows, production of glycerol will also increase. Investigating glycerol's potential as a chemical feedstock could lead to the discovery of new uses for this byproduct created from biofuel production. By developing pathways to use glycerol as a starting material and as a solvent we will be able to synthesize other chemically relevant compounds.

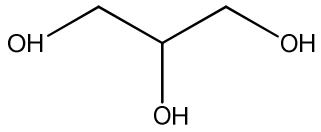


Figure 1: Molecular Structure of Glycerol

Introduction

Biodiesel has been proposed as an alternative to diesel obtained from crude oil in the United States since the passage of the Energy Policy Act in 2005.[1] Biodiesel is a renewable fuel source and is considered to be "greener" than petroleum based fuels. If the waste generated from biodiesel production could be harnessed for alternative uses, the manufacturing of biodiesels could be "greener". To understand the chemistry responsible for creating biodiesels and the type of products resulting from biodiesel production, the reaction shown below must be understood.

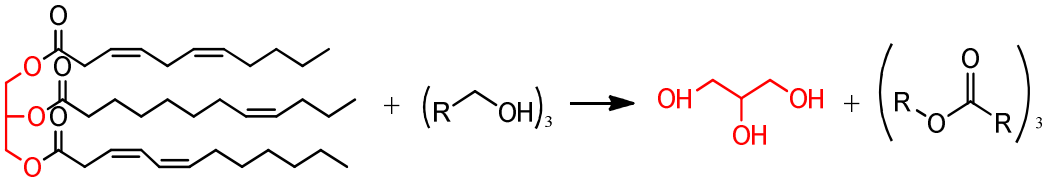


Figure 2: General Chemical Reaction for the Creation of Biodiesel

Triglycerides (Structure 1, Figure 2) produced by plants are utilized as starting materials in the creation of biodiesels. This means that a triglyceride is used in the manufacturing of another, usually more useful substance—in this case biodiesel. The long fatty acids chains (Structure 4, Figure 2) cleaved from the original triglyceride are used as fuel, but the glycerol backbone (Structure 3, Figure 2) is also left after the reaction concludes. With the increased production of biodiesels, it is projected that by the year 2020, glycerol production will exceed its demand by six times.[2] This is an astounding amount of material that is discarded as waste which could be utilized as an additional resource.

Glycerol is a clear and colorless viscous liquid that is commonly used as a preservative for leaves, and as a filler in "low-fat" foods and sugar substitute in the food industry, It also is used in suppositories, as well as in number of other personal-care goods, including mouthwash, toothpaste, hair and skin products. As a chemical intermediate, glycerol is utilized in the production of nitroglycerin as well as smokeless gunpowder and dynamite.[2,3]

By exploring how glycerol can be used as a chemical reagent we are able to synthesize compounds that are used in other chemical processes and to convert the waste glycerol to another usable compound. While glycerol obtained from the production of biodiesel was not used, this research explored possible ways of using the excessive waste that results from the production of biodiesel. Furthermore, glycerol can act as both a reactant and solvent and thus eliminates other chemical waste.[4]

Chirality is commonly discussed in reference to amino acid protein sequences. Naturally occurring amino acids tend to be L meaning they are "left-handed" or S; sugars tend to be D meaning they are "right-handed" or R.[5] A molecule is considered chiral when it contains a carbon that has four different functionalities bonded to it. This molecule can be arranged in two separate configurations that are non-super imposable. These configurations are commonly referred to as R and S or right and left handed respectively.

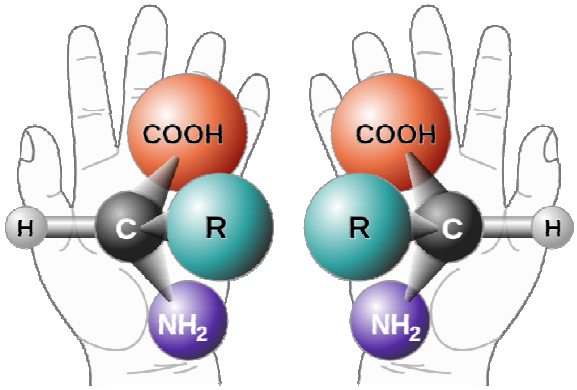


Figure 3: Representation Non-Super Imposable Handedness of a Generic Amino Acid

Picture retrieved from: <

http://commons.wikimedia.org/wiki/File:Chirality_with_hands.svg>

A vast number of chemical species used today contain a chiral carbon. Chirality is important in pharmaceuticals, foods, pesticides and even polymers. Food science can manipulate chirality to for taste and smells. Many drugs utilize a single isomer of a racemic mixture. A common example is Thalidomide. In the late 1950's it was found that while one enantiomer was useful in relieving nausea, the other caused debilitating and often fatal birth defects.[6] This led interests in discovering how to produce and separate isomers of chiral compounds. In industry today chiral species are produced through synthesis of a racemic mixture followed by resolution of the enantiomers or synthesis of a single chirality of the molecule.

Glycerol is an achiral compound. If the one of the end hydroxides could be differentiated from the other, the compound would be chiral with the chiral compound located at the central carbon.

Graham et al[4] showed that the use of catalytic quantities of indium(III) triflate efficiently promoted the formation of a 2,4 dioxolane from glycerol trimethyl orthoformate, and an unreactive ketone, such as benzophenone.[4] The formation of the dioxolane was rapid and solvent free.[4]

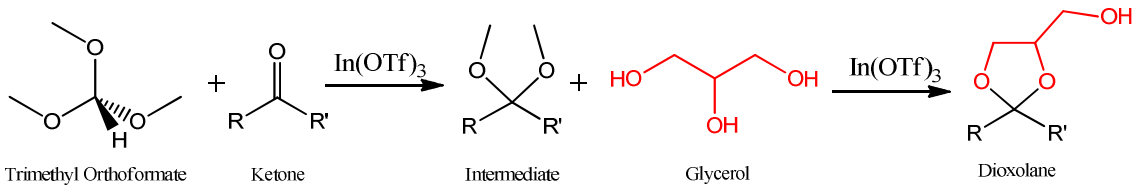


Figure 4: Reaction Scheme to Form the 2,4 Dioxolane

If the chiral racemic acetal, was reacted with a resolved chiral reagent, a mixture of diastereomers would result. As diastereomers are different compounds, it would theoretically be possible to separate the species. Removal of the acetal would result in a 2, 3 diol ester. The compound could then be elaborated on at all three sites.

Results and Discussion

Graham et al[4] utilized glycerol as both a starting reagent and solvent with the intent of lessening the chemical waste produced. Glycerol and trimethyl orthoformate were reacted with various ketones such as benzophenone, acetophenone, and benzaldehyde to create a dioxolane. In all cases the 1,2 addition product not the 1,3 was observed (Figure 3).

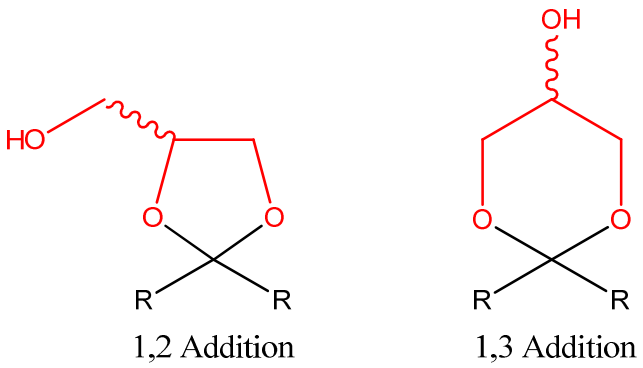


Figure 5: The Possible Additions of Glycerol onto the Ketone

A catalytic amount of indium(III) triflouromethanosulfonate (indium triflate, $In(OTf)_3$) was used to accelerate the rate of the reaction. Purification of the initial product proved difficult. Reactions completed with benzophenone failed to go to completion. HNMR spectra suggested that the reaction remained in equilibrium. Additional catalyst as well as heat failed to push the reaction to completion (Figure 6).

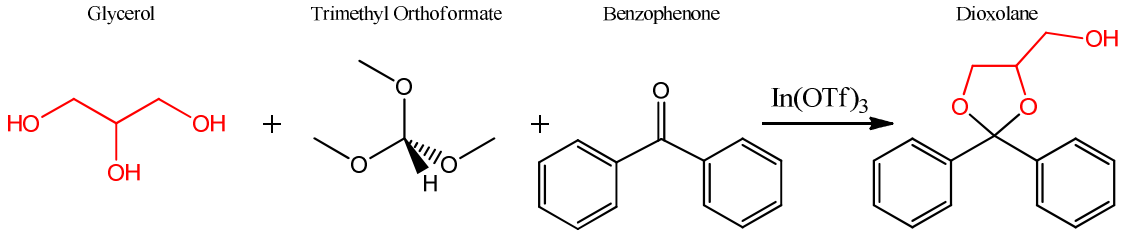


Figure 6: Formation of the Dioxolane Utilizing Benzophenone

Protocols that utilized acetophenone or benzaldehyde as the ketone source resulted in a mixture of products (Figure 7). HNMR data was very complicated for the typical procedure for tandem acetalisation-acetal exchange to form a 2,4-dioxolane since starting material, the intermediate, and product were all present at equilibrium.

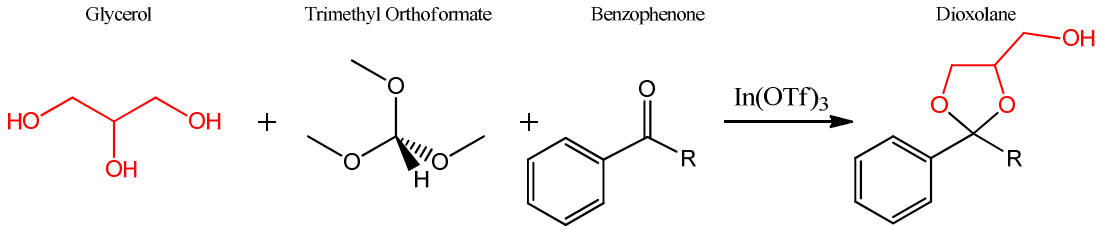


Figure 7: Formation of the Dioxolane Utilizing Acetophenone or Benzaldehyde (R=H, CH_3)

There were two 1,2 dioxolane products possible with unsymmetric ketones, with different groups cis or trans to the third hydroxyl group of the glycerol (Figure 8).

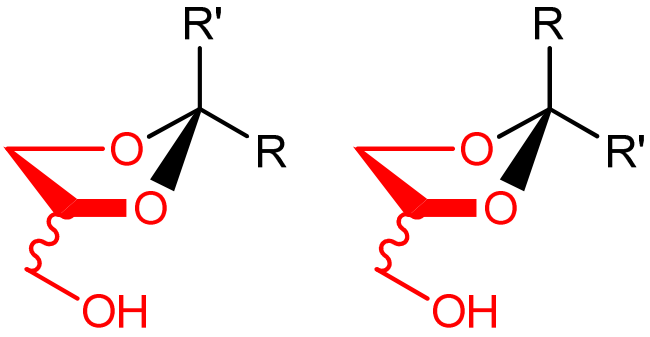


Figure 8: Possible Dioxolane Products from Reactions with Acetophenone and Benzaldehyde

As a result the initial three ketones were abandoned as candidates to form the dioxolane starting material. Dioxolane formation using benzophenone and a cadmium iodide catalyst was later investigated.[7] However, it was also found that the reaction did not proceed to completion.

Acetone was selected to undergo tandem acetalisation-acetal exchange with glycerol, trimethyl orthoformate, and indium triflate due to the simplicity of its molecular structure and low cost (Figure 9). The addition of trimethyl orthoformate encouraged ring

formation and a small amount of indium triflate was used to catalyze the reaction. Since the groups on the ketone were identical, only one dioxolane product was produced.

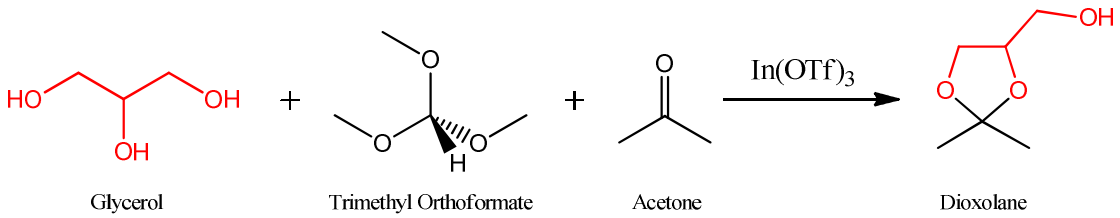


Figure 9: Reaction for the Synthesis of the Starting Material

Very little purification was performed on the 1,2 dioxolane product. Scaled-up reaction conditions provided 78% of the product. Experimentation with different solvents to elute the product off the short plug silica gel column revealed 1:10 methanol to methylene chloride to be the most ideal. Initial purification techniques found hexanes to be too hydrophobic. The use of harsh hydrophilic solvents was necessary. Use of methanol as a solvent introduced too much water into the system. However, methylene chloride alone proved to be incapable of washing the desired product off the column. TLC analysis was utilized to determine approximate amount of the 1:10 solvent mixture needed to wash the product off the column. Proton NMR spectroscopy was utilized to verify that the desired product was purified. Data for the starting material was compared to literature values to further confirm the molecular structure.

Characteristic peaks included a peak at 109.8ppm in the CNMR which implied that the acetal ring had remained intact.[4] Notable HNMR peaks consisted of two asymmetric methyl groups.[4] Figure 7 provides a visual aid of how conformation causes the methyl groups to appear different from one another in the HNMR spectra. Additionally, HNMR

spectra presented with eight distinct hydrogen signals. Experimental HNMR and CNMR were compared with spectra obtained from Sigma Aldrich.

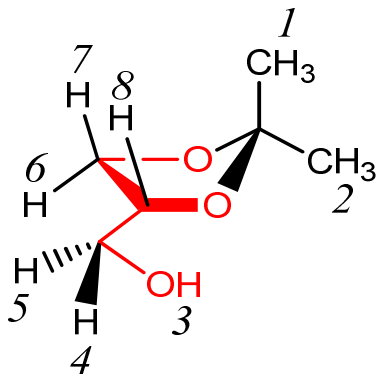


Figure 10: Representation of the 3-Dimensional Acetal Showing the Eight HNMR signals

The goal of the project was to synthesize glycerol derived diastereomers that could potentially be resolved. We chose to convert the terminal alcohol to a chiral ester using a commercially available resolving reagent. Esterification of the starting material was initially done with cyclohexane carbonyl chloride and benzoyl chloride to determine reaction conditions without using an expensive reagent. Conditions needed to be carefully developed to keep the dioxolane ring intact since acetals are very acid sensitive. A number of different reaction conditions were attempted. Initially the racemic acetal was reacted in a 1:1 reaction with carboxylic acid. The presence of acid resulted in cleavage of the dioxolane ring system. Ring cleavage was apparent in the HNMR as the methyl groups became equivalent and in the CNMR there was not a peak at 109.8 ppm. Next, cyclohexane carbonyl chloride was used to form the ester because it was thought the acid present in reaction would not be strong enough to cause destruction of the acetal ring.

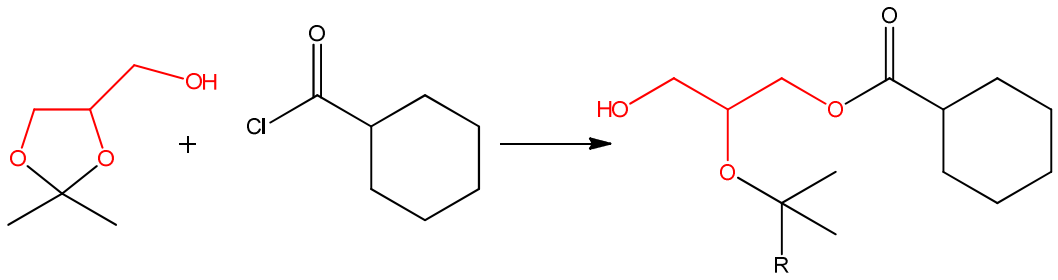


Figure 11: Possible Effect of Acid Present in Reaction

HNMR and CNMR data revealed the reaction was unsuccessful as the methyl peaks were equivalent and the CNMR peak present at109.8 ppm was missing. Several primary literature texts suggested the use of reagents like pyridine to prevent the ring from being affected. It was determined the use of ammine base would be the least toxic and least expensive solution to the issue. The carboxylic acid was then allowed to react with the racemic acetal. However, this time two equivalents of amine base were used to soak up any excess acid in solution. HNMR and CNMR data showed this reaction to be successful. The characteristic asymmetric methyl peaks were present as well as the peak at 109.8 ppm in the CNMR.

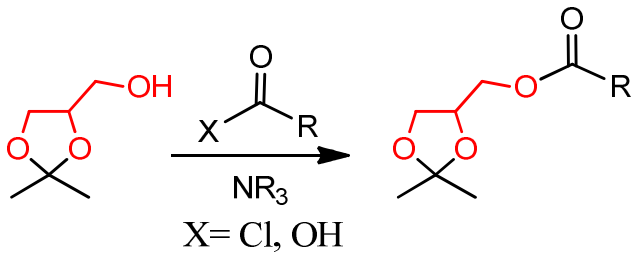


Figure 12: Esterification Utilizing the Presence of Two Equivalents of Amine Base

The use of two equivalents of base with benzoyl chloride was then invested (Figure 12). Once again it was found that the ester was synthesized using HNMR and CNMR data to

characterize the state of the dioxolane ring. It was discovered that any presence of acid in reaction caused ring cleavage. Asymmetric methyl peaks in the HNMR and an indicative peak at 109.8ppm in the CNMR were used as evidence that the ring remained intact and that the ester product had been successfully formed.[8]

Mosher's acid was chosen because it was commercially available on Sigma Aldrich as the acid and the acid chloride for both the R and S derivative.[9] Once the reaction conditions were developed the unprotected alcohol on the starting material was reacted with S-Mosher's acid chloride in the presence of two equivalents of an amine base. (Figure 13). It was thought this reaction would result in a diastereomeric mixture, RS and SS. The diastereomers could then be resolved. This would give a diastereomically pure ester, with a specific R or S chiral center, to form in two steps from the synthesized glycerol feedstock. HNMR and CNMR spectra seemed to indicate the formation of a single diastereomer. The most apparent evidence is that there are only one set of peaks in both the HNMR and the CNMR. Diastereomeric compounds are likely to have slightly different signals. This is likely to be most apparent for the asymmetric methyl peak signals. For a racemic mixture four separate peaks should be observed in this region where only two were detected. The clarity of both spectra further supports the theory that only one diasteriomer is present. Presence of an R and S molecule should also affect the CNMR signal at 109.8ppm. Once again, only one singlet peak was observed where two would be expected in a racemic mixture. These shifts would be observed because the R and S versions of the dioxolane would interact differently with the Mosher's acid

chloride functionality due to proximity. However, it could be that a higher resolution NMR instrument is needed to discern the additional peaks.

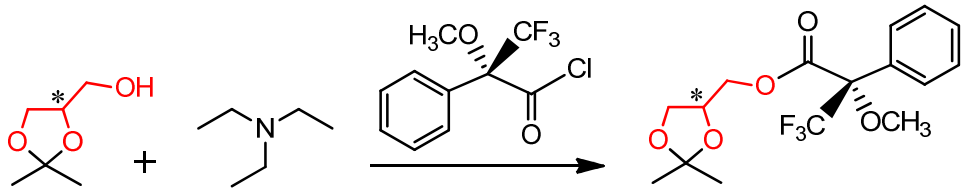


Figure 13: Synthesis of Diastereomically Pure Ester

To better understand why a single diastereomer might be formed, resolved samples of the dioxolane were purchased and used in reaction with the resolved Mosher's acide chloride. In this case, the R dioxolane should only yield the RS, ester. The S dioxolane should only yield the SS ester. The spectrum could then be compared to see if the products were identical. Two separate reactions were set up. Both the RS and SS esters were synthesized by refluxing one equivalent of the pure form of the R or S acetal with one equivalent of pure S-Mosher's acid chloride and two equivalents of triethylammine for two hours.

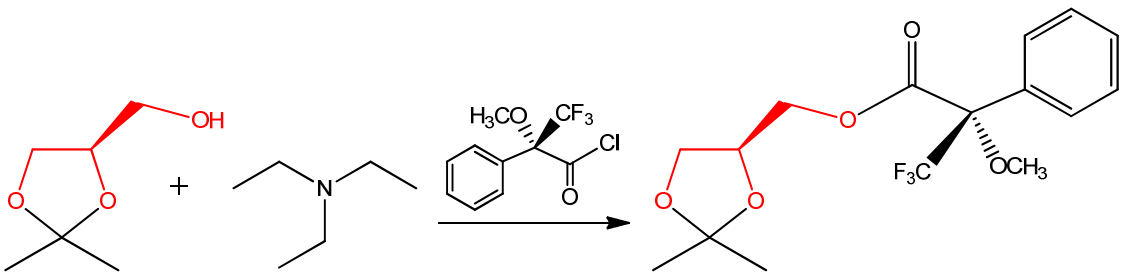


Figure 14: Synthesis of the R Acetal and S Mosher's Acid Chloride Ester

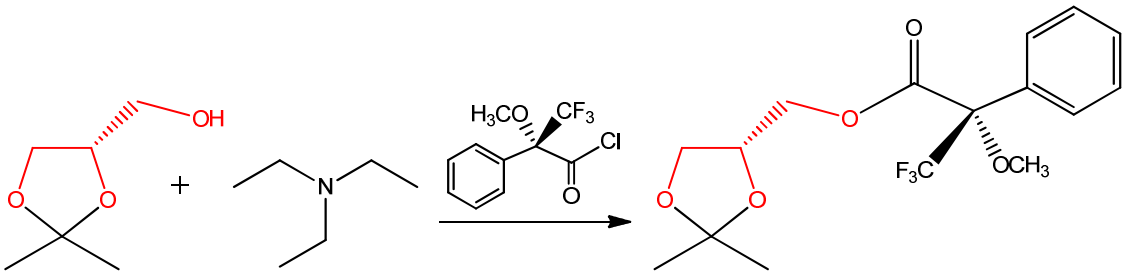


Figure 15: Synthesis of the S Acetal and S Mosher's Acid Chloride Ester

A HNMR spectrum of each resulting product was taken and compared to the initial ester product from the racemic starting material. HNMR comparisons revealed the spectra of the S-acetal and S-Mosher's acid chloride ester to be more comparable to that of the racemic acetal and S-Mosher's acid chloride ester. The R-acetal and S-Mosher's acid chloride ester, while similar, showed the two ester products to be subtly different. The integration of peaks was different. Peak shapes and shifts of the S-acetal reaction most closely mirrored that of the racemic acetal reaction. However, a higher field instrument is needed to determine the exact differences between the spectra. This may suggest that either the initial reaction to form the dioxolane from glycerol and a ketone or that the esterifaction of the starting material is stereospecific. The former hypothesis is more likely as the reaction between the R-acetal and S-Mosher's acid chloride resulted in the formation of a product. However, further research will need to be done to verify this.

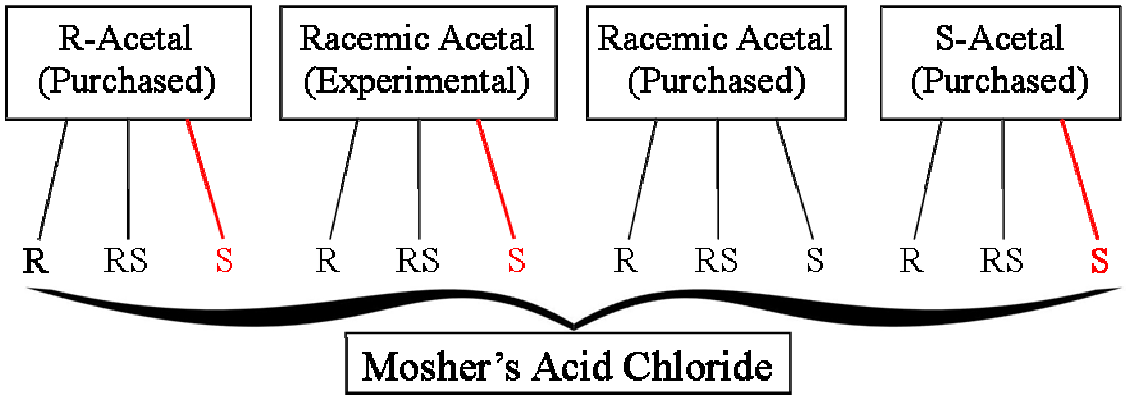


*Figure 16: Possible reactions to investigate synthesis of ester from acetal and Mosher's acid. Varying chirality of reagents would allow for better understanding of the reaction mechanism. *Reaction pathways in red were completed.*

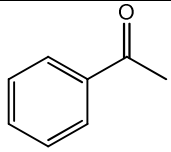
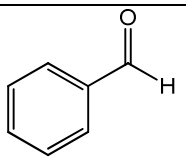
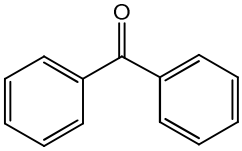
Future projects would investigate the resulting chirality after esterification occurred. Higher resolution instrumentation would be needed to characterize the specific chirality of each reaction (Figure 16). Once the mechanism of esterification was better understood, work to resolve the synthesized diastereomers could be conducted.

Experimental

HNMR (Hydrogen Nuclear Magnetic Resonance) and CNMR (Carbon Nuclear Magnetic Resonance) spectra were collected on a Bruker AVANCE 250 MHz NMR with BVT variable temperature unit and multinuclear, 1H and dual 1H / 13 C 5mm probes. All NMR samples were run in $CDCl_3$.

Typical Procedure for Tandem Acetalisation-acetal Exchange to Form a 2,4-Dioxolane. Indium triflate (5.6 mg, 1 mol%) was added to a round bottom flask containing a ketone (1.0 mmol), glycerol (0.101 mL, 1.10 mmol), and trimethyl orthoformate (159 mg, 1.5 mmol). The reaction mixture was refluxed for one hour on 35% power and passed through a short plug silica gel column wet with hexanes and washed with methanol (60 mL). Reactions involving aromatic ketones were checked with TLC to ensure the entire product had passed through the column. The reaction mixture was then dried with magnesium sulfate and the solvent was removed under reduced pressure. Resulting product was put under vacuum overnight.

Table #: Ketones Used in the Synthesis of Dioxolane and NMR Product Data

Ketone	1.0 mmol	HNMR Data for Dioxolane Product
 Acetophenone	0.120 mL	HNMR: 7.50-7.33 m, 4.45-4.30 m, 4.20-4.10 t, 4.10-4.00 m, 3.86-3.84 d, 3.81-3.76 s, 3.67 s, 3.47 s, 3.19 s, 2.62 s, 1.68-1.66 d, 1.58-1.54 d; **NMR 1**
 Benzaldehyde	0.102 mL	HNMR: 7.49-7.36 m, 5.95 s, 5.85 s, 5.56 s, 5.41-5.39 d, 4.40-4.22 m, 4.16-4.14 d, 3.73 s, 3.68-3.59 dd, 3.44 s, 3.34 s
 Benzophenone	189 mg	HNMR: 7.49-7.32 m, 4.45-4.35 m, 4.25-4.10 t, 4.10-3.80 p, 3.74-3.71 s, 3.67-3.45 dd, 3.41 s, 3.12 s; **NMR 2** Lit Values HNMR[4]: 7.40–7.25 (6H, m), 4.35–4.25 (1H, m), 4.05–3.90 (2H, m), 3.75 (1H, dd), 3.65 (1H, dd), 1.95 (1H, s)
 Acetone	0.073 mL	HNMR: 4.30-4.15 m, 4.10-3.95 t, 3.90-3.75 t, 3.76-3.71 m, 3.70-3.60 dd, 2.18 s, 1.49-1.40 s, 1.35-1.30 s; **NMR 4**

Procedure for the Synthesis of the 2,4-Dioxolane using Benzophenone and Cadmium Iodide.[7] Cadmium iodide (0.925 grams, 2.5 mmol) was added to a round bottom flask containing benzophenone (091 grams, 5.0 mmol), glycerol (0.36 mL, 5.0 mmol), and trimethyl orthoformate (796 mg, 7.5 mmol). The reaction mixture was refluxed for one hour on 35% power and passed through a short plug silica gel column wet with hexanes and washed with methanol (60 mL). TLC was used to confirm that all product had passed through the column. The reaction mixture was then dried with magnesium sulfate and the solvent was removed under reduced pressure. Resulting product was put under vacuum overnight.

HNMR: 7.86-7.71 d, 7.67-7.2 d, 7.55-7.42 d, 7.38-7.22 m, 4.39-4.29 m, 4.10-3.94 dd, 3.89-3.59 dd, 2.19 s, 1.91-1.81 t, 1.75-1.58 s; **NMR 3**

Procedure for the Synthesis of Dioxolane: 2,2-Dimethyl-1,3-dioxolane-4-methanol.[4] In a round bottom flask, indium triflate (120 mg, 1 mol%) was added to a solution of acetone (4.04 mL, 55 mmol), glycerol (4.02 mL, 55 mmol), and trimethylorthoformate (6.5 mL, 56 mmol). The reaction mixture was refluxed for one hour on 35% power and then put under vacuum for one hour. The product was then passed through a short plug silica gel column wet with hexanes and washed with a 1:10 solution of methanol to methylene chloride (60-80 mL). The resulting solution was dried with magnesium sulfate and the solvent was removed under reduced pressure. Resulting product was put under vacuum overnight. Starting material 2,2-dimethyl-1,3-4-methanol was an oil that ranged in color from a clear to light yellow.

HNMR: 4.30-4.15 m, 4.10-3.95 t, 3.90-3.75 t, 3.76-3.71 m, 3.70-3.60 dd, 2.18 s, 1.49-1.40 s, 1.35-1.30 s; **NMR 4**; CNMR: 109.8, 77.8-76.0, 72.9, 66.1-65.6, 63.0, 55.2, 45.6, 26.5, 25.0; **NMR 5**

Procedure for the Synthesis of an Ester from 2,2-Dimethyl-1,3-dioxolane-4-methanol and Cyclohexane carbonyl Chloride. In a round bottom flask, cyclohexane carbonyl chloride (0.10 mL, 0.75 mmol) was added to starting material (0.78mmol), and dried alumina (8 mg, 1 mol%) in methylene chloride. The reaction mixture was allowed to stir overnight. Ether was added to the reaction mixture and then gravity filtered to remove excess alumina. Solvent was removed under reduced pressure.
HNMR: 5.38-5.15 m, 5.25-5.04 s, 4.41-4.03 m, 4.00-3.88 s, 3.81-3.55 m; **NMR 6**; CNMR: 197.0, 178.0, 138.0, 133.0, 131.0, 129.0, 126.5, 78.0-76.5 t, 72.0, 70.0, 68.5, 65.0, 62.5, 46.0, 43.5, 29.5, 25.5; **NMR 7**

Procedure of the Synthesis of the Ester using Benzoyl Chloride. In a round bottom flask, starting material (1.8 mL, 15 mmol), triethylammine (4.2 mL, 30 mmol), and benzoyl chloride (1.74 mL, 15 mmol) were allowed to reflux on 35% power for two hours. The reaction mixture was passed through a short plug silica gel column and washed with methylene chloride (60 mL). The solvent was removed under reduced pressure. An extraction was done to remove the remaining triethylammine. The reaction mixture was washed three times with ether and three times with water. It was then dried with magnesium sulfate and the solvent was removed under reduced pressure. Resulting product was put under vacuum overnight.
HNMR: 8.12-8.07 d, 7.63-7.51 d, 7.50-7.41 t, 4.52-4.28 m, 4.21-3.83 dd, 1.49-1.30 s, 1.30-1.25s; **NMR 8**; CNMR: 166.8, 160.8, 133.5, 130.0, 128.5, 110.0, 78.0-77.0 t, 74.0, 66.8, 65.2,63.0, 45.8,27.0, 25.5; **NMR 9**

Procedure for the Synthesis of the Ester using S-Mosher's Acid. In a round bottom flask, starting material (1.8 mL, 15 mmol), triethylammine (4.2 mL, 30 mmol), and benzoyl chloride (1.74 mL, 15 mmol) were allowed to reflux in methylene chloride solvent (5 mL) on 30% power for two hours. The solvent was removed under reduced pressure. Resulting product was put under vacuum overnight.

Racemic Acetal HNMR: 7.53-7.39 m, 7.38-7.30 m, 4.43-4.18 m, 4.03-3.91 m, 3.75-3.61 m, 3.59-3.48 s, 1.39-1.30 s, 1.30-1.28 s; **NMR 10**; CNMR: 166.0, 131.5, 129.0, 128.0, 126.5, 120.0, 115.5, 109.8, 83.5, 77.0-75.0 t, 72.0, 65.0-64.0, 61.8, 54.5, 25.5, 24.0; **NMR 11**

S Acetal HNMR: 7.56-7.41 m, 7.41-7.32 m, 4.43-4.19 m, 4.02-3.92 m, 3.72-3.60 m, 3.57-3.45 s, 1.38-1.30 s, 1.30-1.25 s; **NMR 12**

R Acetal HNMR: 7.77-7.71 m, 7.58-7.51 m, 7.49-7.38 m, 7.36-7.28 m, 4.40-4.34 s, 4.33-4.19 m, 4.11-4.01 t, 3.86-3.69 m, 3.67-3.59 d, 3.59-3.56 s, 3.19-3.05 q, 1.50-1.44 s, 1.44-1.38 s; **NMR 13**

Starting Material Reference NMR Data

Trimethyl orthoformate HNMR: 4.98 s, 3.34 s, 1.61 s

Glycerol HNMR: 4.85-4.60 m, 3.60-3.45 d, 1.95-1.80 t, 1.55 s

Cyclohexane carbonyl chloride HNMR: 2.83-2.66 m, 2.19-2.03 dd, 1.9-1.15 m; CNMR: 176.82, 55.07, 29.27, 25.54, 25.09

Deuterated Chloroform (solvent) HNMR: 7.40-7.20 m; CNMR 129.5-127

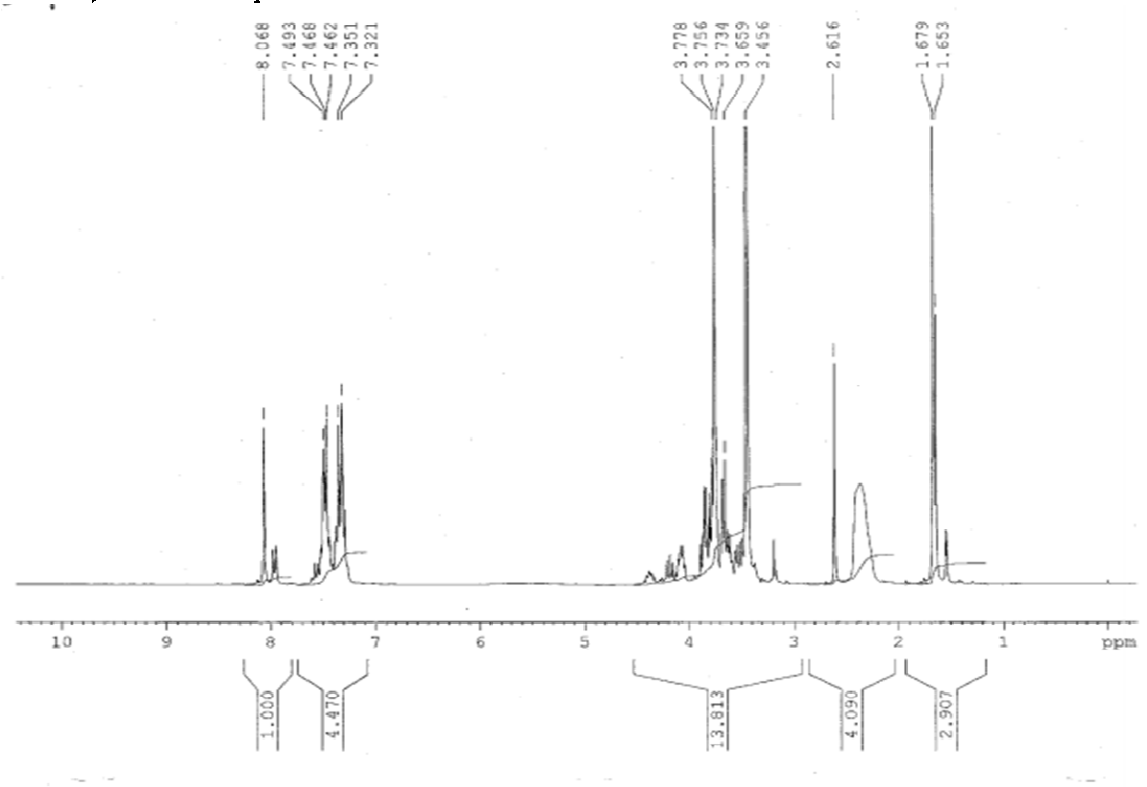
References

1. "Biodiesel." *Wikipedia, The Free Encyclopedia*. Wikimedia Foundation, Inc. 17 Jan. 2013. Web. 18 Jan. 2013.
2. "Glycerol." *Wikipedia, The Free Encyclopedia.* Wikimedia Foundation, Inc. 2 May 2014. Web. 3 May 2014.
3. Ciriminna, Rosaria, Cristina Della Pina, Hiroshi Kimura, Mario Pagliaro, and Micele Rossi. "From Glycerol to Value-Added Products." Angewandte Chemie. *Wiley Interscience*, 2007: 4434-4440. Web. July 2012.
4. Graham, Andrew E., Tomasz M. Kubczyk, and Brendan M. Smith. "Metal triflate catalysed acetal exchange reactions of glycerol under solvent-free conditions." *RSC Advances*. The Royal Society of Chemistry, 21 Feb. 2012: 2702-2706. Web. 13 July 2012.
5. Uwe J. Meierhenrich. *Amino acids and the asymmetry of life*. Springer, Heidelberg, Berlin, New York, 2008. Web 20 Apr. 2014.
6. McCague, Ray, Andy Richards. "The impact of chiral technology on the pharmaceutical industry." *Chemistry and Industry*. 2 June, 2007. Web. April 2014
7. Laskar, Dhrubojyoti Dey, Dipak Prajapati, and Jagir S. Sandhu. "Cadmium Iodide and Efficient Synthesis of Acetals under Microwave Irradiations." *Chemistry Letters*. The Chemical Society of Japan, 28 July 1999: 1283-1284. Web. 4 June 2013.
8. Sigma-Aldrich Catalog. http://www.sigmaaldrich.com/catalog/product/aldrich/122696?lang=en&region=US, 23 June 2013. Product Number – 122696.
9. J.A. Dale et al. *Sigma-Aldrich*. The Journal of Organic Chemistry, 1969: vol 34, 2543. Web. 4 April, 2014.

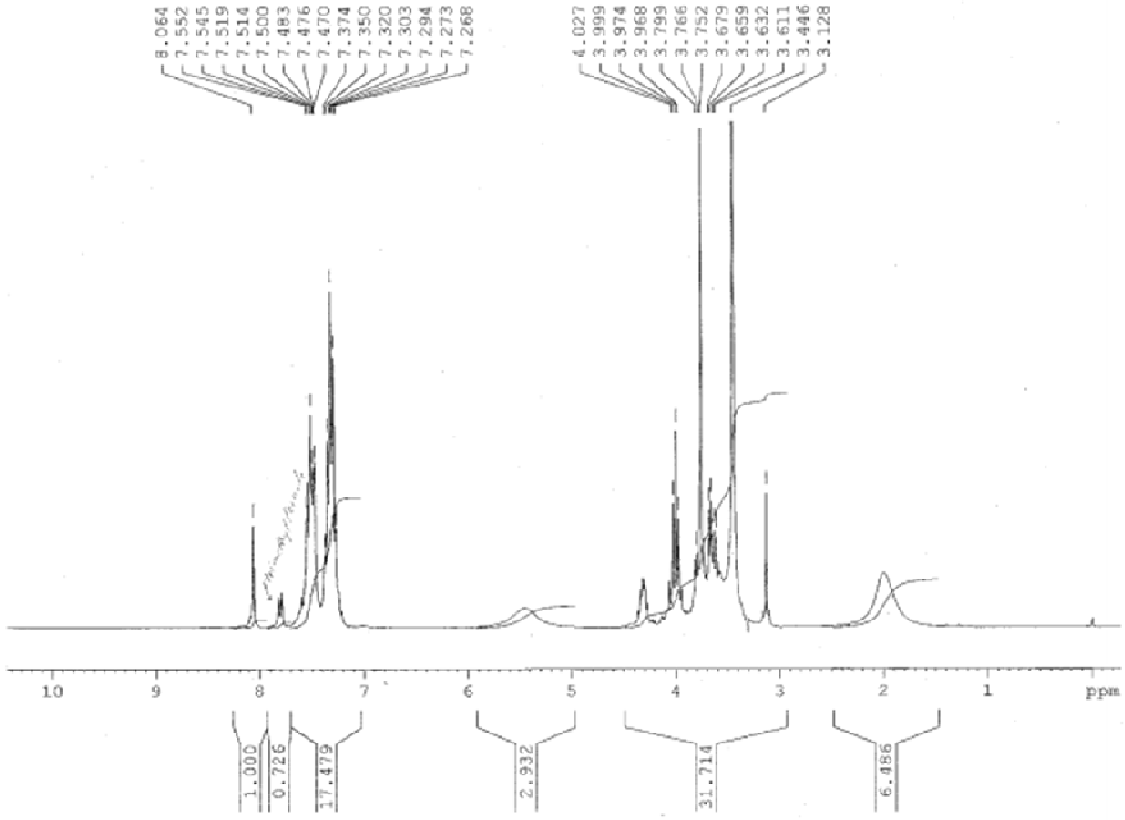
Supplemental Information: HNMR and CNMR spectra of notable reactions

HNMR (Hydrogen Nuclear Magnetic Resonance) and CNMR (Carbon Nuclear Magnetic Resonance) spectra were collected on a Bruker AVANCE 250 MHz NMR with BVT variable temperature unit and multinuclear, 1H and dual 1H / 13 C 5mm probes. All NMR samples were run in $CDCl_3$

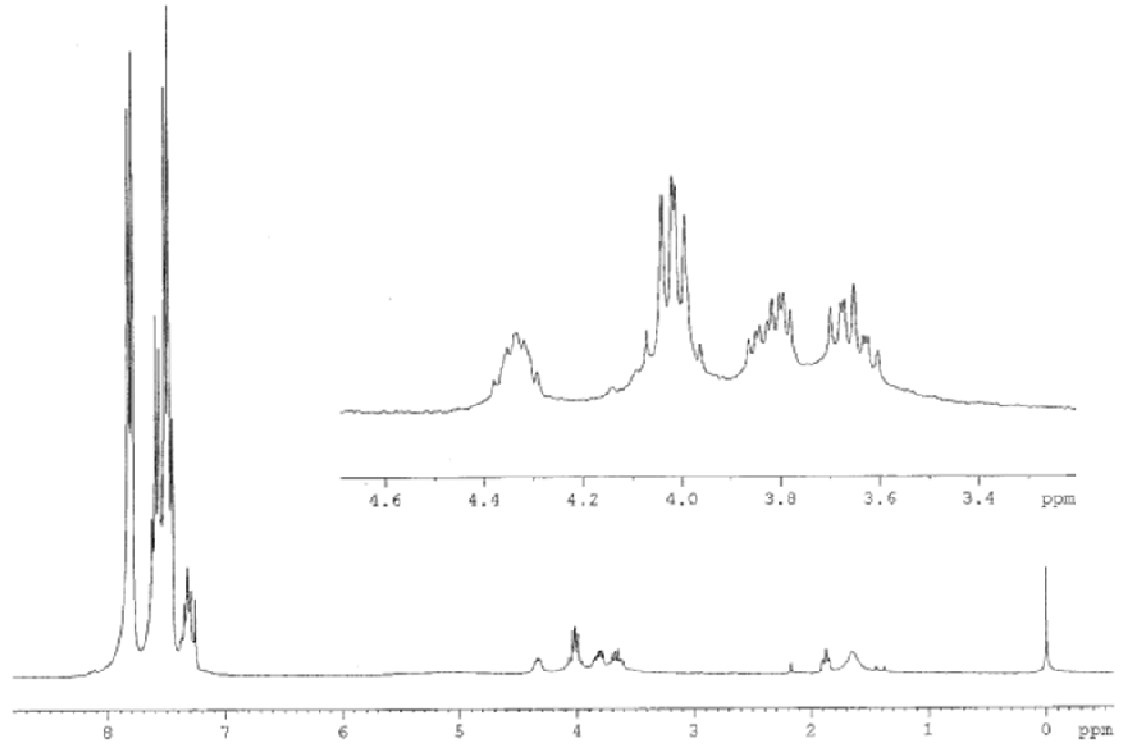
NMR 1.) HNMR: Acetophenone acetal



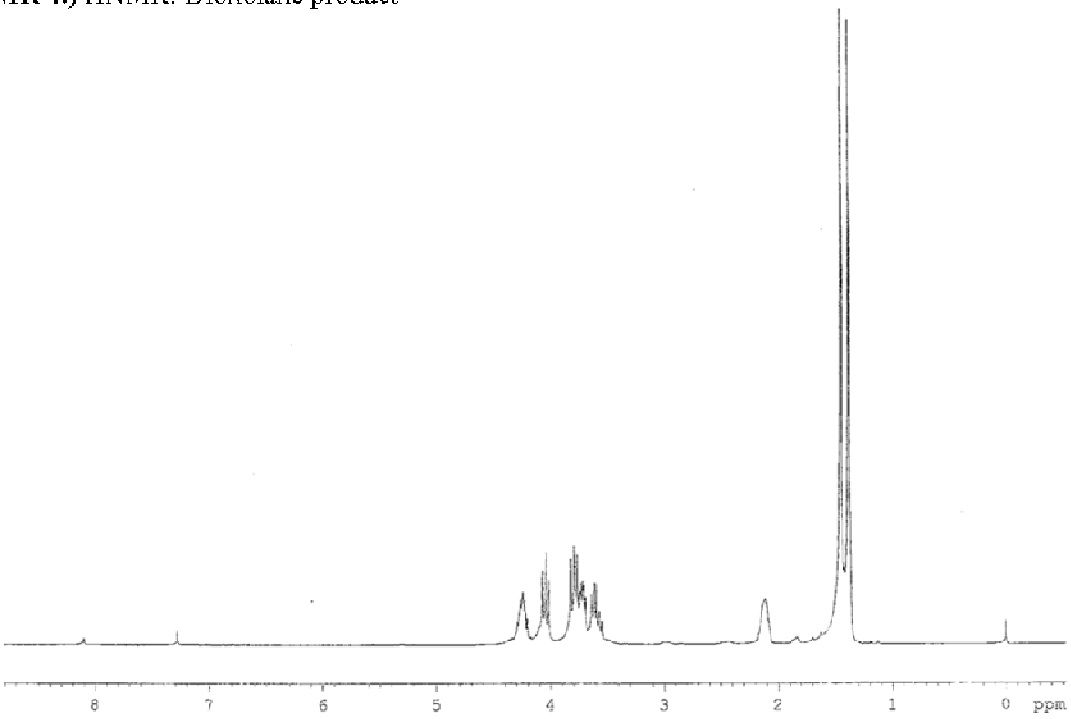
NMR 2.) HNMR: Benzophenone acetal



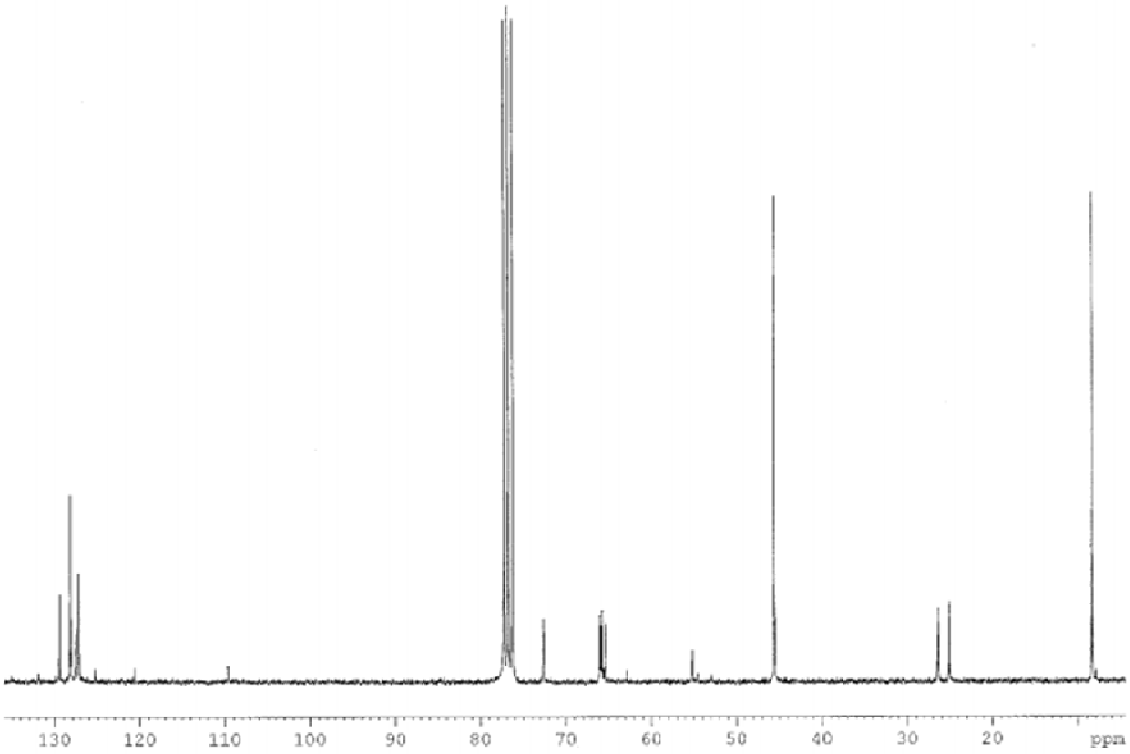
NMR 3.) HNMR: Benzophenone acetal alternate reaction with Cadmium Iodide catalyst



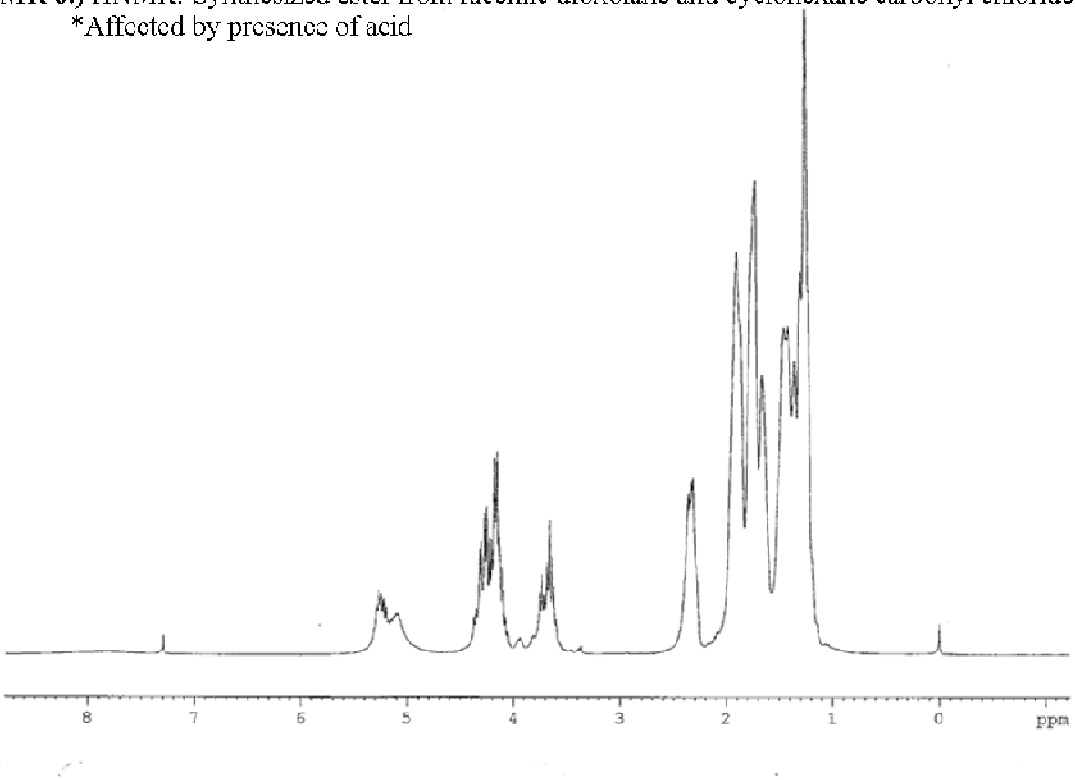
NMR 4.) HNMR: Dioxolane product



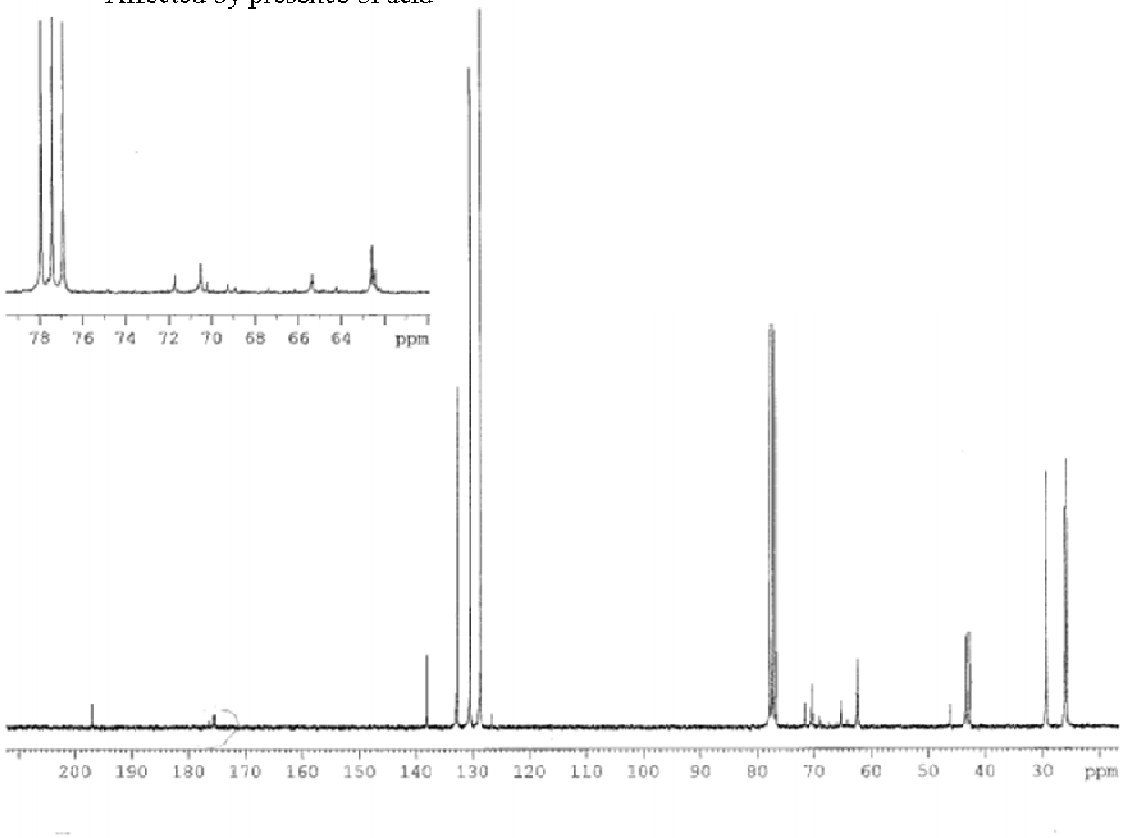
NMR 5.) CNMR: Dioxolane product



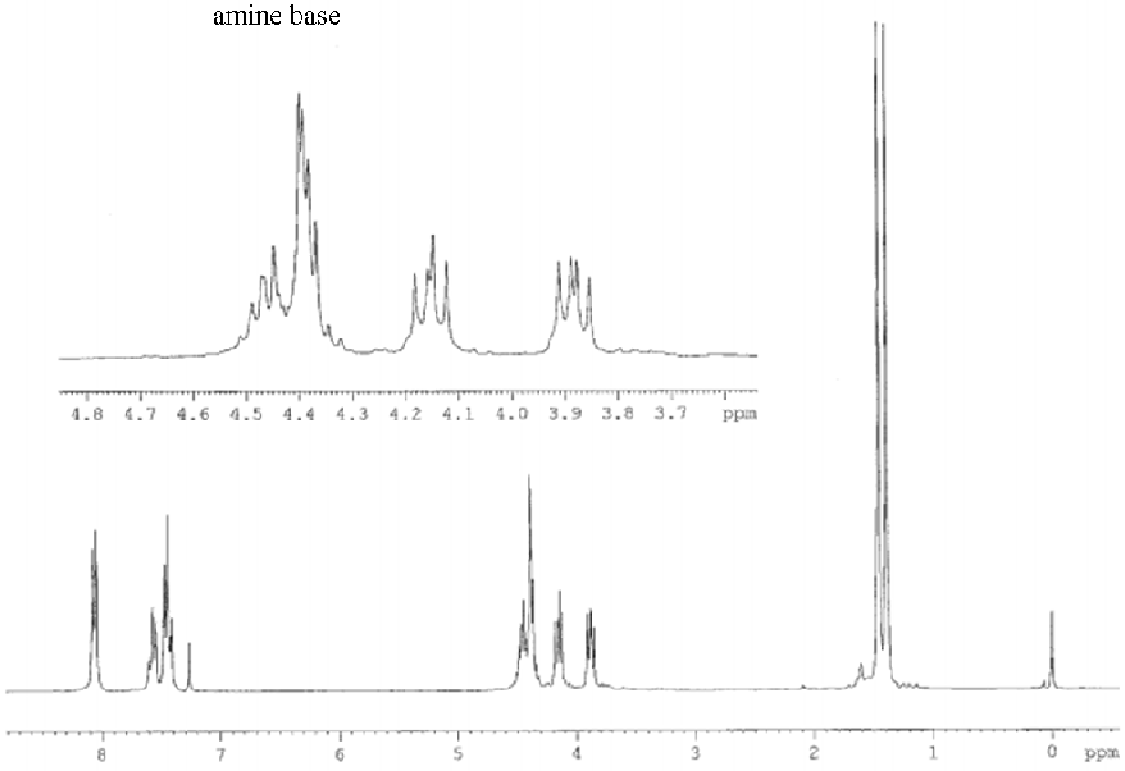
NMR 6.) HNMR: Synthesized ester from racemic dioxolane and cyclohexane carbonyl chloride
*Affected by presence of acid



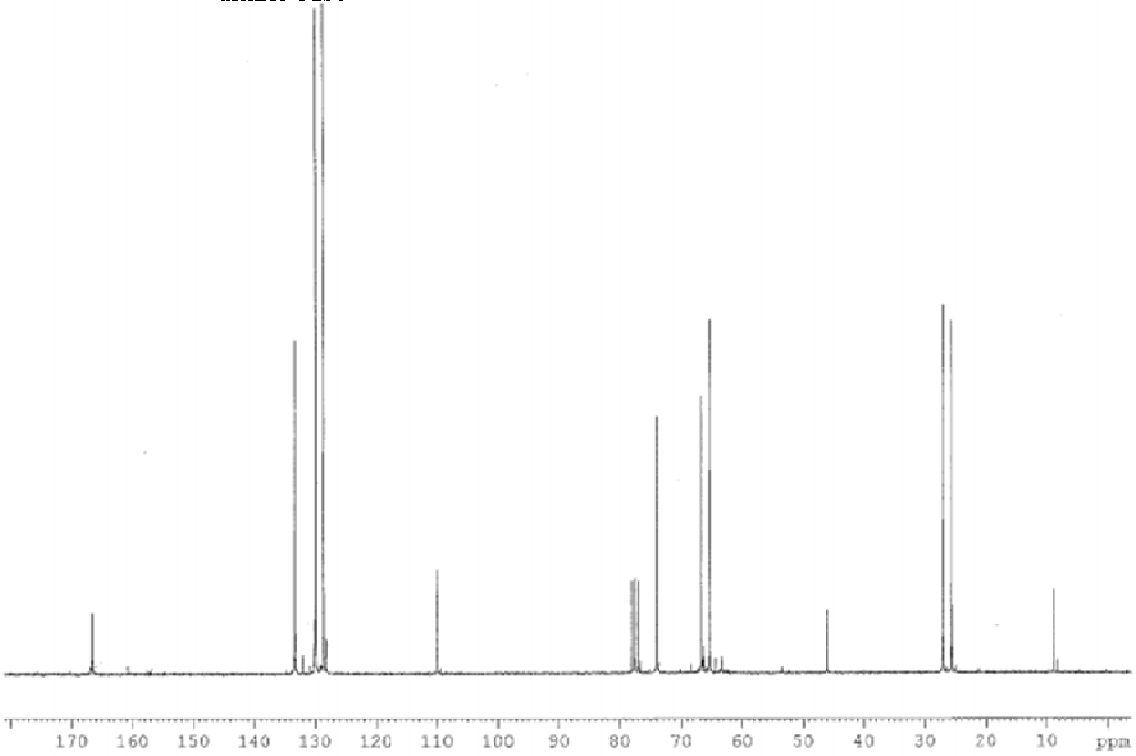
NMR 7.) CNMR: Synthesized ester from racemic dioxolane and cyclohexane carbonyl chloride
*Affected by presence of acid



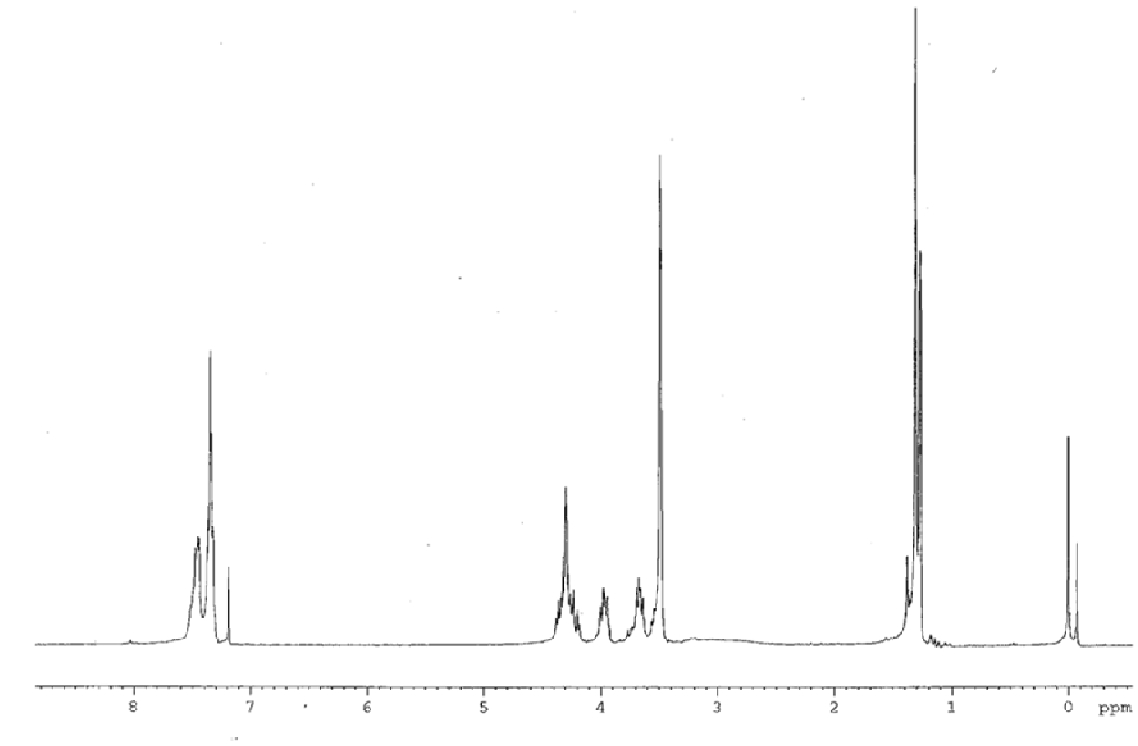
NMR 8.) HNMR: Synthesized ester from racemic dioxolane and benzoyl chloride using an amine base



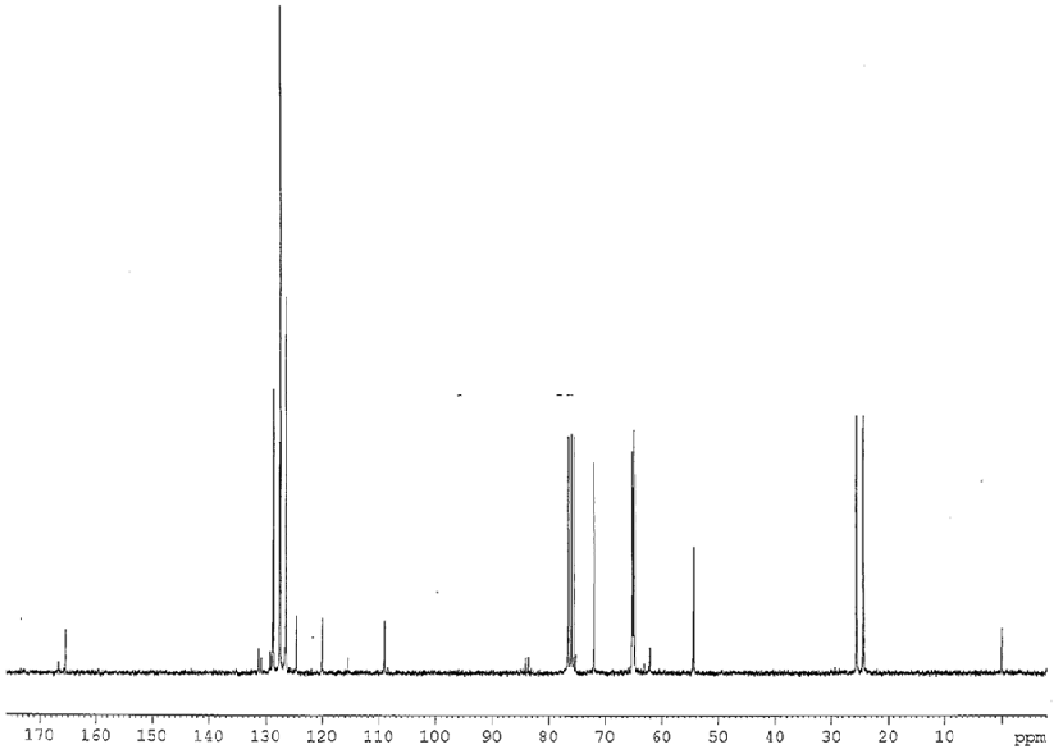
NMR 9.) CNMR: Synthesized ester from racemic dioxolane and benzoyl chloride using an amine base



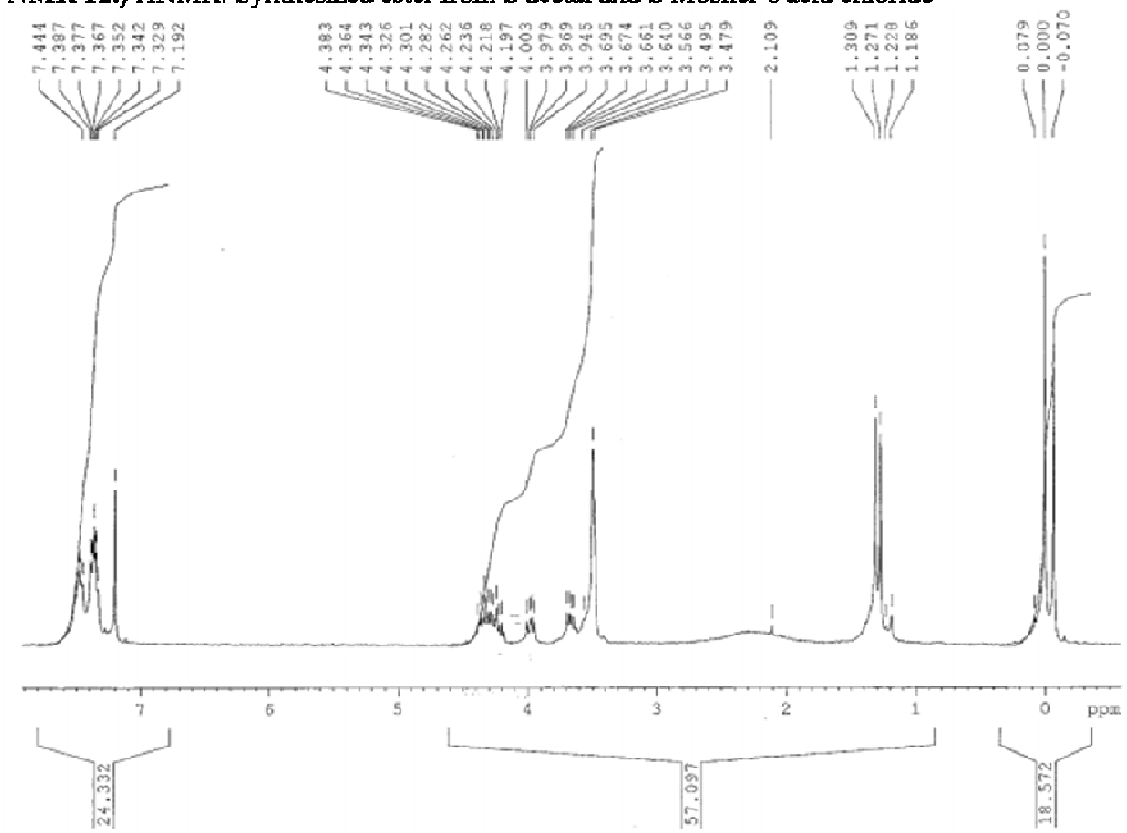
NMR 10.) HNMR: Synthesized ester from racemic dioxolane and S-Mosher's acid chloride



NMR 11.) CNMR: Synthesized ester from racemic dioxolane and S-Mosher's acid chloride



NMR 12.) HNMR: Synthesized ester from S acetal and S Mosher's acid chloride



NMR 13.) HNMR: Synthesized ester from R acetal and S Mosher's acid chloride