Synthesis of Various Catalysts for the Morita-Baylis-Hillman Reaction

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INTRODUCTION

The Morita Baylis-Hillman reaction is a process that has been related to increasing the enantiomer excess of the molecules synthesized. This reaction is a condensation of an acrylate ester and an aldehyde forming a α-methylene-β-hydroxy ester as seen in **Figure 1**. This reaction as stated above is particularly useful to synthetic chemists for its ability to synthesize chiral molecules in a surrounding involving a chiral catalyst. This chiral catalyst generally is a tertiary amine or phosphine based on known literature. These catalysts act as a ligand binding on to the specific aldehyde and acrylate ester using its bifunctional properties.[1]

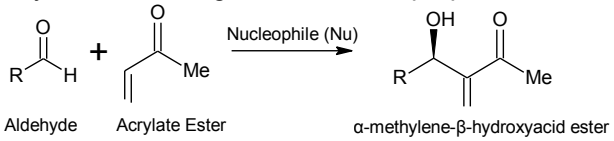


Figure 1. The Morita Baylis-Hillman reaction involving the condensation of an aldehyde with an acrylate ester to form an α-methylene-β-hydroxy ester.

The imine ligand catalyst that would be synthesized would have both a Lewis acid and a Lewis base part to its structure. These parts act as a binding mechanism to form the α-methylene-β-hydroxy ester. Matsunaga's group found that certain metal complexes would bind on to both parts of the process and this would lead to increased reactivity between the aldehyde and the acrylate ester. They also found that the chirality of the metal complex also made a difference. The more chiral the substance was, the greater the chirality that the subsequent product was in response.[2]

The main downfall of the Morita Baylis-Hillman reaction is the slow reaction speed that the process takes. A chiral metal ligand has also been found to reduce the activation energy need for this reaction by drawing the two components closer to each other, thus increasing the reaction rate that the reaction follows. This is shown in **Figure 2**, where the lanthanide metal is the Lewis acid that combines both the aldehyde and the acrylate ester together.[3]

The Morita Baylis-Hillman reaction itself follows a Michael Addition by a tertiary amine on an α,β-unsaturated carbonyl. The resulting zwitterion incorporates both a positively charged and negatively charged portion of the overall molecule; this molecule serves also as an active enolate nucleophile. This will then attack the carbonyl carbon of an aldehyde. After the creation of the carbon-carbon bond through

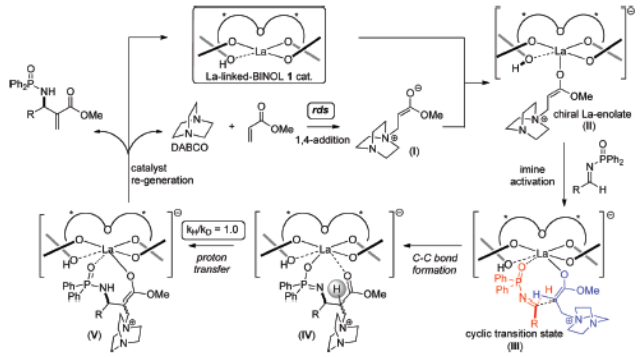


Figure 2. Scheme for the Morita Baylis-Hillman reaction utilizing a bifunctional metal ligand complex as a catalyst

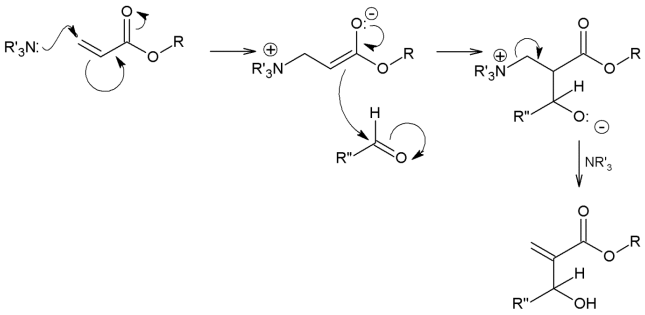


Figure 3. Mechanism for the Morita Baylis-Hillman reaction: acrylate ester binds onto a tertiary amine through a Michael addition and attacks an aldehyde—the resulting product goes through eliminate to form the carbon-carbon double bond.

attaching the zwitterion and the aldehyde, the tertiary amine will then be removed through elimination forming a double bond in its place (**Figure 3**).[3]

The following principles are applied to the Morita Baylis-Hillman reaction that will improve the reaction rate that will occur. First is that the subsequent hydrogen bonding or Lewis acid complex that pulls the electron density from the carbon-oxygen bond in the aldehyde which results in an oxygen atom having a heavy positive charge. This assists in binding the aldehyde to the acrylate ester since the zwitterion created would have the negative charge that would bind on to the increased positive charge that the aldehyde would now have. This increases the reaction rate and produces the product faster.[4]

Bulkier chains have also been found to increase the stereospecificity of the products from the Morita Baylis-Hillman reaction. This bulkier back bone would also prevent the attack of either reagent onto other binding areas on the catalyst. In this study a larger back bone will be used in comparison to other studies done on the subject.

Another addition would be making the catalyst a Schiff base ligand, and there are three separate benefits to this change. First would be the structural modularity which allows for facile preparation of catalyst libraries. They also have a non-C_2-symmetric structure which allow for diversification in their uses. Finally, the availability of multiple Lewis acid binding sites raises the possibility of multifunctional catalysis. All three of these help to improve the functionality of the catalyst to improve the reaction rate that the Morita Baylis-Hillman reaction functions on. They also help to establish great enantioselective products based on how enantioselective the catalyst that is used is.[5]

The Morita Baylis-Hillman reaction is also a good test for the creation of a method for a protein catalyst. This catalyst would both be slow and involve a multistep reaction where no such catalyst yet exists. The application into the Morita Baylis-Hillman reaction falls under enzyme work and many other biological activities.[6] With these biological application, the Morita Baylis-Hillman reaction adducts have three functional groups in close proximity. With manipulation of these groups, these functional groups can undergo tuning to generate an array of pharmacologically important compounds. These compounds include γ-lactam, γ-butyrolactone, epoxides, and azides. The Michael acceptor groups present in these adducts offer further scope for the creation of a certain type of artemisinin. There have been recent studies by the Barua group that supports certain Artemisinin groups having in vitro anticancer activity in a panel of human cancer cell lines. These Artemisinin were very potent in inhibiting the growth of certain human cancer cell lines and were comparable to clinical anticancer drugs. They can even be used as a precursor for the synthesis of libraries of new analogs and this includes dimers.[7]

There are also certain studies that show the Morita Baylis- Hillman reaction proving to be useful in synthesizing naturally found chemicals in plants. There has been much study of using this pathway to synthesize many natural products; however, there have been very few relations to synthesizing natural drugs. The reaction itself can be utilized for the synthesis of natural drugs and be substituted for extracting the drugs from plants.[8]

Carbon-Carbon reactions are fundamental reactions in the world of organic chemistry. There are several divisions of carbon-carbon reactions, but arguably two of the most prominent are the Aza-Morita-Baylis-Hillman reaction[9] as well as the Morita-Baylis-Hillman reaction[10] (**Figure 4** and **5**).

Using the aza-Morita-Baylis-Hillman reaction an appropriate Schiff base ligand can be synthesized

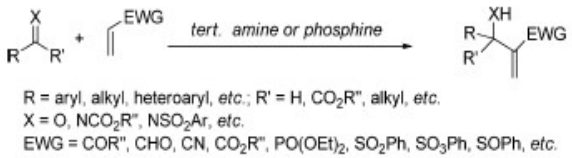


Figure 4. Morita-Baylis-Hillman reactions consist of the formation of α-methylene-β-hydroxycarbonyl compounds by addition of α ,β- unsaturated carbonyl compounds to aldehydes catalyzed by tertiary amine or phosphine

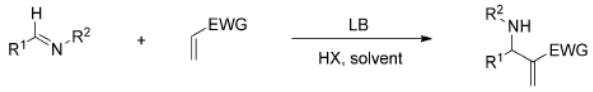


Figure 5. The Aza-Morita-Baylis-Hillman differs in that the imine group participates in place of the aldehyde

with substantial yield. After synthesizing a proper ligand, the ligand would then be complexed with a metal to determine the binding rate using the Job plot method. Job plots or the method of continuous variation is performed using two solutions and UV visible spectroscopy. When two solutions are mixed in different proportions, different absorbance will be measured. By converting the volume of the two solutions to mole fraction you can then plot the data and determine the binding rate of the two solutions.[11]

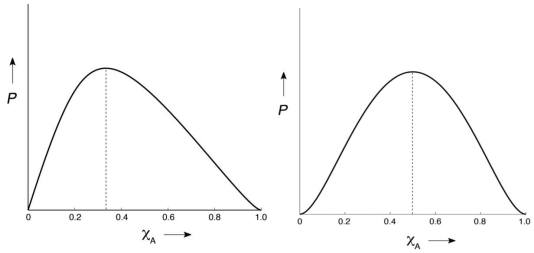


Figure 6: Graph displays absorbance vs. mole fraction where peak is exactly at 0.5 molar translating to a 1:1 binding ration Figure 2: Graph displays absorbance vs. mole fraction where peak is exactly at 0.33 molar translating to a 2:1 binding ration

As you can see in **Figure 6**, the plot of absorbance versus molar fractions displays a clear representation of binding ratio. However, the process for producing job plots is time consuming consisting of prepping many samples. The goal of this project was to find new ways to refine the process by making it faster with no change in accuracy. With this insight from the literature, it was deduced that a continuous job plot in the form of a titration could potentially be a repeatable experiment that would be more efficient than that of the original method.[12-17]

A Schiff base is a compound with a functional group that contains a carbon-nitrogen double bond

with the nitrogen atom connected to an aryl or alkyl group. Schiff bases can be synthesized from an aliphatic or aromatic amine and a carbonyl compound by nucleophilic addition forming a hemi-aminal, followed by a dehydration to generate an imine. They are used for detection and determination of aldehydes or ketones, purification of carbonyl or amino compounds, or protection of these groups during complex or sensitive reactions. Schiff bases are generally bi-or tri- dentate ligands capable of forming very stable complexes with transition metals. Some are used as liquid crystals. In organic synthesis, Schiff base reactions are useful in making carbon-nitrogen bonds. Schiff bases appear to be an important intermediate in a number of enzymatic reactions involving interaction of an enzyme with an amino or a carbonyl group of the substrate One of the most important types of catalytic mechanism is the biochemical process which involves the condensation of a primary amine in an enzyme usually that of a lysine residue, with a carbonyl group of the substrate to form an imine, or Schiff base. More specifically Salen ligands, a type of Schiff base, are usually prepared by the condensation of a salicylaldehyde with an amine. Unsubstituted salen complexes are poorly soluble in organic solvent. The presence of bulky groups near the coordination site is generally desirable, as it enhances catalytic activity and prevents dimerization. Chirality may be introduced into the ligand either via the diamine backbone, via the phenyl ring, or both.

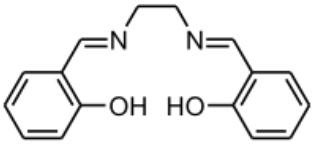


Figure 7. Salen ligand from salicylaldehyde and ethylenediamine

A possible route to creating an asymmetric catalyst involves epoxidation. An epoxide is a cyclic ether with a three-atom ring. This ring approximates an equilateral triangle, which makes it highly strained. The strained ring makes epoxides more reactive than other ethers. Most epoxides are generated by treating alkenes with peroxide-containing reagents, which donate a single oxygen atom. The carbon atoms of an epoxide are approximately sp3-hybridized, and thus may be stereogenic positions. Depending on the mechanism of the reaction and the geometry of the alkene starting material, cis and/or trans epoxide diastereomers may be formed. In addition, if there are other stereocenters present in the starting material, they can influence the stereochemistry of the epoxidation relative to them.

The overall MBH reaction utilizes the Schiff base ligands to make salen ligands which are then used to synthesize a MBH ligand. An epoxide reaction will then be used to further make an asymmetric catalyst. A metal ion will then be complexed with the ligand to make the full catalyst complex. According to literature the complex should yield a green precipitate. After the complex is formed and isolated, a Job plot will be done on it. For continuous titrations, Job plot methods, the total molar concentration of the two binding partners are held constant, but their mole fractions are varied. An observable that is proportional to complex formation, such as absorption, is plotted against the mole fractions of these two components. The maximum on the plot corresponds to the stoichiometry of the two species, if sufficiently high concentrations are used. There are several conditions that must be met in order for Job's method to be applicable: The system must conform to Beer's law, one complex must predominate under the conditions of the experiment, the total concentration of the two binding partners must be maintained constant, and the pH and ionic strength must be maintained constant.

Simple job plots on Ni^{2+} and EDTA were done using UV-Vis spectroscopy to demonstrate and practice for later use. Other Job plots on Praseodymium and copper were attempted but no absorption signal was obtained. Job plots on the MBH reaction with the catalyst complex will be performed hopefully in the next attempt because lack of time did not allow for them to be done during this project period. The completed project involved synthesizing Schiff base ligands, making those ligands into salen ligands, complexing a metal to the ligand to make a catalyst complex and using said complex to catalyze a MBH reaction involving and opening of an epoxide ring.

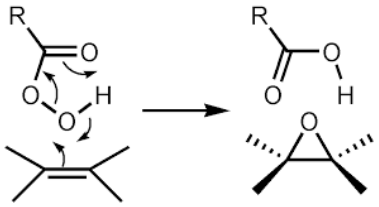


Figure 8. An example epoxidation reaction showing the formation of a strained ring

Methods and Materials

All syntheses used chemicals that were not previously purified or altered, and all were acquired from Sigma-Aldrich. All of the syntheses were carried in a single fume hood and were conducted with the same glass ware for all of the experiments done. A rotary evaporator, FT-IR spectrometer, and NMR spectrometer were all constant and used throughout the process. Some of the processes were taken from Adolfsson's article[10] and other procedures were taken from other articles to substitute for the deprotection phase of the experiment.[18]

Synthesis of Tridentate Imine Complexed Ligand

Synthesis of 1-Pyrrolidinecarboxylic acid, 2-[[[3-(1H-imidazol-1-yl)propyl]amino]carbonyl]-, 1,1-dimethylethyl ester, (2S): The N-Boc-L-proline (10 mmol,1.78 g) was put into a THF solution (30 mL) and submerged into a -15°C ice bath. Potassium carbonate (15 mmol, 1.965 g) and Isbobutyl chloroformate (15 mmol, 1.95 mL) were slow dripped into a THF solution. The solution stirred for 45 minutes, and 1-(3-aminopropyl)imidazole (15 mmol, 1.789 mL) was added to the solution then stirred at room temperature for 3 hours. The solution was washed with through silica gel by ethyl acetate, and then reduced under pressure. TLC is done on the product to test purity and separation of the resulting products. The products are then separated through column chromatography.

Synthesis of Product (1): The Boc-L-α-phenylglycine (10 mmol, 2.51 g) was put into a THF solution (30 mL) and submerged into a -15°C ice bath. Potassium Carbonate (15 mmol, 1.965 g) and Isbobutyl chloroformate (15 mmol, 1.95 mL) were slow dripped into a THF solution. The solution stirred for 45 minutes, and 1-(3-aminopropyl)imidazole (15 mmol, 1.789 mL) was added to the solution then stirred at room temperature for 3 hours. The solution was washed with through silica gel by ethyl acetate, and then reduced under pressure. TLC is done on the product to test purity and separation of the resulting products. The products are then separated through column chromatography.

Deprotection of Product (1) forming Product (1a): Product (1) (5 mmol, 1.79g) was dissolved in a 1:1 mixture of MeOH:HCl (3M) and chilled to 0°C. This solution was stirred for 3 hours, and the solution was reduced under pressure to evaporate the MeOH. The aqueous phase was treated with 6.5 mL of 50% NaOH solution slow dripped for 2 hours at 0°C to adjust to a pH of 12. This was washed with 12 mL of CH_2Cl_2 four times. The organic layer was then dried with K_2CO_3. The solution was then reduced under pressure.

Synthesis of Product (2): Product (1a) (1 mmol, 0.258 g) was dissolved in 30 mL MeOH and added to a solution of salicylaldehyde (1.5 mmol, 0183 g) and 30 ml MeOH. Formic acid was added and the solution stirred for 7 days. The resulting solution was tested through TLC and then put through Column Chromatography using a 70:30 EtOAc : Hexane eluent.

Synthesis of Product (3): Product (2) (0.5 mmol, 0.181 g) was dissolved in 30 mL MeOH and placed into reflux using a heating mantle at 60°C. Copper (II) Acetate (1 mmol, 0.188 g) was dissolved in MeOH and slow dripped into the Product (2) solution. The resulting solution was set in reflux for 3 hours and then cooled to room temperature. The resulting solids were filtered and the liquid was reduced under pressure for the production of crystals.

Synthesis of Chiral Peptidal Hemi-Salen Ligands

Synthesis of the N-[(1S)-1-({[(1R)-2-hydroxy-1-phenylethyl-]amino}carbonyl)-2-methyl-propyl]carbamate product: 6.25 g of N-Boc-L-Valine was mixed with 60mL of THF into a round bottom flask. Potassium carbonate (6.22 g) and isobutylchloroformate (4.62 mL) were added slowly to the reaction mixture at ---15.0°C. The new mixture then stirred for 45 minutes when 3.58 mL of 1-(3-aminopropyl)-imidazole at room temperature, where the reaction mixture stirred for three hours. The product was then rinsed with 40 mL of ethyl acetate and evaporated under vacuum. Thin layer chromatography was performed using silica tubing to add drops of the product, boc-valine, and imidazole that had been diluted with methylene chloride. The TLC was placed in a small amount of 75:25 ethanol: hexane mixture. The paper was then placed under UV light for a better observation.

The previous synthesis was rerun with half the original amounts and using N-methylmorpholine as the base. NMM (1.97 mL) was added slowly with 2.31mL isobutylchloroformate to the reaction mixture. After the imidazole was added, it was allowed to stir for three hours. Due to the product showing signs of being the desired product, column chromatography was run in order to purify the product. The reaction product was dissolved in 20 mL of methylene chloride and mixed with 5 g of silica gel, which was then rotovaped resulting in a reaction powder mixture. The column was then prepared by adding a small piece of cotton ball to prohibit sand from flowing out of the column. One inch of sand was added on top of the cotton ball, and then 6 inches of silica gel was added. The column was then washed with 100% hexane followed by a 100% ethyl acetate. A 75% ethyl acetate 25% hexane mixture was then prepared and used to wash the column to adjust polarity. The reaction powder mix was added to the column followed by a half inch of sand. The column was then

wash with the ethyl acetate hexane mixture and was collected into vials.

Deprotection: The 0.45 g of product was dissolved in 15 mL of methanol, which was then added to 20 mL of HCl at 0°C. The solution was stirred for three hours and then rotovaped. Two mL of a 50% sodium hydroxide solution was added over two hours. The desired deprotected product was extracted with methylene chloride and dried with potassium carbonate. The sample was purified through column chromatography. After column, the sample was deprotected using the same procedure as allude to above.

Synthesis of Schiff base ligand: 0.244 mL of Salicylaldehyde was weighed out into a small beaker. 5 mL of methanol was used to transfer the Salicylaldehyde to a RB flask with the deprotected product. Beaker was washed with an extra 5 mL of methanol to ensure Salicylaldehyde was transferred completely. One drop of formic acid was added to solution; it was then covered and allowed to stir for two days.

Job Plot Titration:Cu_SO_4 and EDTA solutions were prepared using an acetic acid and sodium acetate buffer. The buffer solution is comprised of 0.025M of both acetic acid and sodium acetate translating to 0.715 mL of HOAc and 1.701 g of NaOAc per liter of deionized water. 0.005M EDTA solution was made using 0.19 g of EDTA in a 100 mL volumetric flask filled to the fiduciary mark with buffer, while 0.624g of Cu_SO_4 was added to a 500 mL volumetric flask filled to the fiduciary mark with the buffer. After the solutions were prepped, the apparatus for the experiment were set up. A unique cuvette with an in and outflow was connected to plastic tubing in which the inflow was connected to the outflow of the peristaltic pump. The outflow of the cuvette lead from the cuvette to a 200 mL tall beaker using another plastic tube. A third plastic tube was used to connect the beaker to the inflow of the peristaltic pump. The setup allowed for a continuous flow from beaker to pump, from pump to cuvette, and finally cuvette back to beaker, allowing us to titrate the solution in the beaker and take a sample using the UV visible spectrometer without removing the beaker. 30 mL of EDTA solution was titrated with 100 mL of Cu_SO_4 solution 5 mL at a time. A sample was then taken two minutes after each 5 mL was added allowing the solution in the beaker to equilibrate. After the sample was taken, the amount of titrant used and absorbance was recorded based of peaks in the 700 to 800 nm range. The experiment was then reproduced with a change in the range of the spectrum due to the inconsistency in the peaks recorded. Using the same copper and EDTA solutions the job plot titration was then replicated.

A tetraethylammonium bromide buffer was produced in acetone. Copper and ligand solutions were prepared in the buffer for the second trial of the job plot. 5.254 g of tetraethylammonium bromide was dissolved in one liter of acetone. 4.54 g of cupric sulfate was then dissolved in a 500 mL volumetric flask with the buffer solution.

Morita Baylis Hillman Reaction:

P-nitrobenzaldehyde (.5 mmol) and benzimidazole (.5 mmol) in THF were stirred and 1M $NaHCO_3$ in round bottom flask. Stir p-chlorobenzaldehyde (.5 mmol) and benzimidazole (.5 mmol) in THF and 1M $NaHCO_3$. Add cyclopentene (.75 mmol) to both mixtures. Stir at normal conditions for 392 hrs. Quench reaction with 1M HCl and extract with ethyl acetate (3mL*3). Dry over anhydrous Na_2SO_4. Use gravitational filtration and purify under reduced pressure. Perform thin layer chromatography to characterize.

Preparation of Schiff Base Ligands:

First Method: Add .7mL of N-imidazole to three round bottom flasks. Add 5-chlorosalicylaldehyde (.004 mmol), 3, 5-di-tert-butyl-2-hydroxybenzaldehyde (.004 mmol), salicylaldehyde (.004 mmol) to respective flasks. Stir in with 10 mL of methanol. Add 2 drops of formic acid to each flask. Cover mixture and stir at room temperature for 168 hrs. Do TLC on mixtures after two days to evaluate. Purify under reduced pressure and use column chromatography to separate and purify product.

Second Method: Add 1.4 mL N-imidazole in 25 mL round bottom flask. Add .008mmol salicylaldehyde to beaker and add 5 mL ethanol to beaker. Transfer solution from beaker to round bottom flask. Add 4-6 drops formic acid and stir at room temperature.

Third Method: Weigh 1.25 g of N-imidazole and add 10 mL ethanol. Add 1.22 g of salicylaldehyde in 20 mL ethanol. Combine both solutions into round bottom flask. Let solution reflux for six hours. Distill to remove ethanol. Filter and dry over vacuum.

Column chromatography of Schiff Base Ligands: Add ~20 mL methylene chloride to reaction mixture. Add ~ 5g of silica gel and purify under reduced pressure. Prepare column, add reaction mixture and use solvent 50/50 ethyl acetate/hexane. Run column, take fractions with Schiff base ligand product and characterize with NMR spectroscopy.

Continuous titration of Ni2+ and EDTA: Make 0.025M HOAc/NaOAc buffer solution. Make 0.005M titrant and titrand. Set up UV-Vis with continuous titration apparatus. Run UV-Vis on time dependent variation for two minutes. Start with 30 mL's of titrand. Add 5 mL of titrant into beaker every two minutes and let solution stir and take spectrum. Add 5 mL's until 100 mL's is done. Plot mL of Ni^{2+} vs absorbance and convert to mole fraction.

Epoxide Ring Opening Reaction w/ Catalyst Complex: Add .012 mol styrene oxide to a round bottom flask. Add .0012 mol cyclopentenone. Add 25 mL THF and stir at room temperature. TLC after 1 day. Add catalyst complex and let run for 2 days.

DISCUSSION AND CONCLUSION

There are several advantages to using this product as the catalyst for the Morita Baylis-Hillman reaction, and taking a look at the process to make the catalysts.

Synthesis Attempt of Tridentate Imine Ligand:

The original reaction required that we use N-methylmorpholine, but NMM would be too weak of a base and would cause the reaction rate to fall when coming into contact with the Boc-L-α-phenylglycine. Thus, a new base would need to be chosen for the reaction to work with removing the OH group off of the amino acid. A suitable substitute for this reaction is potassium carbonate as seen in **Figure 9**, which is a stronger base than the N-methylmorpholine. The isobutyl chloroformate was not only attacking the Boc-L-α-phenylglycine but was also attacking the N-methylmorpholine as well. Changing the base that was used helped to improve the reactivity of the reaction itself to increase the yield of the product.

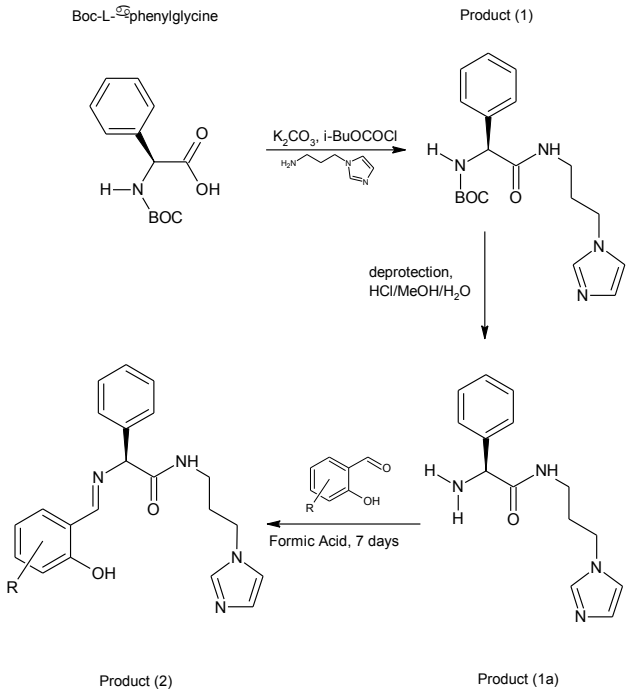
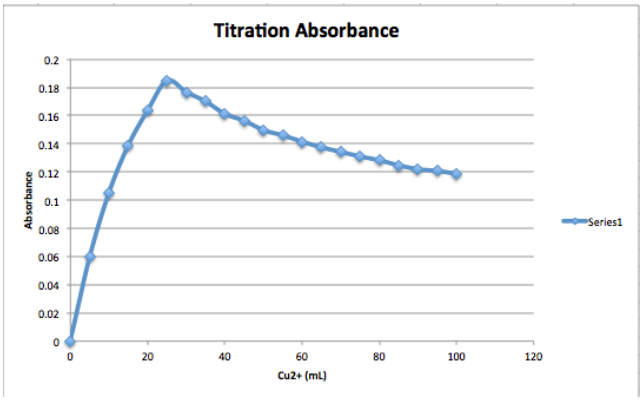


Figure 9: Overall Scheme for synthesizing Product (1), Product (1a), and Product (2)

When deprotecting the product, we split the product into two batches in case the reaction to deprotect it did not work. In this case the product was not deprotected according to NMR characterization.There needs to be further research done on the method for synthesizing these compounds.

Synthesis of Chiral Peptidal Hemi-Salen Ligands and Job Plots:

A surprisingly small amount of product was recovered after the first experiment. The original synthesis called for N-methylmorpholine as the base, but potassium carbonate was used as a substitute. As a result the reaction was allowed to stir for 24 hours instead of the original three hours. After viewing the NMR spectrum it was evident that the correct product was not formed successfully, but after running the column, the desired product was indeed cleaned up, but the amount recovered was so small. It is predicted that the polarity was off resulting in most of the product remaining in the column.



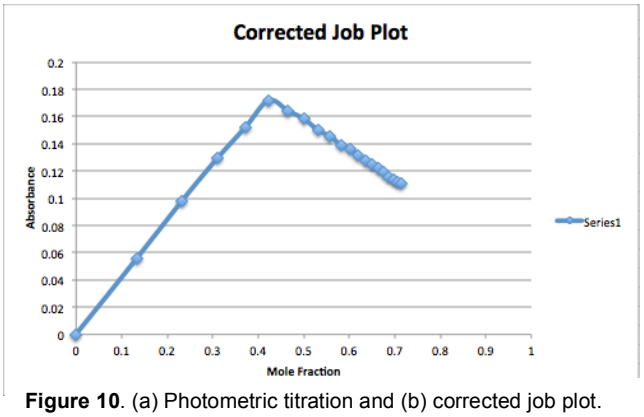


Figure 10. (a) Photometric titration and (b) corrected job plot.

Although only 0.5 g of product was recovered, it was evident that we had deprotected correctly. Next was the preparation of the Schiff Base ligand. The preparation of the Schiff base ligand did not go as hoped. The spectrum shows a substantial amount of impurities within the sample. At this point the synthesis ends and the job plot research has been started in order to make progress (**Figure 10**).

The experiment using the $CuSO_4$ and EDTA solutions was pulled directly from literature and was reproduced. Our results match, both the photometric titration plot and the corrected mole fraction plot, match the literature exactly. Our peristaltic pump setup was successful and harshly cut the time to produce the job plot. Other solutions would have been prepared in order to test the pump system but

solution complications prevented it. However, the peristaltic pump was a huge success, which was much needed after some issues faced previously during synthesis. The materials as well the experiment setup were cost effective and simple allowing most chemists to reproduce the results with little effort and high accuracy.

Preparation of Schiff Base Ligands:

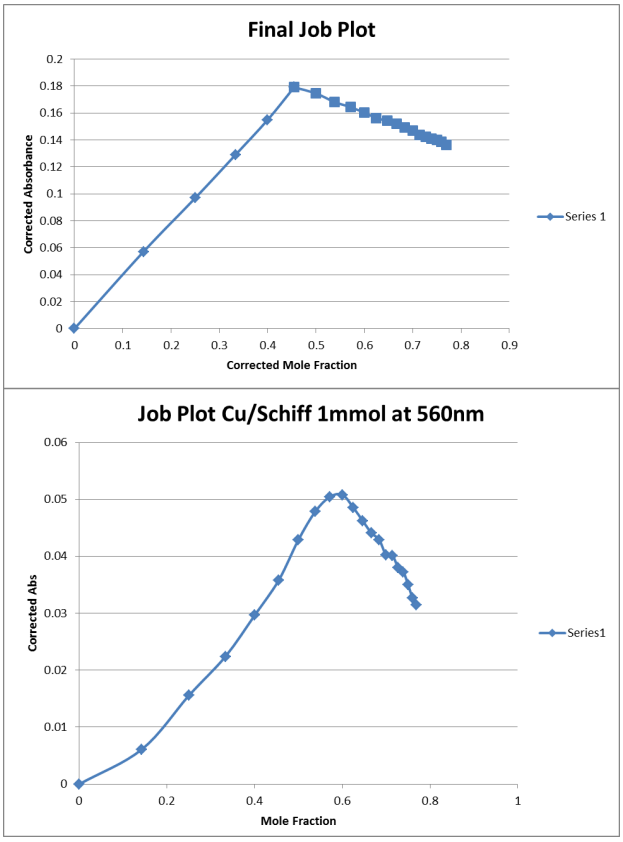


Figure 11. (a) Job Plot of $CuSO_4$ and EDTA and (b) Job Plot of $CuSO_4$ and salicylaldehyde Schiff base.

The synthesis portion of the project posed fewer problems than the Job plot portion of the project. The only Schiff base that seemed to yield a pure product was the salicylaldehyde ligand. After establishing which ligand to use, multiple methods were used to synthesize the same ligand. Large batches were made for complexing the metal because many of the complex products were unusable. After synthesizing the desired ligand and complexing a copper ion to it, the catalyst complex was added to a MBH reaction of cyclopentenone, THF, the catalyst complex, and styrene oxide. Characterization will be done soon, along with a potential Job plot of the rate of the reaction given the percent of catalyst in the reaction. Gas chromatography- Mass spectroscopy will be used to characterize the product of the epoxide ring opening reaction.

A Job plot of the Schiff base ligand and copper was done to find the absorption signal so we could use that for the later epoxide ring opening reaction using the complex (**Figure 11**). Several different variations of Job plots were done using different metals, ionic strengths and solvents. Copper in ethanol yielded the best signal and the complex was soluble in it. Tetrabutylammonium iodide was used to keep the ionic strength constant. After characterization of the epoxide ring opening product, a job plot can be done to find the stoichiometric proportions for the equation. Further analysis will be done in the future.

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