

Testing of Multiple Methods for the Synthesis of Tetradentate Schiff Base Ligands and their Characterization and Metal Coordination

Benjamin W. Lam '17 and Nicholas P. Deifel

Department of Chemistry, Hampden-Sydney College, Hampden-Sydney, VA 23943

Introduction

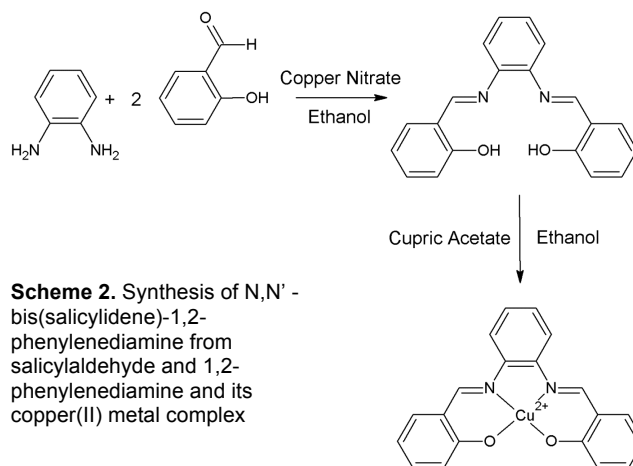
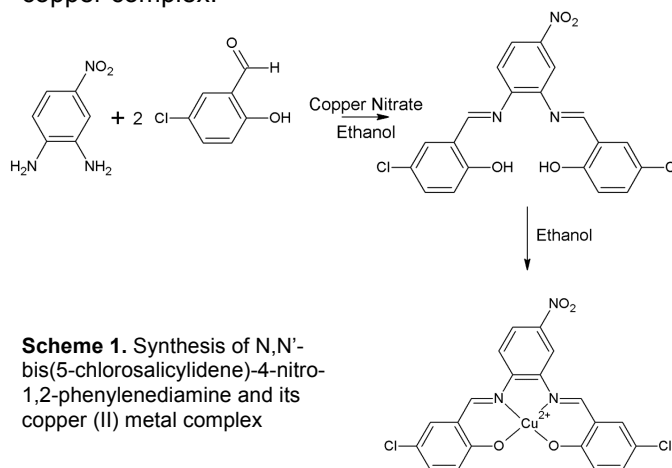
The field of Schiff base ligands is a wide field as it is both a new one and many of the ligands remain undiscovered. Many people study them now due to their simple synthesis and variety of uses. Schiff base ligands are constructed of double-bonded nitrogen to a carbon atom and generally bond an aryl or an alkyl groups. The compound is also a tetradentate ligand—a chelating compound that will bind on to a metal ion in 4 different areas such as a copper (II) ion.¹ Schiff base ligands have a wide variety of synthesis pathways and are preferable due to their short and efficient synthesis. The metal complexes also have anti-cancerous, anti-bacterial, and anti-diabetic properties and are used in many pharmaceutical productions.² Schiff base ligands are also found in many biological studies and their complexes are used in many clinical and analytical fields.³ They are used in these fields due to their stability and various uses based on their structure. Copper (II) complexes of Schiff base ligands have demonstrated electrochemical properties that can be used for cathodes and other various conductors as well.⁴

The study of Schiff base ligands is very important, as virtually few of them have been synthesized in comparison to how many of them there are. Not only that but they are very stable and may be used for selective chemical separation in the future studies.⁵ Schiff base ligands have also been found to be catalysts for organic redox reactions.⁶ An example is in the oxidation of hydrocarbons and the copolymerization of CO₂ to epoxides.⁷ There are so many applications of these Schiff base ligands that many remain undiscovered. Additionally, their metal complexes are known to have antibacterial properties. However, these complexes cannot be used to cure any harmful diseases yet. The metal complexes do have practical use as a cleanser, however. They can be applied to surfaces to kill bacteria that has contaminated the areas such as a hospital floor.⁸

This is a major reason for why the study of the synthesis of these compounds is relevant to the chemical sciences and why there is a boom in the number of papers concerning these compounds. The applications of these ligands and their complexes are many, and the methods to synthesize these compounds are even greater. These complexes are available and in use now and the discovery of new ones are prevalent. It seems less necessary now to focus on the synthesis of novel Schiff base ligands. Thus, this project focuses on finding efficient and fast

ways to make Schiff base ligands. In this study, we synthesized a novel Schiff base ligand and its copper complex (**Scheme 1**).

The first experiments will be to add a salicylaldehyde to the amine groups of the 1,2-phenylenediamine (see Scheme 2). Finding an efficient and fast procedure to first synthesize this before adding chloride and nitro backbones will be more effective both in cost and time. Afterwards, a suitable procedure for the efficient and fast synthesis of the copper complex of will be sought after. Once these procedures are identified they will be put to good use in synthesizing the novel ligand and its copper complex.



Methods and Materials

All synthesis 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 glassware for all of the experiments done. The

following instruments or apparatuses were not altered in any way: rotary evaporator, FT-IR spectrometer, NMR spectrometer, UV-vis spectrometer, and hydraulic press. Some of the processes were taken from the Darensbough article,⁹ while others were taken from various other sources to synthesize the following compounds. There were a total of 15 experiments that used similar methods.

Results and Discussion

The first experiment is fashioned after Darensbough⁹; their main focus was to synthesize novel ligands and they had found a way to synthesize these specific Schiff base ligands. This method was split into four experiments varying the position of each chemical. In the first experiment the salicylaldehyde was mixed with formic acid and added to the 1,2-phenylenediamine. The second was a salicylaldehyde drip into a 1,2-phenylenediamine and formic acid solution. The other two experiments had the two chemicals switched with one dripping into the other and the formic acid remaining in the same position. The best order of addition was the aldehyde dripped into the amine. This showed us that the aldehyde should always be dripped and set a basis for the following experiments.

The second experiment was also reported by Darensbough, where metal coordination of the ligand with chromium (III) chloride was done. The process used nitrogen to prevent the oxidation of the Chromium (II) into Chromium (III) until it was stable on the tetradentate region of the ligand.

However, to remove the precipitates from the solution required multiple washes from both a super saturated ammonium chloride and a brine solution. Once we identified the organic layer we removed the waste into a waste beaker. However, when adding the sodium sulfate to the product, all of the solution was absorbed. This led us to the conclusion that the product had been washed into the waste beaker. The waste beaker was then heated at 70°C in small portions until a precipitate was formed. However, after several weeks of heating, there was too much salt in the precipitates to distinguish from the product. Eventually this experiment was terminated.

Following this experiment we tried a 10 hour reflux of N,N'-bis(salicylidene)-1,2-phenylenediamine with copper acetate⁴. This procedure only took 10 hours versus the 2 days and the previous experiment did not seem to work at all. For this particular experiment DMSO was used as the solvent instead of the usual ethanol or methanol of the other experiments. This was because DMSO can dissolve both polar and nonpolar compounds and is a common ligand and this makes DMSO the perfect solvent for copper(II) complexes. However, the other properties of DMSO added another barrier to the process as DMSO has a boiling point of 178.9°C.

After reflux, there were no precipitates that formed from the reaction and therefore we rotary evaporated the solution. Due to the high boiling point of DMSO the experiment was left to slow evaporate, and at the end of the research period no product formed and the procedure was eventually terminated.

A 3 hour reflux procedure was attempted since it was shorter than the previous experiment; instead of using DMSO as the solvent, the procedure called for ethanol that could be rotary evaporated in case no products came out of solution.⁷ This produced products within one hour and gave a percent yield of 51.63%. This was significantly higher than all the other syntheses done by far. This was also the first time that a product was made, and there were very few issues with the process itself. However, when the waste was left by itself to slow evaporate for the production of crystals, very few came out of solution. To continue on the experiment for finding a suitable way to produce crystals efficiently and quickly another method was proposed.

To attempt to form crystals, a 2 hour synthesis through reflux was conducted and the solvent was methanol. Methanol evaporates much quicker than ethanol would in a slow evaporation environment. Furthermore the reduction in the time that the reflux takes place would allow for fewer products to be produced since a 3 hour reflux only produced 51.63%. This leaves more of the product in solution to be slow evaporated into crystals. This experiment, however, did not prove to work as the slow evaporation left the majority of the product on the sides of the test tubes in small quantities and did not come out as crystals. This led to adding more solvent to the test tubes to see if there was a change in the slow evaporation a second time. However, no change occurred and this was left to evaporate to near completion to extract the small amount of crystals left over.

Since the 3 hour reflux for the synthesis of N,N'-bis(salicylidene)-1,2-phenylenediamine copper(II) worked well, the process was redone at a larger scale. This new batch of copper complex ligand was used to see if the copper had attached itself to the ligand at the tetradentate position of the compound. The NMR results of the tests were inconclusive and did not show any peaks besides the solvent. This is a key that the compound was created successfully since paramagnetism would prevent the NMR from properly detecting the compound. When conducting IR spectroscopy of the original ligand N,N'-bis(salicylidene)-1,2-phenylenediamine and the metal complex N,N' bis(salicylidene)-1,2-phenylenediamine copper(II), some interesting details were observed. First, the phenolic O-H bond at 2361 cm⁻¹ was present in the ligand; however, when looking at the metal complex this vibrational mode was almost completely gone. The remaining vibrational mode may have been unreacted start material that was

present. Then there was the vibrational mode at 501 cm^{-1} that signifies the Cu-O bond. All of these details justify that there is a metal implanted at the tetradentate region of the ligand.

The next experiment was a new procedure that was to help synthesize additional ligands for metal complexes. This was due to the exhaustion of all made ligand. The procedure was a 15 minute heavy stir process of the start material with a 0.1% weight equivalence of the limiting reagent of the catalyst—copper nitrate—to be added. This procedure was both effective and fast acting; however, the time was increased to 3 hours to ensure that all of the start material was fully reacted. This was also confirmed with both ^1H and ^{13}C NMR spectroscopy. This was also confirmed with prediction software that almost matched the spectra completely. With this, a process of synthesizing both novel ligands and their metal complexes is made available (Table 1).

Table 1: ^1H -NMR and ^{13}C NMR of Novel Ligand		
^{13}C NMR (ppm)		
Special Carbon	Actual Value	Predicted Value
C-aromatic	113.7950	117.99
H-aromatic	115.0567	118.15
H-aromatic	118.6507	118.15
C-aromatic	120.8072	120.61
Cl-aromatic	123.4453	123.63
H-aromatic	124.3859	124.83
H-aromatic	132.0787	129.78
N-aromatic	133.1645	132.16
N-aromatic	133.9435	145.24
H-aromatic	137.9897	147.64
N-aromatic	149.1618	149.61
O-aromatic	159.5044	158.98
C-N	164.0273	167.80
^1H NMR (ppm)		
2H	2.042	
2H	2.815	
2H	6.155	
1H	6.964	
1H	7.573	
1H	8.015	
2H	8.998	
2H	12.401	

The next step was to synthesize a novel ligand, N,N'-bis(5-chlorosalicylidene)-4-nitro-1,2-phenylenediamine. This was synthesized with the 3 hour stir process and copper nitrate as the catalyst. The ligand was confirmed by both ^1H and ^{13}C NMR and the percent yield was 95.6%. This made the 3 hour stir process the most efficient and quick procedure that worked for all ligands of this nature.

Next a 3 hour reflux was done to synthesize N,N'-bis(5-chlorosalicylidene)-4-nitro-1,2-phenylenediamine copper (II). When characterizing the copper complex similar problems that were on the ^1H and ^{13}C NMR spectra of N,N'-bis(salicylidene)-1,2-phenylenediamine showed up. No peaks showed up on the ^{13}C NMR, but on IR spectroscopy it was the same as well; the phenolic O-H vibrational mode at 2361 cm^{-1} was present in the ligand spectra. On the copper complex spectra the vibrational mode had almost completely disappeared. The remaining noise there could be unreacted starting material. There was also a vibrational mode at the finger print region of 504 cm^{-1} which signifies the Cu-O bond.

Conclusion

The goal of this project was to synthesize ligands and their metal complexes in the most efficient and quickest ways possible. The research has concluded that the 3 hour stir process with the addition of copper nitrate as a catalyst is the fastest synthesis for synthesizing ligands. For synthesizing their complexes would be the 3 hour reflux of metal acetates and ligands. In total, 2 ligands were successfully synthesized and 3 variations of their complexes were as well. Only one of the ligands was novel and only one of the complexes was as well. This research was mainly focused on synthesis and could have produced more novel complexes after finding these two efficient and fast procedures.

The ligand itself will be a good catalyst for various reactions. On top of that the copper complex also created will be good for electrochemistry and can be utilized as a good condenser. As far as testing with anti-bacterial and other properties, these tests were not done on this specific ligand. However, ligands that are similar to N,N'-bis(5-chlorosalicylidene)-4-nitro-1,2-phenylenediamine have had anti-bacterial properties and other various uses. There are still many ligands that remain to be synthesized and now that these two procedures are capable of synthesizing them efficiently, they should be the best procedures to begin this task. Hopefully those who do start to take on these tasks will find these procedures useful.

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