SYNTHESIS AND CHARACTERIZATION OF A MONONUCLEAR SCHIFF-BASE COPPER COMPLEX AND ITS ACTIVITY TOWARDS BENZYL ALCOHOL OXIDATION

A Dissertation submitted in partial fulfillment
of the requirements for the degree
of

M.Sc. Chemistry

Submitted by

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July 2017

CERTIFICATE

This is to certify that dissertation entitled, **"Synthesis and Characterization of a Mononuclear Schiff-base Copper Complex and It's Activity Towards Benzyl Alcohol Oxidation"** being submitted by **Ms. Tarun kaur** in partial fulfilment of requirements for the award of the degree of **Masters of Science** in **Chemistry** and being submitted to School of Chemistry and Biochemistry, Thapar University, Patiala is a bona fide work carried out by her under my supervision. The work has reached the standard necessary for submission, the content of this dissertation have not been submitted to any other university or institute for the award of any degree or diploma.

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CANDIDATE'S DECLARATION

I hereby declare that the work being presented in the dissertation entitled **"Synthesis and Characterization of a Mononuclear Schiff-base Copper Complex and It's Activity Towards Benzyl Alcohol Oxidation"** in partial fulfilment of the requirements for the award of the degree of **Masters of Science** in **Chemistry** and being submitted to School of Chemistry and Biochemistry, Thapar University, Patiala is my own work during the period of January to July 2017 under the supervision of **Dr. Davinder Kumar**. I have not submitted the contents embodied in this dissertation for the award of any degree.

Tarun

Tarun Kaur

Date: 18th July 2017

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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Words fail me to express my thanks to my family and friends who have always supported me and have been a source of strength and inspiration to me during the entire period of the work.

ABSTRACT

In this work, Schiff base derived copper complex was synthesized using N,N'-(ethane-1,2-diyl)bis(1-(pyridin-2-yl)methanimine) ligand and a copper perchlorate salt as a source for copper. The electronic spectroscopy revealed a weak d-d transition band (621nm). The electrochemical characterization of copper complex revealed one cathodic event at Epc_1 = −0.343 V vs $Ag/AgNO_3$ and two anodic events at Epa_1 = −0.189 V and Epa_2 = +0.220 V vs $Ag/AgNO_3$, respectively. The two events at −0.343 V and −0.189 V formed a redox couple with a peak separation of 154 mV. The ratio of ipc_1 / ipa_1 = 0.24 and ΔEpa = 154 mV suggested that the redox couple is quasi-reversible in nature. The copper complex with TEMPO as a nitroxyl radical and NMI as a base was used to study the oxidation of benzyl alcohol at different loading quantities of catalyst which suggested that the copper complex is only stoichiometrically oxidizing benzyl alcohol to corresponding aldehyde.

Keywords: Schiff Base, Alcohol Oxidation, Copper, TEMPO, NMI.

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LIST OF ABBREVIATIONS AND SYMBOLS

❖ Cu	Copper
❖ TBP	Trigonal bipyramidal
❖ tyr	Tyrosine
❖ His	Histidine
❖ Cys	Cysteine
❖ GO	Galactose Oxidase
❖ °C	Degree Celsius
❖ TEMPO	2,2,6,6-tetramethyl-piperidinyloxyl
❖ NMI	1-methyl imidazole
❖ PINO	Phthalimide N-oxyl
❖ SINO	Saccharin N-oxyl
❖ NHPI	N-hydroxyphthalimide
❖ UV-Vis	UV- Visible
❖ GC	Gas chromatograph
❖ FID	Flame ionization detector
❖ TCD	Thermal conductivity detector
❖ GSC	Gas solid chromatography
❖ GLC	Gas liquid chromatography
❖ µL	Microlitres
❖ mL	Millilitres
❖ mol %	Mole percent
❖ mmol	Millimole
❖ g	Grams
❖ Epc	Peak cathodic potential
❖ Epa	Peak anodic potential
❖ ipc	Peak cathodic current
❖ ipa	Peak anodic current
❖ TON	Turnover Number
❖ vs	Versus
❖ mV	Millivolt
❖ A	Ampere
❖ Min	Minutes
❖ w.r.t	With respect to
❖ kg	Kilogram
❖ DMAP	4-dimethylaminopyridine

CHAPTER 1

Introduction

1.1 Schiff base and its Importance in Catalysis

Transition metal Schiff base complexes have been of great importance due to their high potential catalysing reactions that are of significance to both academia and industry. Transition metals readily form coordination complexes with ligand as they are lewis acid and possesses partially filled d-orbitals.[1]

Hugo Schiff described the Schiff base as the condensation between an aldehyde and an amine in 1864.[2] Structurally, a Schiff base also known as imine or azomethine moiety (C=N) which can behave as a flexi-dentate ligand. Formation usually takes place under acids or base catalysis or in presence of heat. They are generally crystalline solids, which are feebly basic.

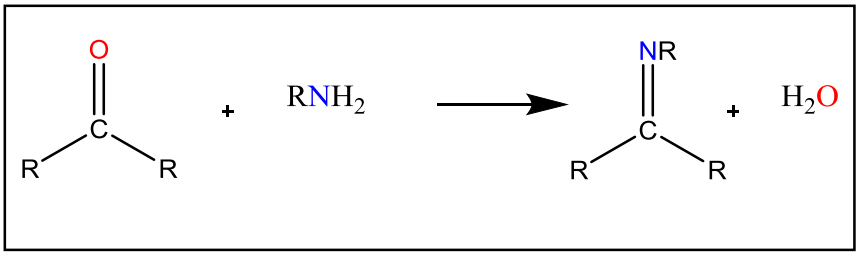
Schiff base derived transition metal complexes can catalyze both heterogeneous and homogeneous reactions. There activity mostly depends upon the ligand denticity, sterics, and electronic environment, and type of central metal ions used.

Aromatic aldehydes having an effective conjugation system form stable Schiff bases, as compared to aliphatic aldehydes that are unstable and readily polymerize. Aromatic Schiff bases or their metal complexes are found to catalyse various types of reactions such as oxygenation, hydrolysis, electro-reduction and decomposition.[3] Schiff base have been used as chelating ligands in coordination chemistry and are generally are bi,tri, or tetra-dentate chelate ligands and form very stable complexes with metal ions.

Schiff base complexes are also known to show some degree of antibacterial, antifungal, antitumor and anti-inflammatory activities.[4]

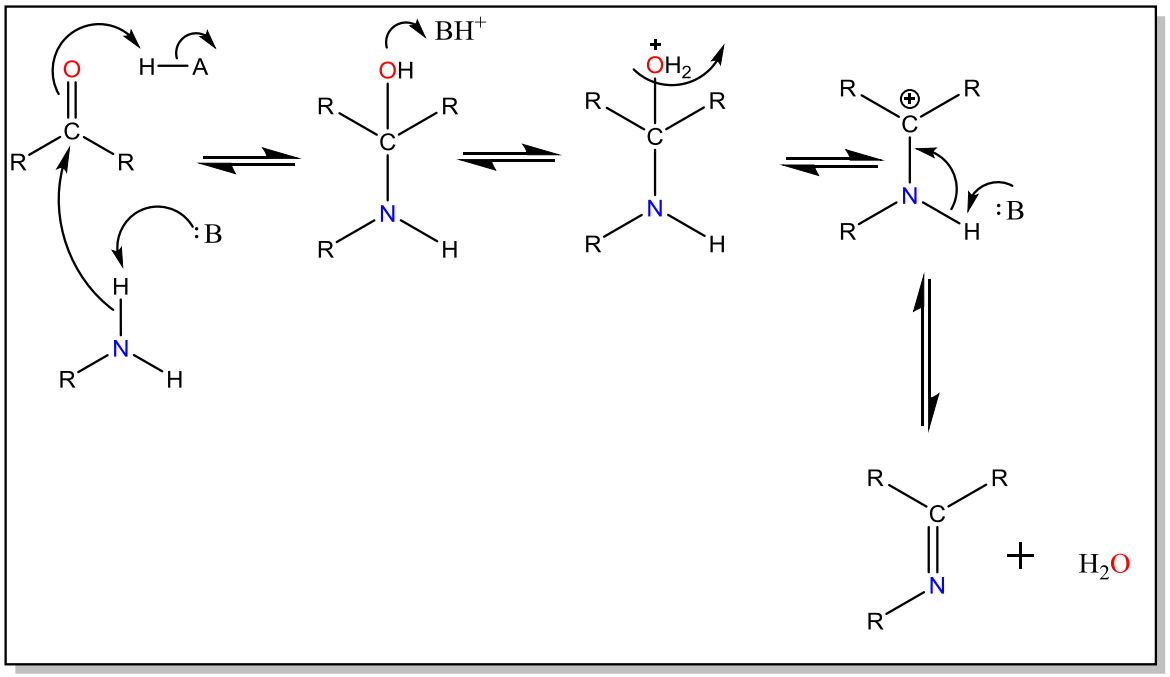
Schiff base can be prepared by condensation reaction between amine and the aldehyde or ketone. The C=N moiety formed (Scheme 1.1) which is known as an imine or azomethine group forms the basis of Schiff base.

Scheme 1.1: Synthesis of Schiff base



In the first step the nitrogen of amine attacks on electrophilic carbonyl carbon. Then the hydroxyl group is protonated which leads to formation of carbocation, after removal of a water molecule. Then the carbocation rearranges itself to afford the imine product via proton transfer (Scheme 1.2).

Scheme 1.2: Proposed mechanism of formation of Schiff Base



Copper being a natural element which is essential to all forms of life and is the third most abundant trace element found in the human body, after iron and zinc. Cu is either found as Cu(I) or Cu(II) in its native state. Cu(I) can form complexes with chelating/non-chelating ligands. Usually, Cu(I) complexes lead to four coordinated structure either in tetrahedral or trigonal–pyramidal (TBP) geometry. Cu(I) complexes with a coordination number 2 or 3 have also been reported but complexes with coordination number of 5 are unusual and have at least one significantly elongated copper–ligand bond.[5]

Many metalloenzyme utilize copper at the active site to perform their respective functions such as Galactose oxidase (GO), laccases, hemocyanin, cytochrome c oxidase, which play an important role in different oxidation reactions of biological relevance. These enzymes include "oxygenases", which mediate oxygen-atom transfer to organic substrates, and "oxidases", which also reduce O_2 to H_2O (or H_2O_2).[6]

Galactose oxidase is an enzyme secreted by fungi functions in extracellular space. The active site employs mononuclear Cu^{II} in N_2O_2 environment where one of ligand is redox-active tyrosine residue that helps in oxidation of alcohols to aldehydes.

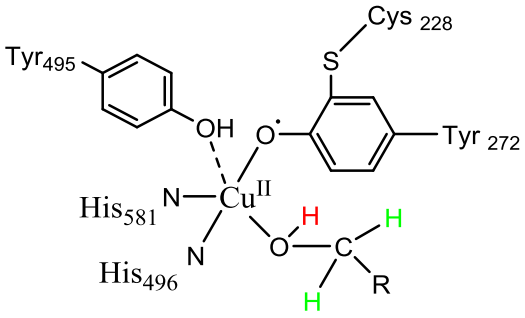


Figure 1.1: Galactose oxidase Active site

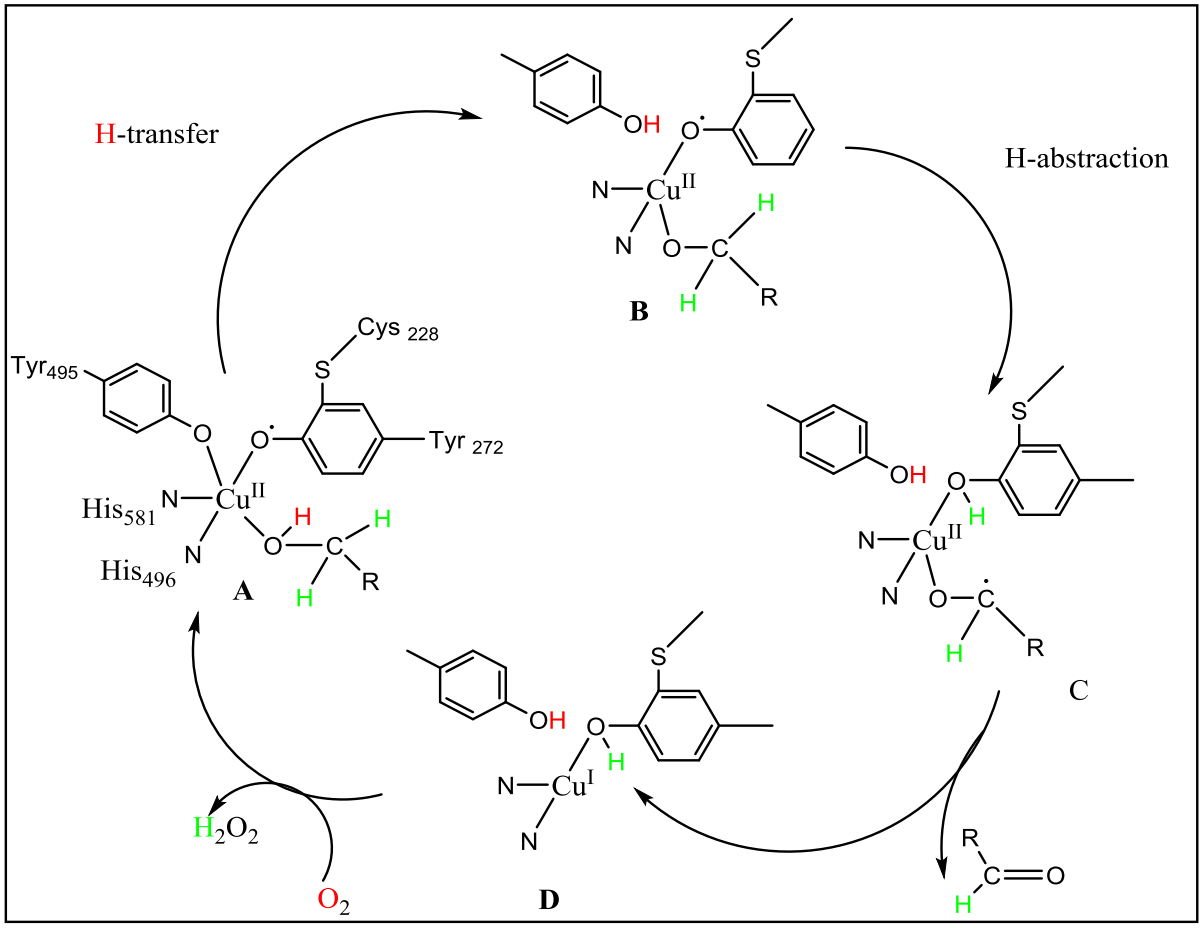
The mechanism starts with alcohol binding to the active Cu(I or II) centre **(A)** and is deprotonated by phenolic tyr–495.

The phenoxyl radical abstracts a β–H from the coordinated alcohol **(B)** to form a bound ketyl radical **(C).**

The ketyl radical converts to aldehyde by a single electron transfer with twenty three units of simultaneous formation of a Cu^I species **(D).**[7-8]

Lastly, due to the presence of O_2, Cu^I is re-oxidized back to **A** and O_2 is reduced to H_2O_2.

Scheme 1.3: Mechanism of Galactose Oxidase



Aldehydes and ketones both play important role in academia and industry. Classical oxidation routes use hazardous reagents such as PCC, Chromic acid or $KMnO_4$ lack selectivity. Therefore, it has attracted the interest of scientific community to develop this reaction under environmental benign condition.[9]

For better oxidation of alcohols, several copper complexes have been reported to selectively catalyse alcohols to aldehyde under aerobic conditions in presence of nitroxyl radicals such as (2,2,6,6-tetramethyl-piperidinyloxyl) TEMPO and (1-methylimidazole) NMI as a base.

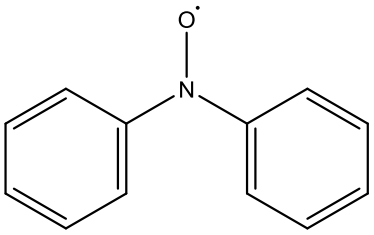
1.2 Nitroxyl Radicals

TEMPO being a non-conjugated nitroxyl free radical is a powerful inhibitor of free radical chain processes. It is well known for effective mediator in oxidation reactions.

Two types of nitroxyl radicals are classified based on their properties and applications:

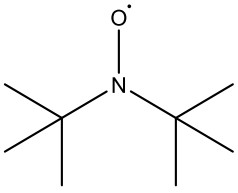
1.2.1 Stable (persistent) radicals: inhibitors

(a) Conjugated

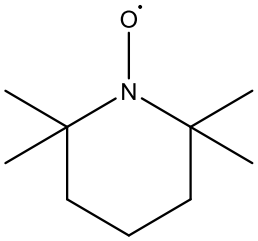


Di-phenylnitroxyl radical

(b) Non conjugated

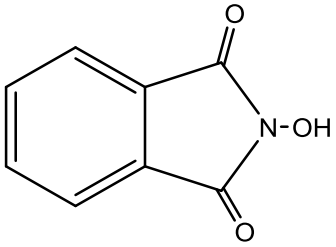


Di-tert-butylnitroxyl radical

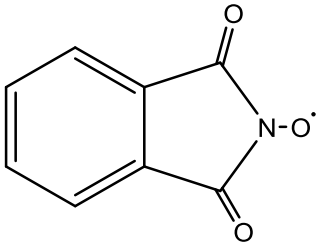


TEMPO

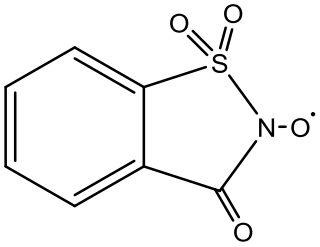
1.2.2 Reactive (non–persistent) radicals: catalysts



NHPI



PINO



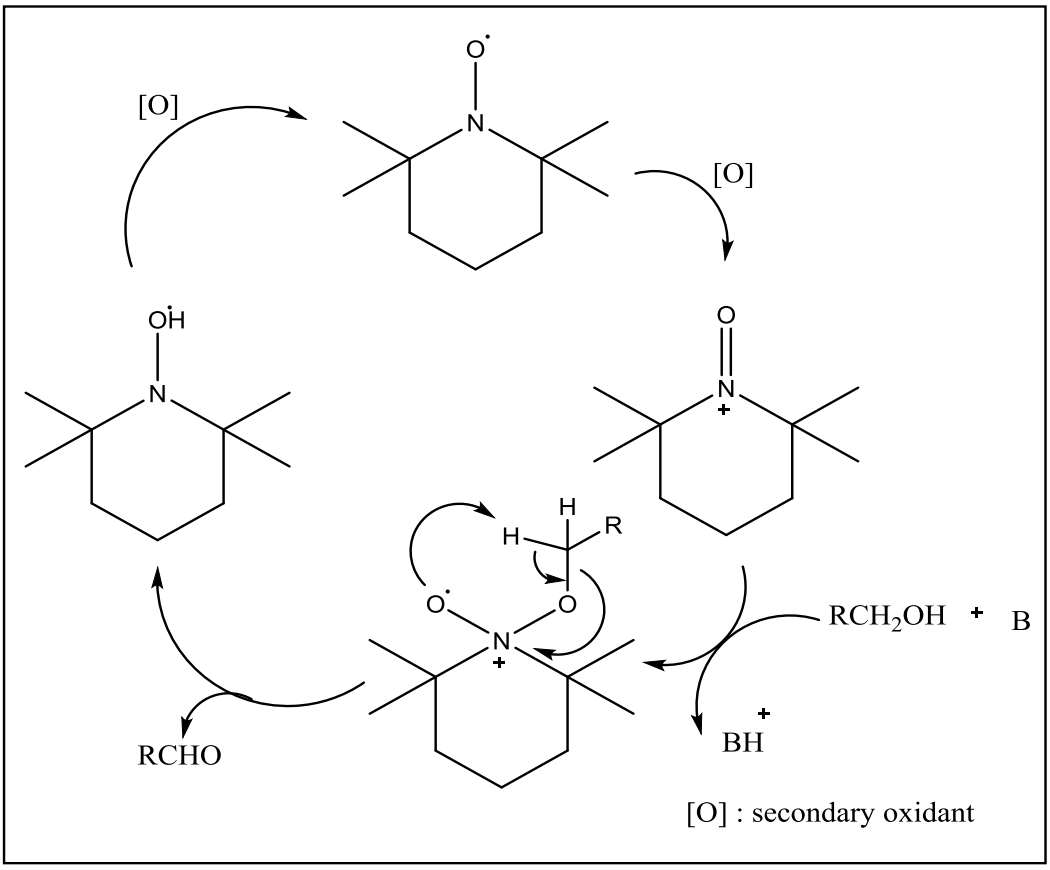
SINO

Molecular oxygen, a non-poisonous and inexpensive oxidant is used for the oxidation of alcohols.[10] The molecular oxygen converts the metal to M^n to M^{n+1} and reduces itself to water which is eco-friendly. For conversion of alcohols, the air which is a source of atmospheric oxygen is used as the end oxidant.

Mechanism

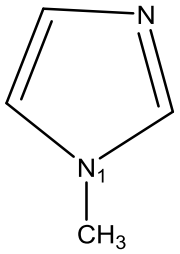
TEMPO works by substituting on position 4 (4-hydroxy-TEMPO, 4-acetamido-TEMPO).

Scheme 1.4: Proposed Mechanism for the oxidation of alcohols in presence of base



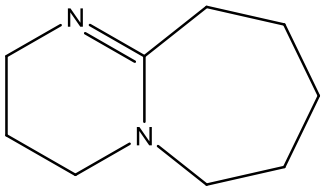
1.3 Bases

NMI is reported to enhance oxidation of alcohols in Cu/Tempo systems. The basic nitrogen of NMI (N_1 nitrogen) may coordinate to Cu centre and may serve as an external proton acceptor.

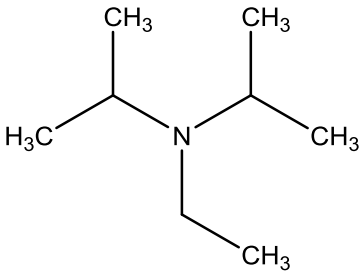


1-methyl imidazole

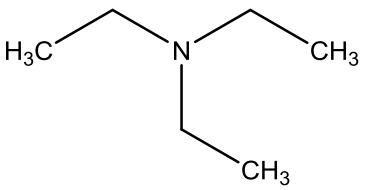
Other bases like 1,8-diazabicycloundec-7-ene (DBU), N,N-diisopropylethylamine (DIPEA), triethylamine (NEt_3) are also used but NMI gives highest activity among all due to its low pk_a (17.1) and is the weakest base with poor nucleophilicity as compared to DBU with pk_a = 24.13 which is non coordinating and the strongest base. Lower catalytic activity was noted for Et_3N with pk_a = 18.5 and DIPEA with pk_a = 18.6, they have similar basicity as NMI but a higher nucleophilicity.[11]



DBU



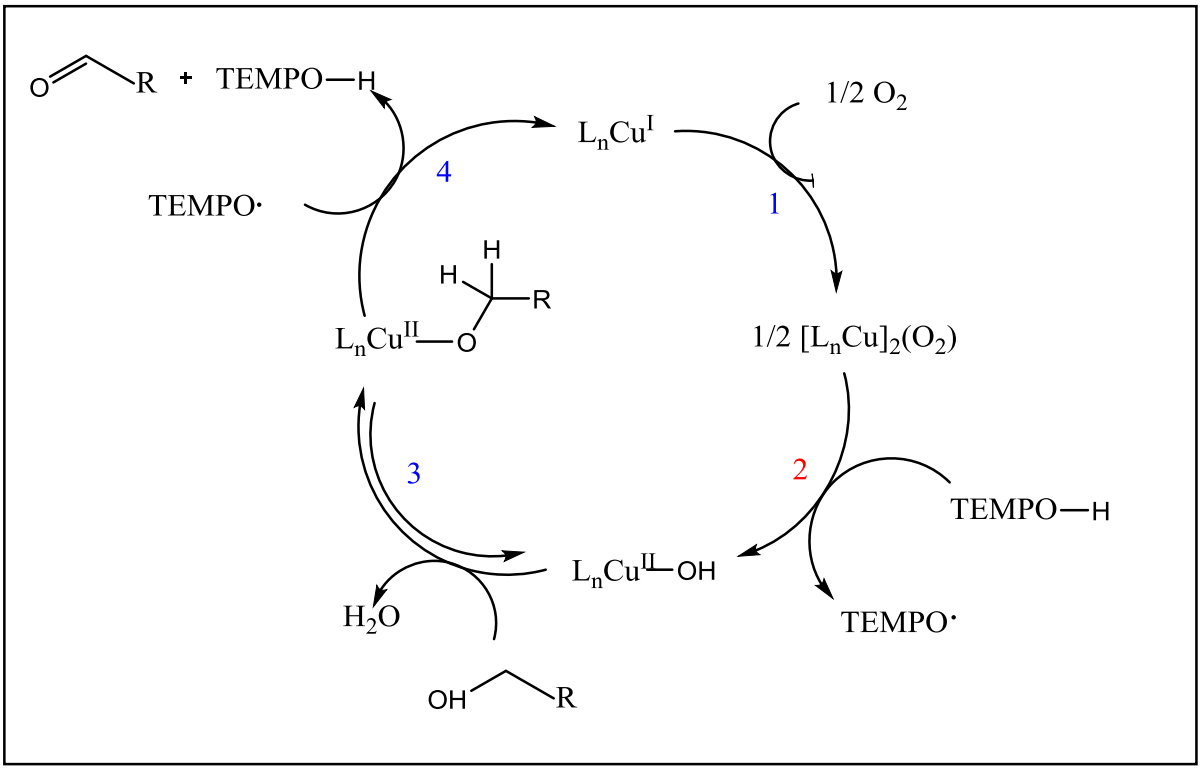
DIPEA



Et_3N

1.4 General Mechanism of Cu/TEMPO systems:

Scheme 1.5: General mechanism of Cu/TEMPO system



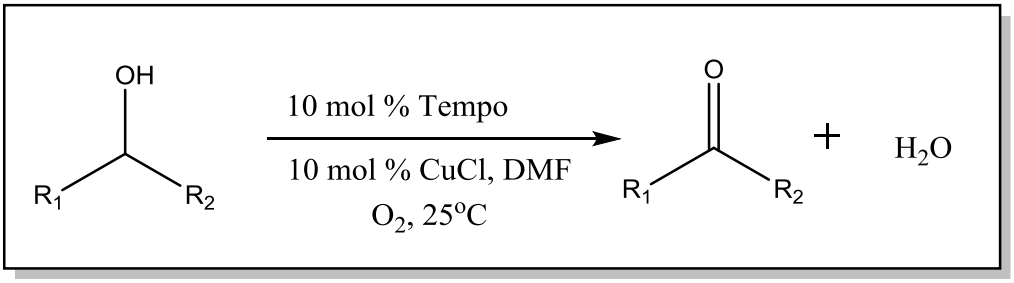
Mechanism begins with molecular oxygen oxidizing $Cu^{(I)}$ to Cu^{II}–OH species and the hydroxylamine (TEMPOH) and producing TEMPO radical in steps 1 and 2, and Cu^{II}–OH and TEMPO then mediate oxidation of the alcohol to the aldehyde.

CHAPTER 2

Literature Review

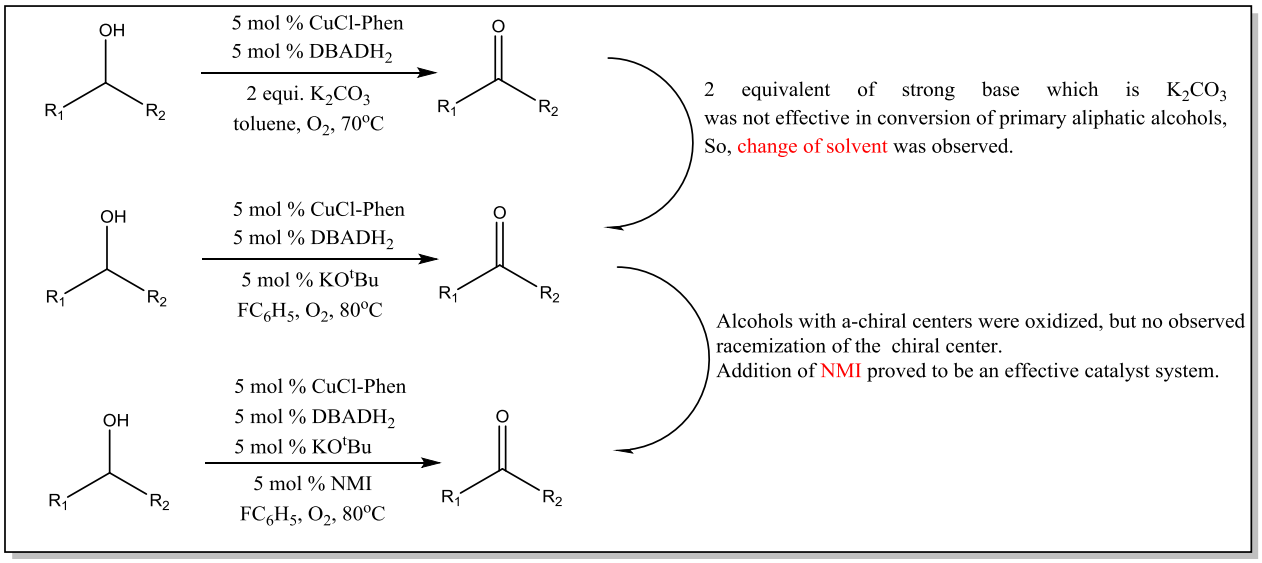
In 1984, Semmelhack reported the first Cu-catalyzed aerobic oxidation of alcohols employing CuCl /TEMPO system that was effective for aliphatic, benzylic, and allylic alcohol oxidation but secondary alcohols were oxidized at significantly slower rate.[12]

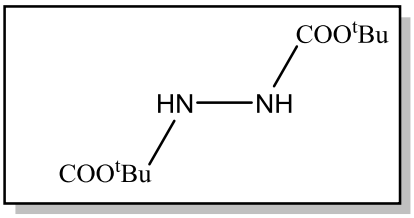
Scheme 2.1: Oxidation of various alcohols to aldehydes using CuCl/TEMPO



Since the early work of Semmelhack, the development of this kind of catalyst emerged. Marko and co-workers, reported alcohol oxidation to aldehyde using CuCl, phenanthroline ligand, di-tert-butyl hydrazine-1,2-dicarboxylate ($DBADH_2$), and 2 equivalents of K_2CO_3.[13]

Scheme 2.2: Oxidation of alcohols using CuCl/Phen as ligand





$DBADH_2$

The addition of NMI to the CuCl/Phen system proved to be the most efficient system for oxidation of primary aliphatic alcohols.

Sheldon and co-workers coupled copper with 2, 2-bipyridine ligand using $CuBr_2$. Their observations were very similar to that of Semmelhack (Table 2.1, Method A) except that their system was ineffective towards secondary alcohols.[14]

Punniyamurthy and co-workers employed salen type ligand with Cu for oxidation of primary alcohols.[15] (Table 2.2, Method B).

Scheme 2.3: Conditions for oxidation of alcohol mediated by bipydine and salen ligands

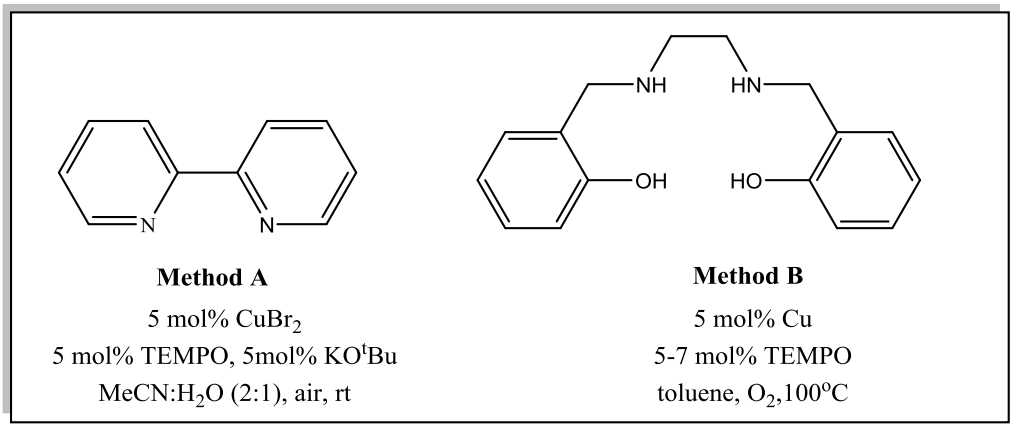
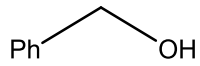
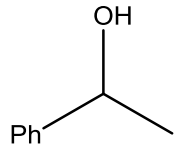
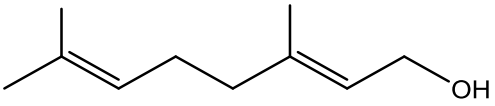
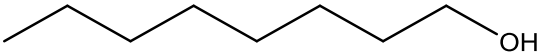
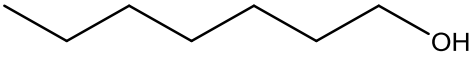
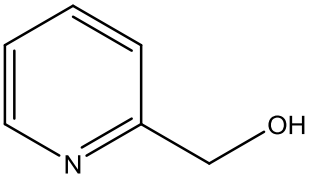


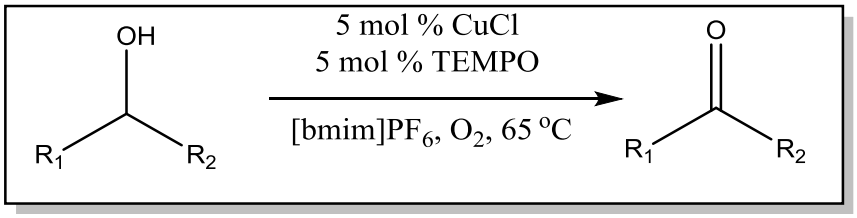
Table 2.1: Cu-TEMPO catalyzed aerobic alcohol oxidations

Reaction 7[a] was performed at 40°C

Entry	Substrate	Method	Time (h)	Yield (%)
1		A	2.5	>99
2		B	10	99
3		A	5	N.R.
4		B	12	2
5		A	5	>99
6		B	23	79
7[a]		A	24	95
8		B	21	90
9		B	26	92

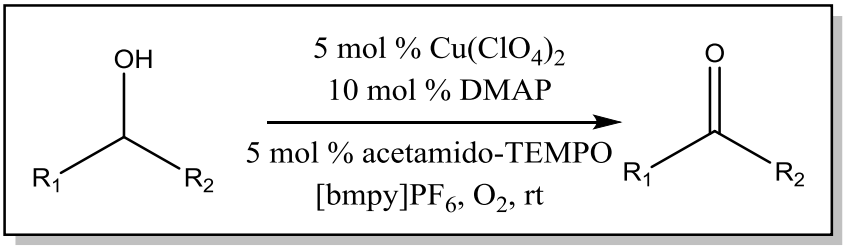
Ansari and co-workers reported a CuCl/TEMPO catalyzed aerobic alcohol oxidation in 2002, using an ionic liquid 1-butyl-3-methylimidazolium hexafluorophosphate ([bmim]PF_6 that could oxidise primary alcohols, secondary benzylic, and allylic alcohols. However, aliphatic alcohols were incompletely oxidized at slower rates. The catalyst could be successfully recycled upto eight times.[16]

Scheme 2.4: Cu-TEMPO catalyzed aerobic alcohol oxidations



Jiang and Ragauskas also used ionic liquid but it could be recycled upto five times only. The system contained 1-butyl-4-methylpryridinium hexafluorophosphate ([bmpy]PF_6), along with acetamido-TEMPO and 4-dimethylaminopyridine (DMAP) for the Cu-catalyzed aerobic alcohol oxidation. The reactions were successful at room temperature for broad range of primary benzylic, allylic, and aliphatic alcohols however no aldehyde was produced from secondary alcohols.[17]

Scheme 2.5: Aerobic oxdidation of alcohols using $Cu(ClO_4)_2$/DMAP



Knochel and co-workers used a biphasic solvent using copper. A modified bidentate bipyridine ligand was used that resulted in successful oxidation of variety of primary and secondary benzylic, allylic, and aliphatic alcohols. Primary alcohols could be easily oxidized compared to secondary alcohols. Authors also demonstrated that the catalyst could be reused up to eight times with little loss of catalyst activity.[18]

Scheme 2.6: Oxidation of alcohols using CuBr with fluorinated bpy ligand

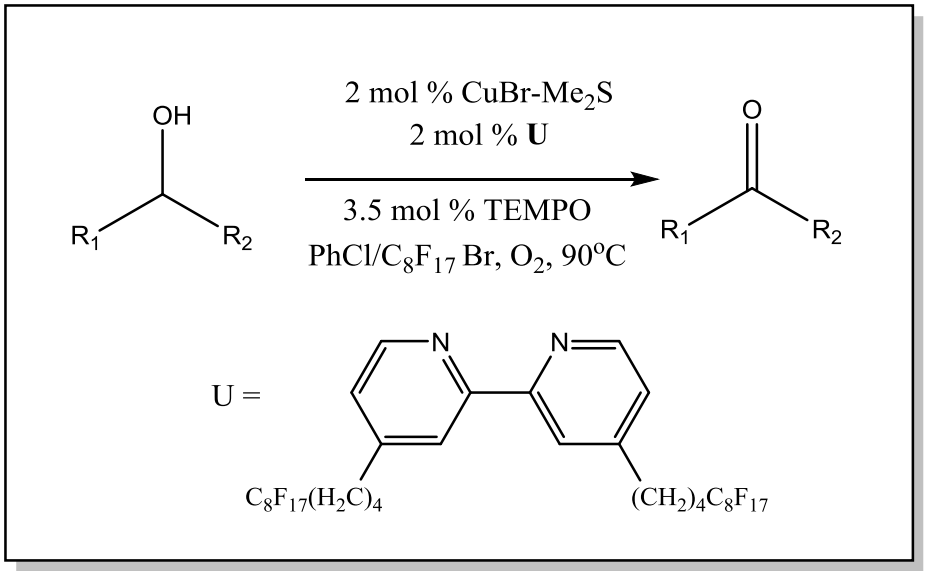
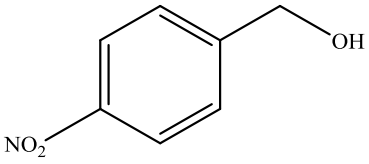
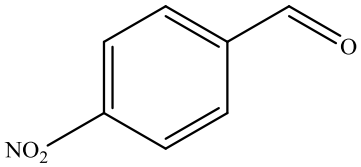
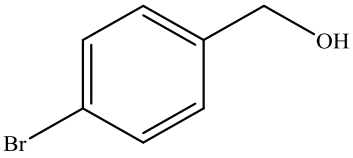
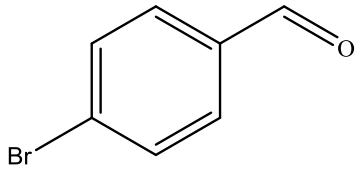
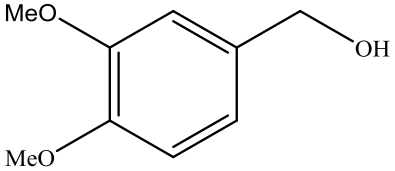
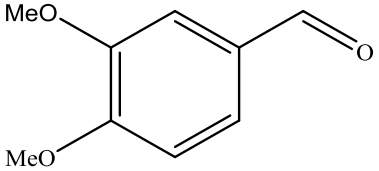


Table 2.2: CuBr-TEMPO catalyzed aerobic alcohol oxidations

Substrate	Product	Yield
		93
		96
		93

Recently, Stahl and co-workers developed a CuOTf/bpy/TEMPO in combination with a base N-methylimidazole (NMI). There system was able to oxidize benzylic, allylic, aliphatic alcohols under ambient air. Copper (I) enhanced the oxidation of alcohols as compared to copper (II). The use of non-coordinating anions (e.g CuOTf) required only mild conditions for oxidation.[19]

Scheme 2.7: Aerobic oxidation of alcohols by Cu(OTf)/bpy system

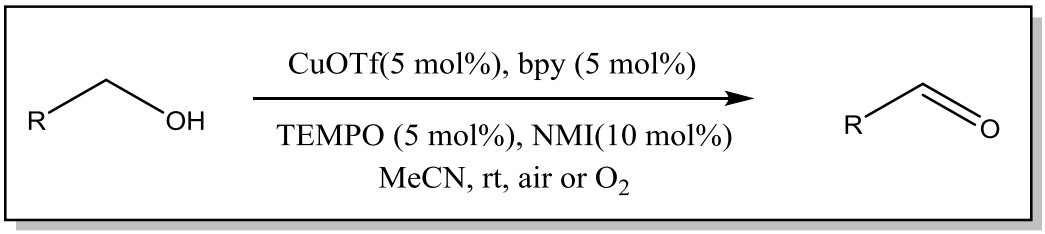
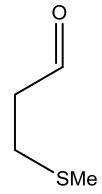
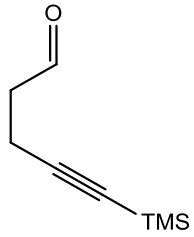
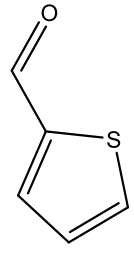
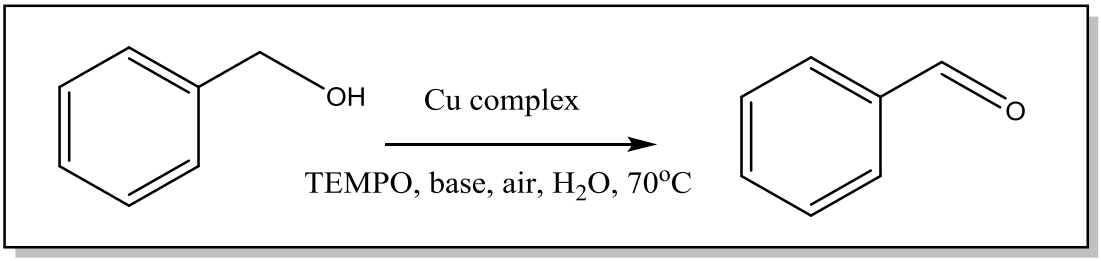


Table 2.3: CuOTf-TEMPO catalyzed aerobic alcohol oxidations

Product	Yield
	78%
	86%
	83%

Zhang and co-workers synthesized a tetranuclear copper (II) complex which contains a $\{Cu_4(\mu\text{-}O)_2(\mu_3\text{-}O)_2N_4O_4\}$ core and a dinuclear complex containing $\{Cu_2(\mu\text{-}O)_2N_2O_2\}$ core. Both the complexes were studied for catalytic aerobic oxidation of benzylic alcohols with TEMPO which revealed that the tetranuclear copper complex (R1) could oxidaise aromatic alcohols quantitatively. Tetranuclear complex was found to be more active.[20]

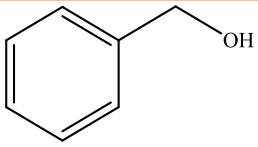
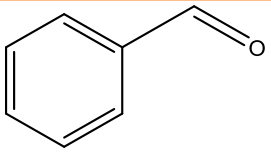
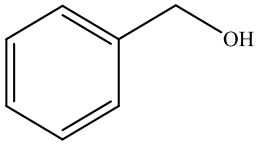
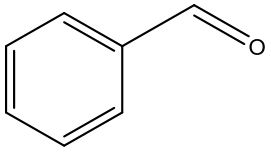
Scheme 2.8: Cu/TEMPO mediated aerobic oxidation of benzylic alcohol



R1 = Tetranuclear copper complex containing $\{Cu_4(\mu\text{-}O)_2(\mu_3\text{-}O)_2N_4O_4\}$ core

R2 = Dinuclear copper complex containing $\{Cu_2(\mu\text{-}O)_2N_2O_2\}$ core

Table 2.4: Oxidation of benzyl alcohol to benzylaldehyde using R1and R2

Entry	Complex	Substrate	Base	Product	Yield	TON
1.	R1		K_2CO_3		77	770
2.	R2		K_2CO_3		78	156

CHAPTER 3

Materials and Methodology

This chapter deals with materials and methodology used during research work which includes chemicals, glass wares and instruments like UV- Visible spectrophotometer, Gas Chromatogram and Cyclic voltammetry.

3.1 Materials:

3.1.1 Apparatus

Beakers (100mL), round bottom flasks (250mL and 100mL), measuring cylinder, micro pipette, tips, magnetic bead, guard tube, condenser, rubber tubing, conical flask, spatula, dropper, filter paper, oil bath, glass vial, thermometer and magnetic stirrer.

3.1.2 Chemicals and Instrumentation

All the chemicals were of reagent grade and used without further purification.2-Pyridine carboxaldehyde (98%), 1-methyl imidazole (99%) were obtained from Spectrochem Pvt Ltd India. Ethylene diamine (98%), benzyl alcohol (99%), 2,2,6,6 teramethyl piperidine-1-oxyl (98%), were obtained from Loba Chemie Pvt Ltd India. The copper perchlorate salt was obtained from Sigma Aldrich. Solvents were of analytical grade and were used as received.

The GC instrument was obtained from Nucon, India augmented with GC system 5765 equipped with a flame ionization detector with nitrogen as a carrier gas with pressure of 5 kg/ cm^2 and hydrogen and air were used at a pressure of 3 kg/cm^2.A fused silica capillary column (0.25 mm internal diameter, 30 m length and 0.25 μm film thickness, wall coated with EC wax (polyethylene glycol) was used.

Potentiostat was obtained from Autolab /PG STAT 12/ Eco Chemie , Netherlands equipped with a three electrode cell, including a glassy carbon as working electrode (area = 0.0314 cm^2) , Pt electrode as counter electrode and Ag/Ag^+ (0.1 mol/L) $AgNO_3$ in acetonitrile.

3.2 Instrument Used

3.2.1 Magnetic Stirrer

A magnetic stirrer of REMI 2MLH is a laboratory device which uses magnetic field to mix liquid samples with the help of small magnetic bar which is to be placed in the liquid sample.

Figure 3.1: Magnetic Stirrer

3.2.2 Weighing balance

To measure accurate quantities of used chemicals, Shimadzu AY220 weighing analytical balance was used.

Figure 3.2: Weighing Balance

3.2.3 Gas Chromatograph

Chromatography is a technique which deals with purification and separation of the components in a mixture. The primary requirement for any specie to be analyzed using Gas chromatograph (GC) is that it should be volatile. The components are separated by distribution of the sample between stationary phase and the mobile phase (carrier gas). The mobile phase is a chemically inert gas that carries the molecules of the analyte. The stationary phase is either a solid adsorbant, and corresponding chromatography is termed as gas-solid chromatography (GSC) or a liquid on an inert support and corresponding chromatography termed gas-liquid chromatography (GLC).[21]

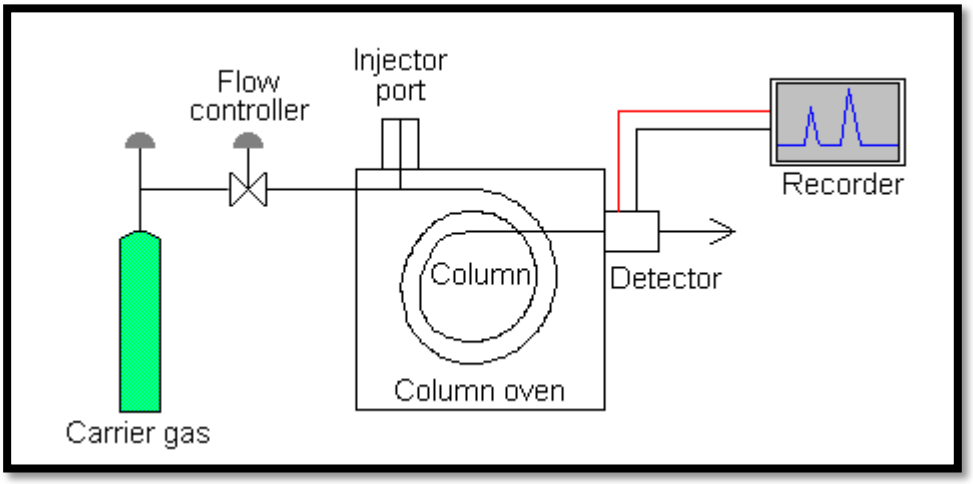


Figure 3.3: Block diagram of a Gas Chromatogram

Major Components of GC

Carrier gas: The carrier gas should not react with the mixture components. Commonly used carrier gases include nitrogen, helium, argon, and carbon dioxide. The choice of carrier gas is often dependent upon the type of detector which is used. The carrier gas also is passed through molecular sieve column to remove moisture and other impurities.

Sample injection port: The most common injection method is where a microsyringe is used to inject sample through a rubber septum into a flash vaporiser port at the head of the column.

Capillary Columns: They have a very small internal diameter order of a few tenths of millimeters, and lengths between 25-60 meters are common.

Column Temperature: The optimum column temperature is dependent upon the boiling point of the sample. Usually it is held at 20 °C above the boiling point of analyte.

Detectors: The detector is the last component of the gas chromatograph used to detect the sample. Some of the commonly used detectors are as follows:

- Flame Ionization Detector
- Thermal Conductivity Detector
- Electron Capture Detector
- Nitrogen Phosphorus Detector
- Flame Ionisation detector

Flame Ionisation Detector – Flame ionization detectors (FID) are the most widely used detectors in gas chromatography. In a FID, the sample after exiting the column is directed towards an air-hydrogen flame. At high temperature of this air-hydrogen flame, the sample undergoes chemical decomposition through intense heating which produce ions and the resulting flame will have a higher electrical conductivity than the carrier gas burned alone with hydrogen. Different substances being analyzed produce different changes in conductivity and elute from column at different time also known as retention time which helps in identification of the sample.

Thermal Conductivity Detector – Thermal conductivity detector (TCD) works by having two parallel tubes both containing gas and heating coils. One tube contains a reference gas and the other contains the sample to be analyzed. The gases are examined by comparing the heat loss rate from the heating coils. So when the sample is mixed with the carrier gas, the difference in the thermal conductivity of this mixture and the carrier gas is measured which thereby helps in quantification of the various compounds.

3.2.4 UV-Visible Spectrometer

UV-Vis Spectrometer involves excitation of electrons (σ,π,n electrons) from ground state to higher energy state in the range of 190-800nm. When light from deuterium lamp, a light source passes through the transparent side of cuvette, it yields an adsorption spectrum. As a result, the electrons which have absorbed the light, transit from highest occupied molecular orbital (HOMO) to lowest occupied molecular orbital (LUMO)

Figure 3.4: UV-Visible Spectrometer

The excitation process is quantized, meaning the electromagnetic radiation so absorbed has the energy exactly equal to the energy difference between the excited and the ground states.

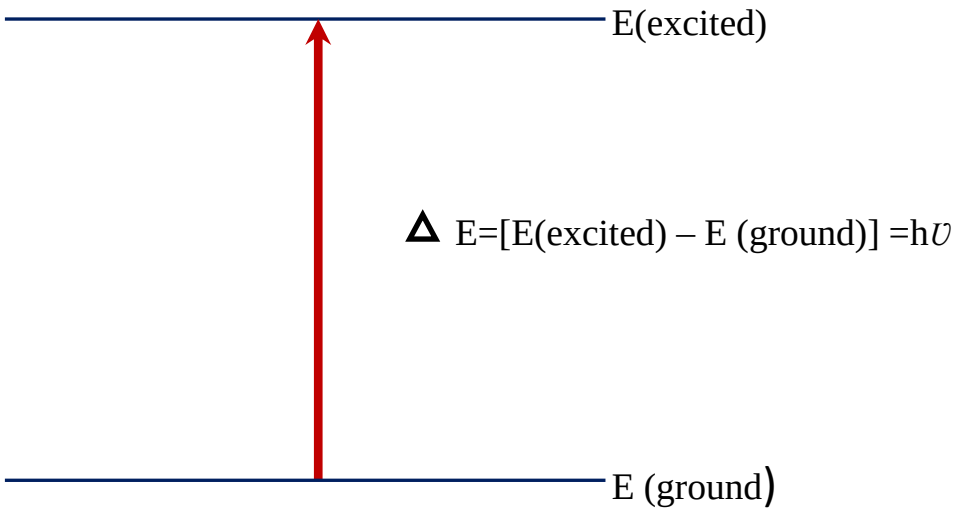


Figure 3.5: Excitation Process

The lowest occupied molecular orbitals are the σ orbitals, which corresponds to σ bonds. The π orbitals somewhat have higher energy levels and the non-bonding orbitals n, lie at even higher energies and tell us about unshared pairs. The unoccupied or antibonding levels such as σ* and π* are the orbitals having the highest energy.

Not all the transitions take place, some transitions are forbidden. The selection rule tells us about the transition which are forbidden. During the transition, the electron spin should not change.

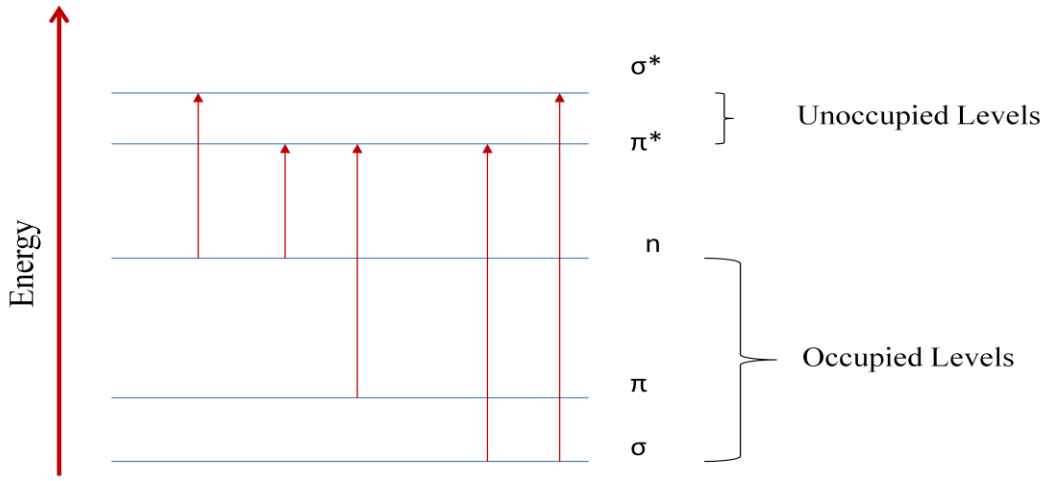


Figure 3.6: Possible Electronic Transitions

Some important transitions are as follows:

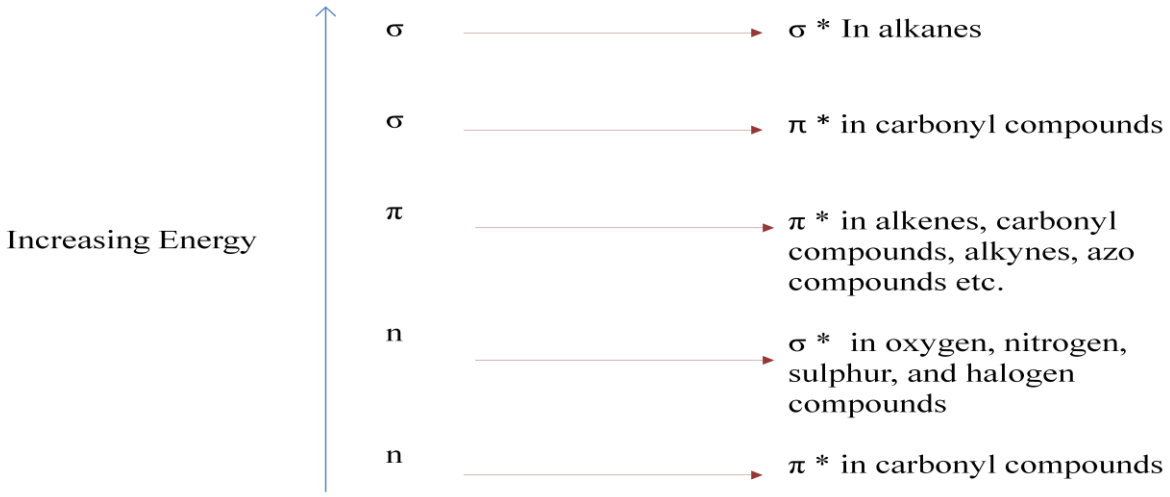


Figure 3.7: Important Transitions

The basic principle of UV-Vis spectrometer works on Beer-Lambert law which gives a linear relationship between absorbance and concentration of absorbed species.

$$\mathbf{A = \log(1/T) = Ɛcl}$$

Where,

A = absorbance

T = transmittance = I_o/I

I_o = intensity of incident light

I = intensity of transmitted light

c = molar concentration of solute

l = length of sample cell (cm)

Ɛ = molar extinction coefficient

Working

The light from the light source which is mostly a deuterium lamp, emits light in the ultraviolet range and a second light source which is a tungsten lamp emits light in the visible range and enters the monochromator having adjusting slits which focuses on the wavelength of sample cell, usually made of glass or plastic with a transparent side from where the light enters. The light then passes through the sample cell reaches the detector which records the intensity of the transmitted light I.

3.2.5 Cyclic Voltammetry

In cyclic voltammetry, the potential is applied to the working electrode which is usually a triangle waveform as shown in figure 3.8. In a voltammogram, current from a working electrode, originating from electrochemical/chemical process, is plotted versus the potential of the working electrode that is scanned cathodic or anodic. Usually, the solution is left static while collecting the data. Under these conditions the measured redox current is determined by several factors like the reactant concentration, electrode area, the diffusion coefficient of reactant and product, and scan rate.[21]

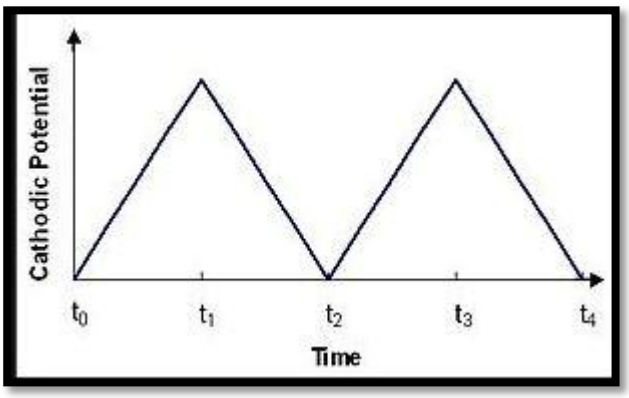


Figure 3.8: Triangular Waveform in CV

As the electrode and the solution are kept undisturbed, the redox reaction takes place at the electrode surface and the potential is scanned between the two extremes, the current first increases when the reaction is under thermodynamic control and then start to fall as the concentration of the analyte decreases near the electrode and the current becomes diffusion-controlled.

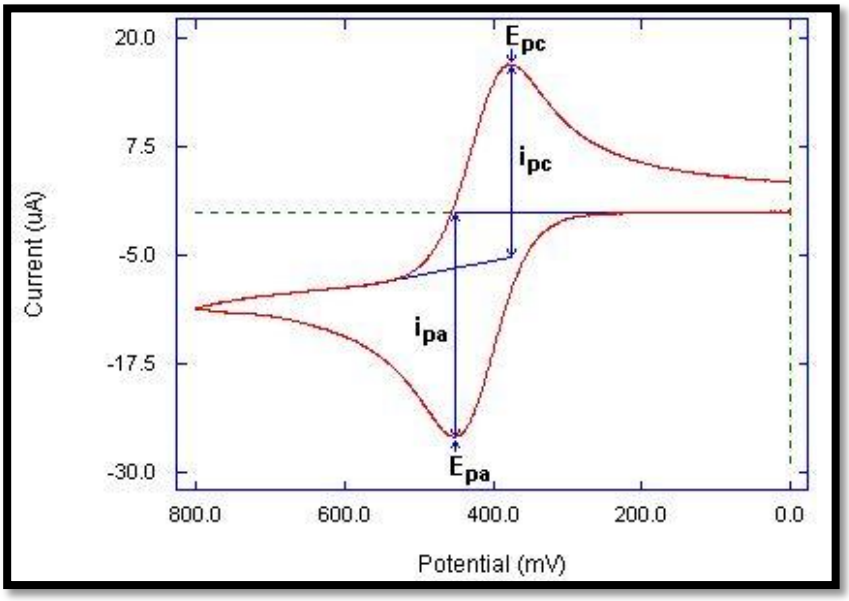


Figure 3.9: A typical Voltammogram

The peak current, i_p is given by, Randel-Sevcik equation:

$$\mathbf{i_p = 2.69 \times 10^5\ n^{3/2}\ AD^{1/2}\ v^{1/2}\ C}$$

n = stoichiometric number of electrons participating in the redox reaction

A = electrode area in cm^2

D= diffusion coefficient of redox species cm^2/sec

v = scan rate in mV/s

C = concentration of redox species in mol/L

3.3 Methodology

3.3.1 Preparation of Schiff base Cu Complex

For the preparation N,N'-(ethane-1,2-diyl)bis(1-(pyridin-2-yl)methanimine) ligand (L_1), ethylene diamine (2 mmol) with two equivalents of pyridine-2-carboxaldehyde (4 mmol) was dissolved in methanol (30 mL). The mixture was vigorously stirred for 2 hours under reflux and cooled to ambident temperature which led to the formation of red - orange coloured solution. To the solution, was added a solution of $Cu(ClO_4)_2.6H_2O$ (2 mmol) dissolved in 20 mL methanol resulting in dark blue precipitate (41.83% yield) was isolated via filtration and product was washed with methanol (5 mL).

Figure 3.10: Reaction set up for synthesis of Schiff base ligand

Figure 3.11: Copper perchlorate salt in methanol

Figure 3.12: Change of colour from red – orange to blue due to addition of Copper perchlorate salt

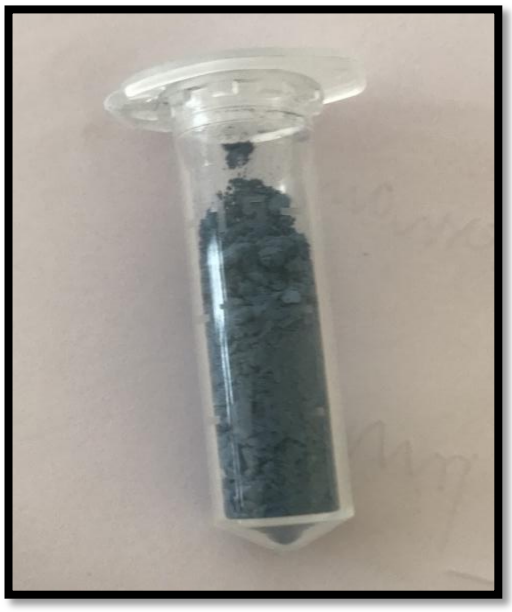
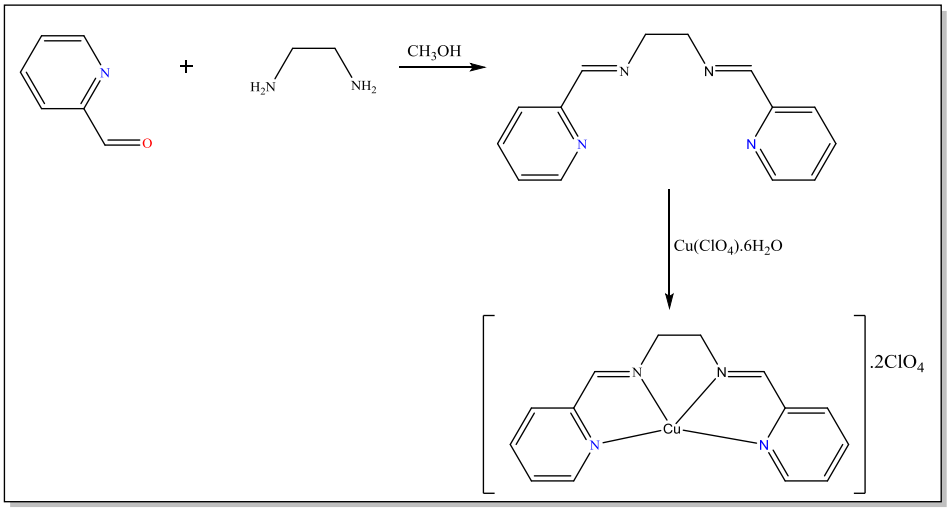


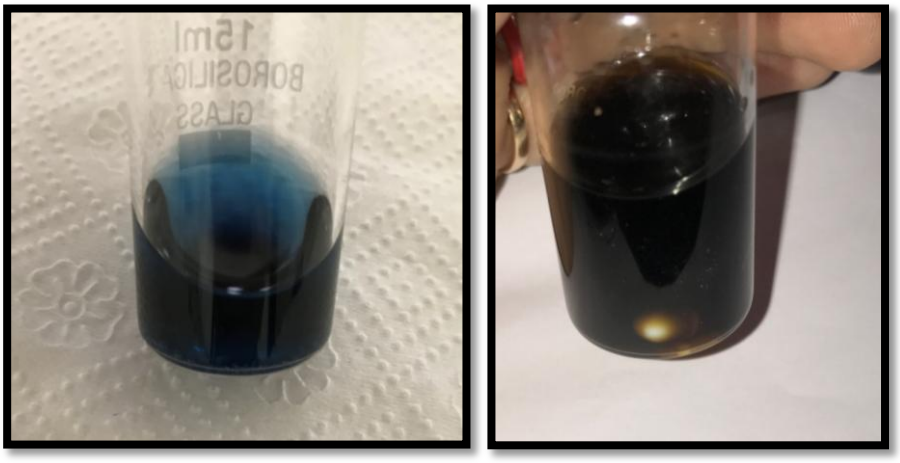
Figure 3.13: Copper Schiff Base Complex

Scheme 3.1: Reactions for Synthesis of Cu- Schiff Base Complex



3.3.2 Catalytic Oxidation of Benzyl Alcohol

0.5 mL (5 mmol) benzyl alcohol was dissolved in 10 mL acetonitrile in a clean vial containing small magnetic bar. 5 mol% (w.r.t alcohol) of $[L_1Cu]^{+2}$ was added to the vial followed by addition of 0.039 g of TEMPO (5 mol % of alcohol) and 20 µL NMI (5 mol% of alcohol).The reaction mixture which is blue in colour was allowed to stir open to air for 48 h resulting in colour change from blue to dark brown. After 48 hours, 0.5 mL of reaction mixture was taken in a falcon tube and diluted with 5 mL of petroleum ether. The blue reaction mixture, now turned to dark brown was subjected to GC-TCD analysis to determine the yield and TON.



(A) **(B)**

Figure 3.14: (A) Reaction mixture immediately after mixing the reactants (B) Reaction mixture after 48 hours

CHAPTER 4

Results and Discussion

4.1 Electronic Spectroscopy

The electronic spectroscopy of $[L_1Cu]^{+2}$ complex in acetonitrile shows three bands with a λ_{max} of 310 nm (ε = 1686 M^{-1} cm^{-1}) which corresponds to $\pi \rightarrow \pi^*$, 400 nm (ε = 167 M^{-1} cm^{-1}) which corresponds to $n \rightarrow \pi^*$ and 610 nm (ε = 248 M^{-1} cm^{-1}) corresponding to $^2B_{1g} \rightarrow {}^2A_{1g}$ with a wave number of 16393.44 cm^{-1}.[22] The presence of three bands is indicative of a square planar structure.[23] The first two bands at 310 nm and 400 nm corresponds to ligand based charge transfer bands, whereas the band at 610 nm corresponds to a d-d transition.

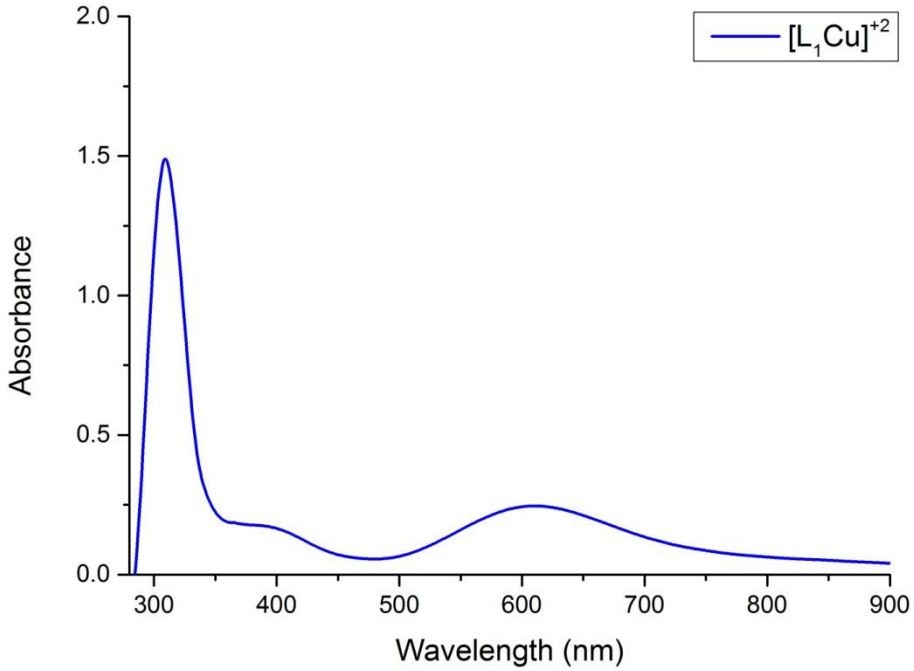


Figure 4.1: UV-Visible spectra of 0.1 mM solution of $[L_1Cu]^{+2}$ in acetonitrile

4.2 Electrochemical Characterization

The complex $[L_1Cu]^{+2}$ was studied using cyclic voltammetry in the potential range of -1.0 V to +1.0 V at various scan rates ranging from 50 mVs^{-1} to 1000 mVs^{-1} (Fig.4.2). 2.0 mM solution (5.0 mL) of complex was used to collect the voltammograms. One cathodic event at Epc_1 = −0.343 V vs $Ag/AgNO_3$ and two anodic events were identified at Epa_1 = −0.189 V and Epa_2 = +0.220 V vs $Ag/AgNO_3$ respectively (Fig. 4.3). The two events at −0.343 V and −0.189 V, form a redox couple with a peak separation of 154 mV. The ratio of ipc_1 / ipa_1 = 0.24 and ΔEpa = 154 mV suggests that the redox couple is quasi-reversible in nature.[24] The Epc_1 = −0.343 V is assigned to a metal centered event that is Cu $^{(II/I)}$ and return peak at −0.189 V is assigned to Cu $^{(I/II)}$. The irreversible event at +0.220 V is assigned to ligand centered oxidation in which imine group may participate. No cathodic return peak was observed for ligand – centered event.

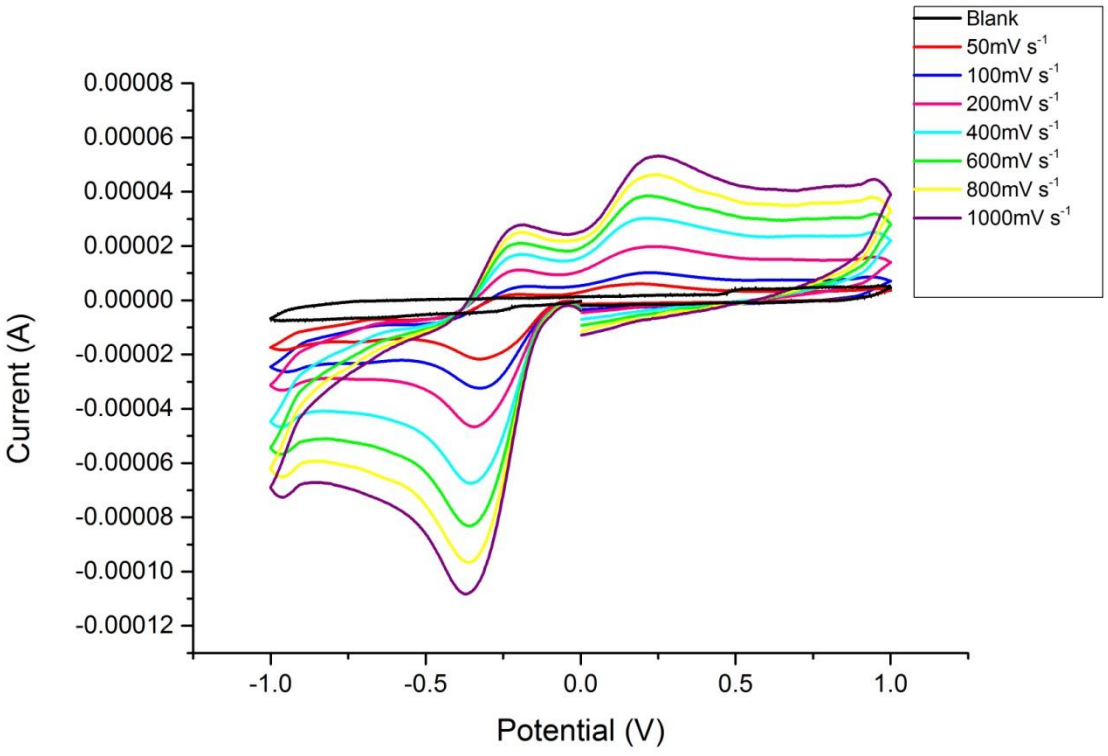


Figure 4.2: Cyclic Voltammograms of $[L_1Cu]^{+2}$ at various scan rates ranging from 50 mV s^{-1} to 1000 mV s^{-1}

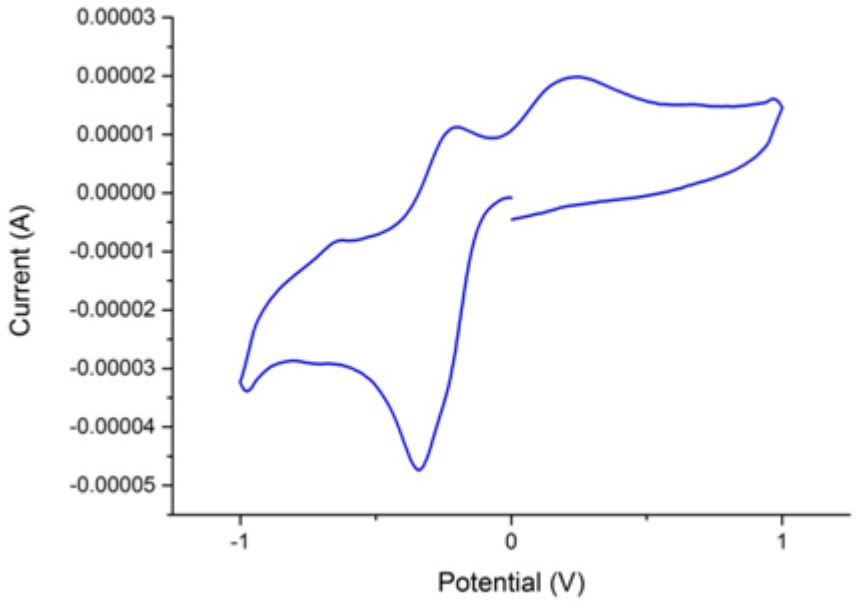


Figure 4.3: Cyclic Voltammogram of 2 mM solution of$[L_1Cu]^{+2}$ in CH_3CN at 200 mV s^{-1}

The quasi-reversible metal – centered couple indicates a diffusion controlled process. To confirm this, voltammograms at various scan rate ranging from 50 mVs^{-1} to 1000 mVs^{-1} were recorded and plot of ip vs ν affords a straight line which suggests that indeed this redox event is diffusion controlled (Fig. 4.4)

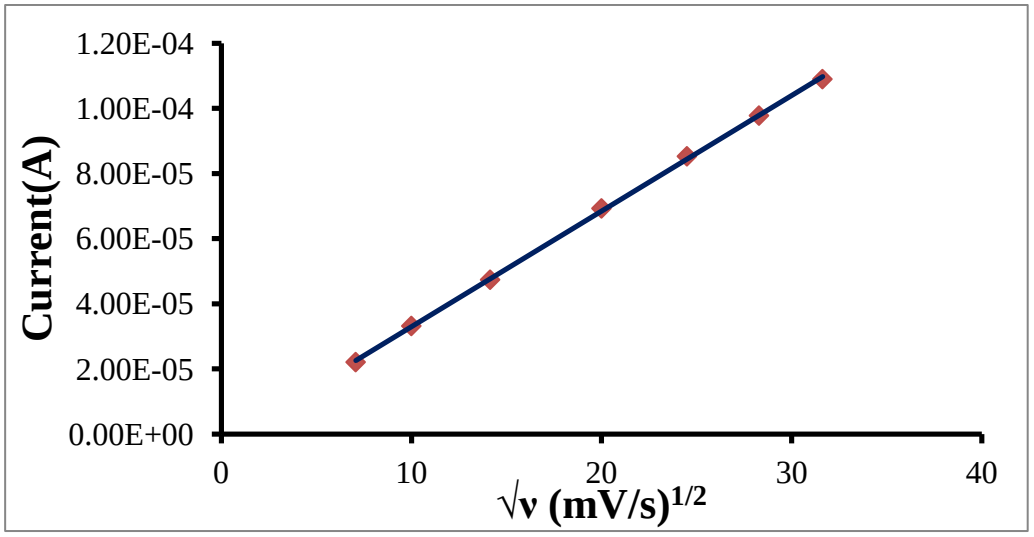


Figure 4.4: Plot of Peak current vs square root of scan rate

4.3 Representative Chromatograms and Detailed Calculation

Following the reaction (48 hours), an aliquot (0.5 mL) was withdrawn using syringe and diluted with 5 mL of pet ether. A red-brown precipitate was observed with organic layer on the top which was subjected to GC-FID analysis. The quantification of the product benzaldehyde was performed using calibration curve. The calibration curve was obtained using four different standards of benzaldehyde with concentration (v/v) 0.5%, 1%, 5% and 10% in 10 mL of acetonitrile (Fig.4.5). 1µL of each standard was injected and the corresponding area obtained was used for calibration curve (Fig. 4.6). The retention time of both benzyaldehyde and benzyl alcohol was determined by injecting pure samples in acetonitrile solvent (Fig. 4.7)

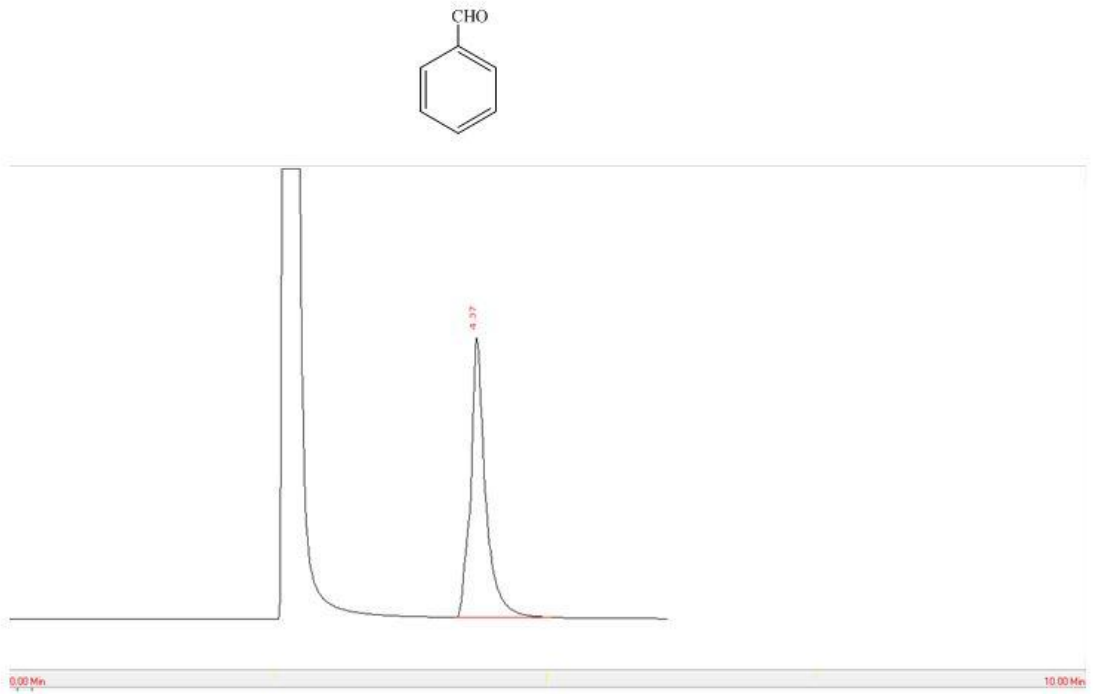


Figure 4.5: Chromagram showing Benzaldehyde in 5% standard solution

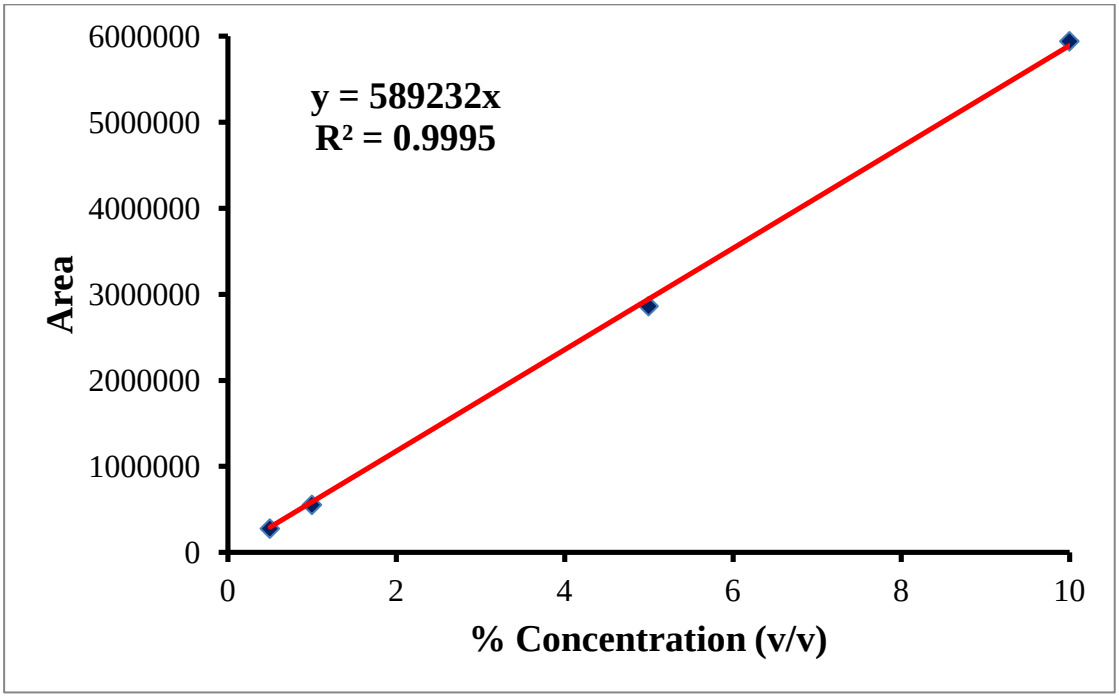


Figure 4.6: Calibration Curve for benzaldehyde

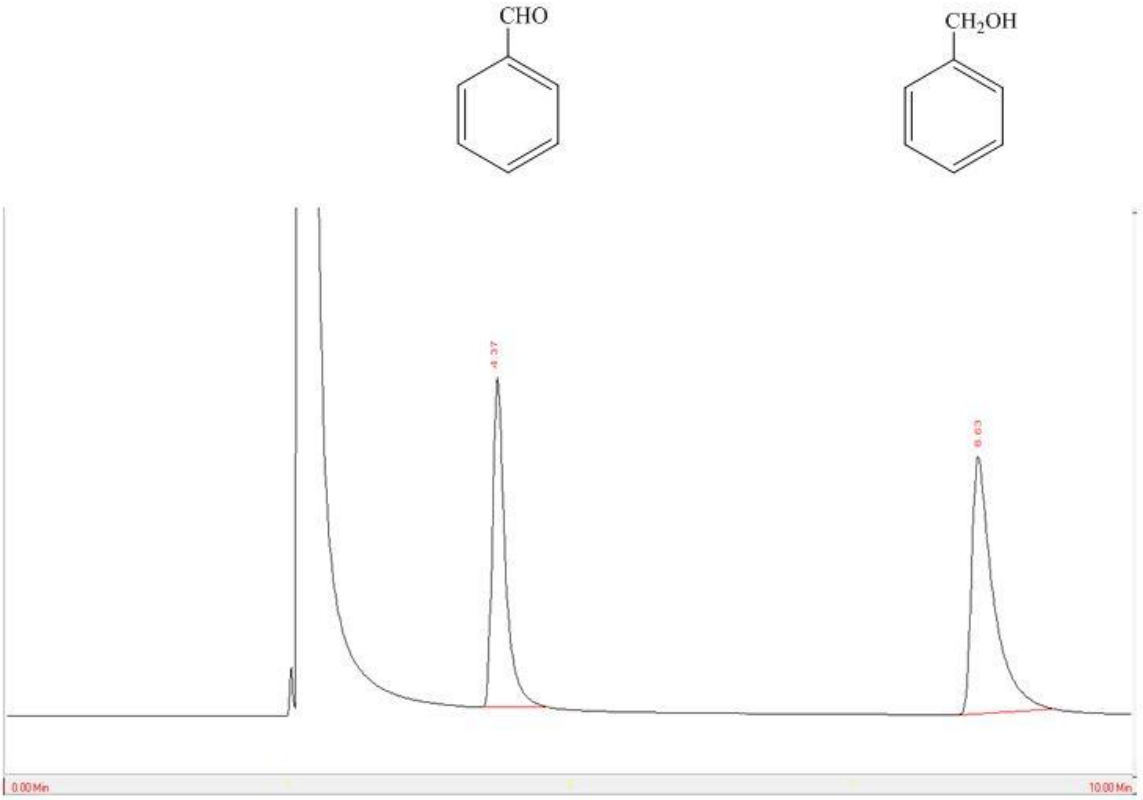


Figure 4.7: Chromatogram of benzaldehyde and benzyl alcohol mixture

Detailed Calculation to determine the Yield and TON

- For 5 mol% of catalyst used,
- Area obtained = 20142
- y = 589232x
- x = (20142 /589232) = 0.0341 % (v/v)
- The volume of benzaldehyde present in 5.5 mL aliquot = (5.5×0.035)/100

  = 0.0018 mL
- 0.0018 mL is the actual volume present in 0.5 mL.
  - The volume of benzaldehyde present in 10.5 mL reaction mixture = (10.5×0.0019)/0.5

    = 0.0394 mL
- Mass = volume of benzaldehyde × density of benzaldehyde

  = 0.0394 mL × 1.047 g/mL

  = 0.04188 g
- Moles of benzaldehyde = 3.9×10^{-4} moles
- % yield = $(3.9 \times 10^{-4} / 5 \times 10^{-3}) \times 100 = 7.8$ %
- TON = $(3.9 \times 10^{-4} / 25 \times 10^{-5}) = 1.56$

4.4 Benzyl alcohol oxidation studies using $[L_1Cu]^{+2}$

To assess the potential of $[L_1Cu]^{+2}$ in benzyl alcohol oxidation studies, the reaction was carried out with 5 mmol of benzyl alcohol, 1.25×10^{-4} mmol of $[L_1Cu]^{+2}$ (2.5 mol % of alcohol), 1.25×10^{-4} mmol (2.5 mol % of alcohol) of NMI and 1.25×10^{-4} mmol (2.5 mol % of alcohol) of TEMPO under aerobic conditions at room temperature (Table 1, entry 1)

Table 4.1: Oxidation of benzyl alcohol to benzaldehyde at different mol% of catalyst

Entry	Benzyl Alcohol (mmol)	Catalyst (mol%)	NMI (mol%)	TEMPO (mol%)	H_2O_2 (mol%)	Yield (%)	TON
1.	5	2.5	2.5	2.5	-	3.2	1.33
2.	5	5	5	5	-	7.8	1.56
3.	5	10	10	10	-	11.6	1.16
4.	5	2.5	2.5	-	2.5	-	-

With a catalyst loading of 2.5 mol %, 3.2 % yield of benzaldehyde was obtained with a corresponding TON of 1.3. In the first catalytic run, only stoichiometric alcohol oxidation was observed. As a next step, we looked at the effect of catalyst loading on alcohol oxidation. In the next assay, keeping the concentration of alcohol the same, the catalyst loading was increased to 5 mol % and equivalent amount of TEMPO and NMI was used (Table 1, entry 2). The yield came out to be twice giving approximately the same TON. The data suggests that only stoichiometric alcohol oxidation is observed using $[L_1Cu]^{+2}$. This was further confirmed by increasing the catalyst loading to 10 mol %, which resulted in increased yield of benzaldehyde (Fig. 4.8), but the corresponding TON did not change. The set of data suggests that $[L_1Cu]^{+2}$ does not oxidize benzyl alcohol catalytically.

The reaction was carried with H_2O_2 (Table 1, entry 4) as an oxidant to assess the effect of TEMPO on the reaction. Under the similar reaction conditions, the benzaldehyde was not detectable. TEMPO, a nitroxyl radical is known to coordinate to transition metals and can selectively oxidize alcohols, whereas H_2O_2, a source of hydroxyl radical is not known to oxidize alcohols to corresponding aldehydes.[6]

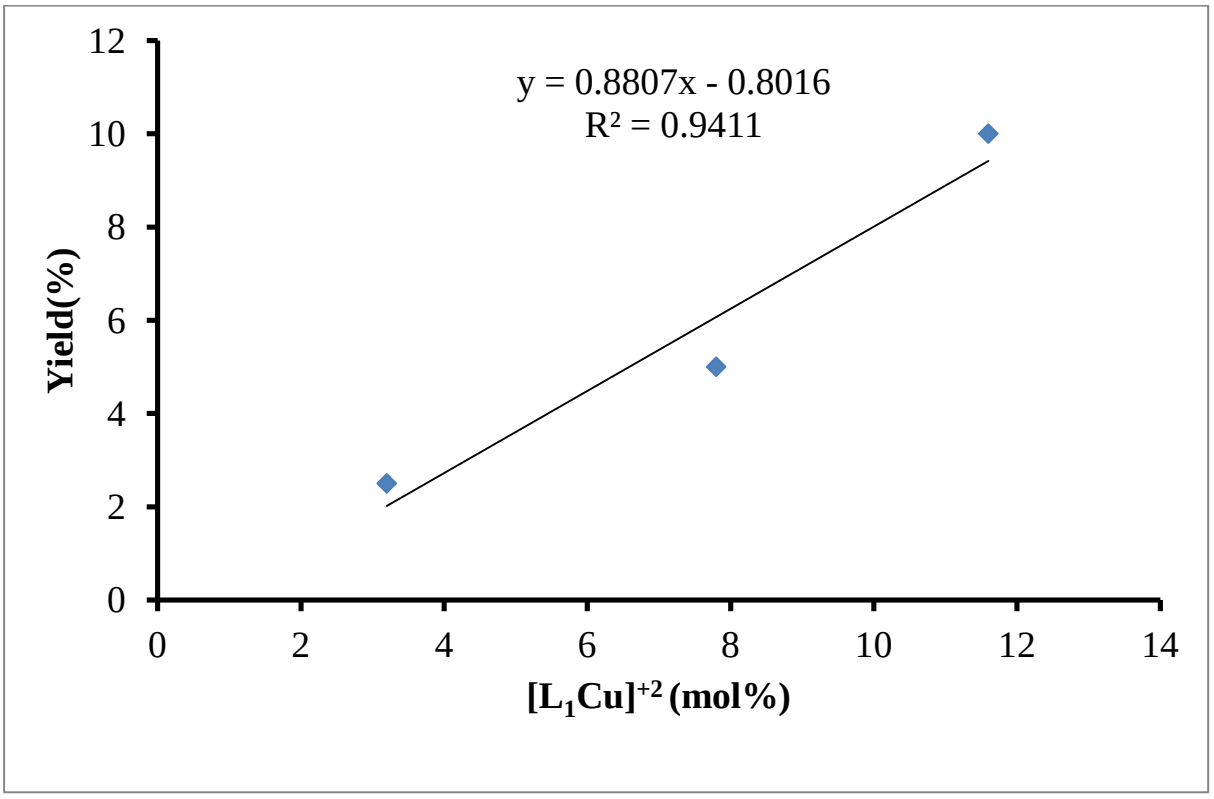


Figure 4.8: Plot of yield of benzaldehyde vs catalyst concentration

To probe the role of ligand in aerobic alcohol oxidation, control experiments were carried out using $Cu(ClO_4)_2 \cdot 6H_2O$. Keeping the copper salt loading at 5 mol% with equivalent amount of NMI (5 mol %) and TEMPO (5 mol%) and benzyl alcohol (5 mmol), the reaction was carried out under similar conditions which resulted into 4.6% yield (TON = 0.92) of benzaldehyde (Table 2, entry 2). The yield and TON obtained using copper perchlorate hexahydrate salt (Table 2, entry 2) are statistically similar to yield and TON obtained in case of $[L_1Cu]^{+2}$ (Table 1, entry 2) complex which suggests that ligand does not have a significant effect on promoting benzyl alcohol oxidation. To determine the role of NMI, assay was carried out without NMI (Table 2, entry 1) that produced 5.2 yield (TON = 1.04). the data suggests that over the reaction time period, NMI does not show any significant affect on yield of benzaldehyde.

Table 4.2: Oxidation of alcohols using $Cu(ClO_4)_2 \cdot 6H_2O$

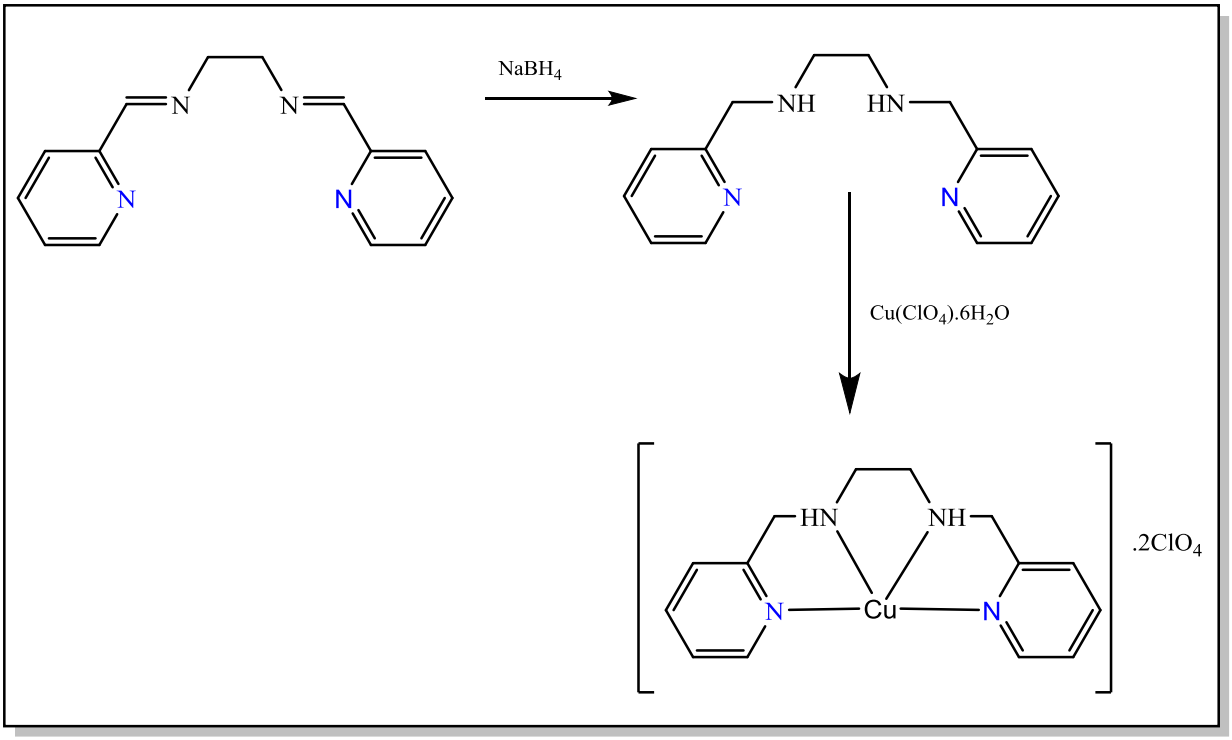
Entry	Complex (mol %)	Substrate	Base	Initiator	Yield (%)	TON
1.	$Cu(ClO_4)_2 \cdot 6H_2O$ (5 mol%)	$C_6H_5CH_2OH$	-	TEMPO	5.2	1.04
2.	$Cu(ClO_4)_2 \cdot 6H_2O$ (5 mol%)	$C_6H_5CH_2OH$	NMI	TEMPO	4.6	0.92

To the best of our knowledge, no mononuclear Schiff base derived copper complex has been reported as a catalyst for aerobic oxidation of benzyl alcohol. Grapperhaus and co-workers have recently reported an imidazole derived reduced Schiff base copper complex in an N_4 environment that efficiently catalyses benzyl alcohol oxidation whereas, it's corresponding Schiff base copper complex is inactive towards aerobic oxidation of benzyl alcohol.[24] However, only multinuclear Schiff base copper complexes have been reported as a benzyl alcohol oxidation catalyst.[20]

CHAPTER 5

Conclusion and Future Directions

In summary, A Schiff base derived Copper complex was synthesized, and characterized by electronic spectroscopy, and electrochemically. The benzyl alcohol oxidation assays employing the copper complex resulted only in stoichiometric oxidation of benzyl alcohol to benzaldehyde only. The ligand did not significantly improve the activity as suggested by control experiments. TEMPO serves as the better choice of oxidant as compared to H_2O_2 for these types of reaction. In future, the reduced Schiff base copper complex can be tested for various types of reactions such as alkene epoxidation, C–H functionalization including alcohol oxidation.



CHAPTER 6

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