Abstract

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Thesis title: "Cobalt and Copper-Based Homogeneous Catalysis For C-C and C-N Bond Formation Reactions: Applications in Organic Synthesis and Sensing."

The objective of the research work is to explore the use of low-cost earth-abundant metal complex and salts of Co and Cu, in catalysis of C-C and C-N bond formations, which gives value-added synthetic intermediates as products. To accomplish this aim, several new green and atom-economic methodologies with commercially available salts of Co and Cu have been developed. The products formed by these new methodologies have been explored in the applications of synthesis and metal sensing.

In the **first work**, a feasible one-pot synthesis of dimerized arene and heteroarene systems was achieved by employing 2 mol% of Co(II) catalyst along with Zn dust, at room temperature for 2-4 h. The Co(II)/Zn(0) system *in situ* generates Co(I) as the active catalyst. This catalyst can effectively substitute the expensive Pd catalysts and hygroscopic and air-sensitive $ZnCl_2$, generally employed to generate such dimerized heterocyclic cores. The Pd is replaced by the Co core and the anhydrous $ZnCl_2$ is replaced by the easy-to-handle and highly economic Zn dust, in its activated form. Where conventional methods use high temperature and/or longer reaction times, our synthetic strategy achieves the desired goal with a high % yield of products (70-89%) at room temperature with moderate reaction time (2-4 h) replacing expensive reagents at the same time. The Co(II) catalyst is easy to synthesize, economically viable, thermally stable, and insensitive to air or moisture. The catalyst has been well-characterized by EPR, IR, CV and UV-vis spectra and EDX studies. With a view to extend the Co-based catalysis with commercially available Co salt, an unprecedented microwave-assisted $CoCl_2$-catalyzed acceptorless dehydrogenative coupling of benzyl alcohol and amine for the synthesis of *E*- aldimines, *N*-heterocycles and H_2 under mild condition, without any complicated exogenous ligand template, oxidant, or other additives was developed in the **second work**. This environmentally benign methodology exhibits broad substrate scope (43 including 7 new products) with fair functional-group tolerance on the aniline ring. Detection of metal-associated intermediate by gas chromatography (GC) and HRMS, H_2 detection by GC and kinetic isotope effect reveal the mechanism of this $CoCl_2$ catalyzed reaction to be *via* acceptorless dehydrogenative coupling (ADC). Furthermore, kinetic experiments, and Hammett analysis with variation in nature of substituents over the aniline ring were performed to reveal the insight of the reaction mechanism with different substituents. Stable imines were

targeted next in the **third work**, by Co-catalysis, where, we have developed the first Co(II) catalyzed one-component one-pot sustainable synthesis of acyl hydrazones only from acyl hydrazides under mild reaction conditions. Traditional and contemporary methodologies use two components (usually acyl hydrazides and aldehydes/ ketones/ alcohols/ styrene) as the coupling partners. Our protocol, on the other hand, involves the *in situ* generation of aldehyde intermediate (detected by gas chromatography) from the acyl hydrazide, which then undergoes condensation with another molecule of the same acyl hydrazide in the same pot to yield acyl hydrazones in presence of mild base K_2CO_3 and low-cost $Co(OAc)_2 \cdot 4H_2O$ as catalyst. Some of the resulting acyl hydrazones have been used as synthetic precursors and explored in various post-synthetic modifications to afford *N*-heterocyclic compounds. Furthermore, photoswitchable properties of few synthesized acyl hydrazones are also explored using their *E/Z* isomerization around the C=N bond, as realized by high-pressure liquid chromatography (HPLC) and UV-vis spectroscopic studies. Unveiling the potential of $CoCl_2.6H_2O$ as catalyst, a one-step two-component visible light-mediated oxidative acylation of alkenes by aldehydes to synthesize *α,β*-epoxy ketone has been achieved in water at room temperature in the **fourth work**. The photocatalytic activity of Co(II) presented a remarkable achievement for synthesis of *α,β*-epoxy ketones from aldehydes and olefins, with a wide substrate compatibility including aromatic, hetero-aromatic and aliphatic aldehydes, styrenes with both electron-donating and withdrawing groups, *α*-substituted styrenes, stilbene, acrylates, and even the challenging unactivated aliphatic alkenes. Mechanistic studies including radical trapping experiments, intermediate detection by GCMS and Hammett analysis unveil the nature of the photocatalytic pathway.

After a series of reactions with Co-complex or salt as catalyst, we tried Cu-based C-C coupling in **fifth work**, where, a C_2-symmetric internally conjugated 1,3-di-alkyne system, containing phenolphthalein as a fluorophore and ferrocene as a redox moiety has been synthesized *via* microwave-assisted Cu(II) catalyzed Glaser-Hay coupling in neat condition for the first time. The compound was found to be highly selective towards Fe^{3+}, Cu^{2+} and Hg^{2+} ions *via* multi channels. Interestingly, Fe^{3+} and Cu^{2+} ions simply promote oxidation of ferrocene unit to ferrocenium ion without binding to the receptor whereas Hg^{2+} binds with the receptor, which was found to be the conjugated di-alkyne unit of the compound, as confirmed by ^{1}H, ^{13}C NMR and IR titrations and DFT calculations. The oxidation and binding phenomena were also investigated by optical and electrochemical analyses. Hg^{2+} ion interacts with the dialkyne system by a favorable soft-soft interaction. To investigate the interaction between Hg^{2+} ion and

alkyne unit in more details, we have designed and synthesized two thermally stable probes, one acyclic another cyclic in the **sixth work**. The acyclic compound contains two terminal alkyne units, whereas the cyclic molecule has an internally conjugated C_2-symmetric 1,3-dialkyne unit. The acyclic probe with two terminal alkynes interacted with two Hg^{2+} ions whereas the cyclic probe with cage-like structure interacted with only one Hg^{2+} ion. Hg^{2+} ion can only interact with either alkyne unit at any instant in the probe to avoid steric repulsion between two Hg^{2+} ions. The differences in the selective responses of the cyclic and acyclic structures towards Hg^{2+} ion was thoroughly established by UV-vis, emission spectroscopy and electrochemical analysis along with theoretical (DFT) studies. The probable binding site of Hg^{2+} ion with the synthesized probes were determined by ^1H NMR and IR titrations, which indicated that terminal as well as conjugated di-alkyne unit interact with Hg^{2+} ion by a favorable soft-soft interaction. Furthermore, the sweeping motion of Hg^{2+} ion between the two alkyne units of the 1,3-dialkyne moiety, was also confirmed by DFT calculations. Unlike Hg^{2+} ion, Cu^{2+} and Fe^{3+} ions did not interact with the probes, rather they induced oxidation of ferrocene centre. Both the receptors and their corresponding metal complexes are stable in the physiological pH range (pH around 7) and thermally stable up to 60°C. This study focuses for the 1st time on the comparative responses of the acyclic and cyclic architectures of same molecular unit towards metal ion recognition and it supports the fact that the alkyne group in different environments behaves differently with the same soft metal.

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