Synthesis of Tridentate NNS-Ligand Derived Manganese Complexes and Their Application toward Acceptorless Dehydrogenation and Borrowing Hydrogen Catalysis

A Dissertation

Submitted in partial fulfilment of the

Requirements for the Degree of

Doctor of Philosophy

by

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INDIA, July, 2019

Dedicated

To

My Parents, Brother, Sister, Friends

&

Teachers

INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

Department of Chemistry

Guwahati, Assam-781039, INDIA

STATEMENT

I, hereby declared that the work comprised in this thesis entitled "***Synthesis of Tridentate NNS-Ligand Derived Manganese Complexes and Their Application toward Acceptorless Dehydrogenation and Borrowing Hydrogen Catalysis***" is the outcome of the research work carried out by me under the supervision of **Dr. Dipankar Srimani, Department of Chemistry, Indian Institute of Technology Guwahati, India**, for the award of the degree of Doctor of Philosophy.

In harmony with the general practice of reporting scientific observations, due acknowledgements have been made if the work is established on the findings of other investigators.

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CERTIFICATE

This is to certify that the work incorporated in the thesis entitled "***Synthesis of Tridentate NNS-Ligand Derived Manganese Complexes and Their Application toward Acceptorless Dehydrogenation and Borrowing Hydrogen Catalysis***" which is being submitted to the Indian Institute of Technology Guwahati for the award of Doctor of Philosophy in Chemistry by **Mr. Kalicharan Das** (Roll No: 156122008) was carried out by him under my supervision at this institute. The work presented in his thesis is original and that has not been submitted elsewhere for a degree.

Guwahati

Dr. Dipankar Srimani

July, 2019

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Sincerely,

Kalicharan Das

CONTAINS

Abbreviation

Ac	Acetyl
α	Alpha
Å	Angstrom
Ar	Argon
ACN	Acetonitrile
AD	Acceptorless dehydrogenation
ADC	Acceptorless dehydrogenative coupling
br.	Broad
bi pyridine	2,2′-bipyridine
β	Beta
Bn	Benzyl
Bu	Butyl
BH	Borrowing hydrogen
CCDC	Cambridge crystallographic data centre
COD	1,5-Cyclooctadiene
$CDCl_3$	Chloroform-d
Cy	Cyclohexyl
Cat	Catalyst
^oC	Degree Celsius
d	Doublet or day
dd	Doublet of doublet
δ	Chemical shift or delta
DA	Donor-acceptor
DCE	Dichloroethane
DCM	Dichloromethane
DFT	Density functional theory
DMSO	Dimethylsulfoxide
DMF	Dimethylformamide
DMA	Dimethylacetamide
dppe	1,2-Bis(diphenylphosphino)ethane
dppf	1,1′-Bis(diphenylphosphino)ferrocene
dppp	1,3-Bis(diphenylphosphino)propane
EtOAc	Ethyl acetate
equiv.	Equivalent
ESI	Electrospray ionization
Et	Ethyl
EWG	Electron withdrawing group
EDG	Electron donating group
g	Grams
γ	Gamma

HA	Hydrogen-autotransfer
h	Hours
HRMS	High resolution mass spectrometry
Hz	Hertz
MHz	Mega Hertz
i	Iso
FT-IR	Fourier transform infrared spectroscopy
J	Coupling constant
m	Multiplet
m	*Meta*
Me	Methyl
mg	Milligram
mL	Millilitre
mmol	Millimole
Mp	Melting point
MS	Molecular seive
MLC	Metal-ligand cooperation
NMR	Nuclear magnetic resonance
Ts	Tosylate
o	*Ortho*
ω	Omega
ORTEP	Oak ridge thermal ellipsoid plot program
p	*Para*
Ph	Phenyl
Py	Pyridine
Pr	propyl
PNP	2,6-bis-(di-*tert*-butylphosphinomethyl)pyridine
ppm	Parts per million
q	Quartet
rt	Room temperature
s	Singlet
THF	Tetrahydrofuran
TEMPO	2,2,6,6-tetramethyl-1-piperidinyloxy
t	*Tert*
TMS	Tetramethylsilane
TS	Transition state
XRD	X-ray diffraction

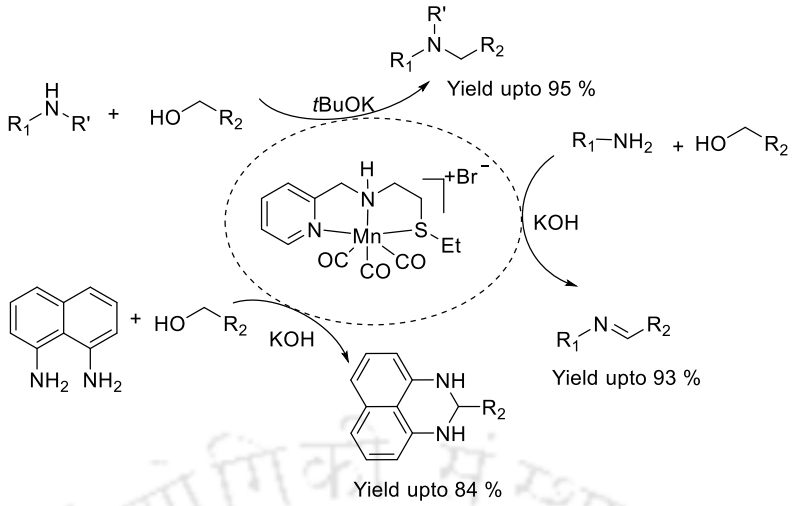
Abstract

The contents of the present thesis entitled as "***Synthesis of Tridentate NNS-Ligand Derived Manganese Complexes and Their Application toward Acceptorless Dehydrogenation and Borrowing Hydrogen Catalysis***" have been divided into five chapters based on the results achieved from the experimental works performed during the entire course of the PhD research programme.

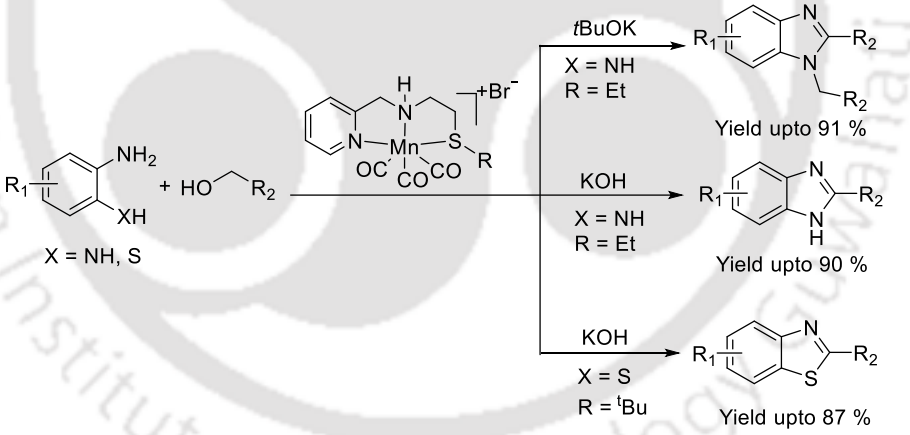
Chapter 1 contains a brief introduction about the literature review of borrowing hydrogenation, acceptorless dehydrogenation *via* metal-ligand cooperation.

Each of these chapters (**Chapter 2- Chapter 4**) contains an introduction, previous reported works, present results and discussion, an experimental section, and references, along with characterization data of products including spectral data. Overall, this thesis demonstrates some new and efficient approaches for the synthesis of different functionalized target compounds.

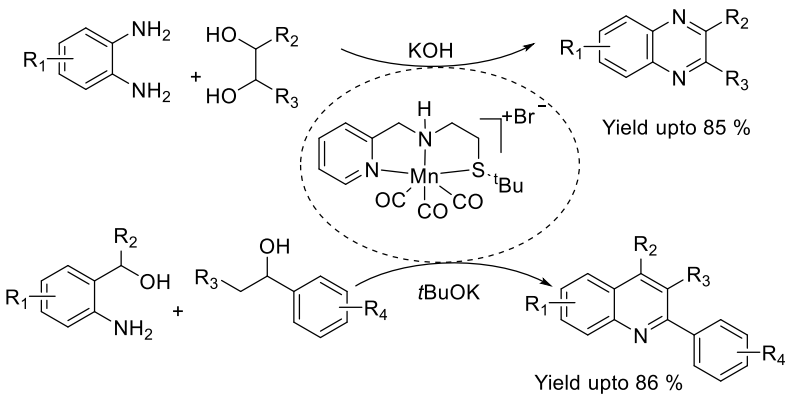
Chapter 2 highlights for the synthesis and characterisation of phosphine free tridentate NNS-ligand derived manganese complexes and an effective route for the synthesis of secondary, tertiary amine and imine *via* hydrogen-autotransfer or acceptorless dehydrogenative coupling from amine and alcohol using phosphine-free well-defined Mn(I) complex with good to excellent yield. This protocol was also used for the synthesis of 2,3-Dihydro-1*H*-perimidine derivatives as they are important class of compounds having useful biological activity. The scope of this reaction is quite broad for different substrates such as alkyl, aryl as well as heterocyclic moieties.



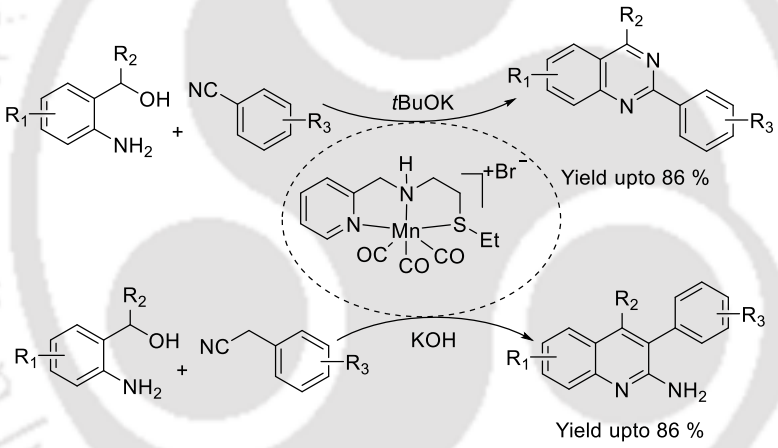
Chapter 3 demonstrates an efficient and atom-economic method for the facile synthesis of benzimidazoles and benzothiazoles using well defined new NNS manganese complexes. This protocol is quite general to access the desire products in a wide range of substrates with good to excellent yields. In addition, mechanistic studies were performed to understand the plausible reaction pathway involved for the target product formation which is discussed in this section in details.



Chapter 4 describes a general route to access highly substituted quinoxalines *via* benzene-1,2-diamine with 1,2-diol without solvent condition at 140 ^{o}C providing the desired products with different substituents. The synthetic utility of this method was also illustrated for the synthesis of valuable quinolines derivatives from amino benzyl alcohol and secondary alcohol using same Mn-catalyst just tuning the reaction condition. The generality of the reaction permitted the synthesis of quinoxaline and quinoline bearing aryl, alkyl and heteroaromatic groups.



Chapter 5 reports the development of a convenient method for the synthesis of quinazolines and 2-aminoquinolines derivatives under the catalysis of cat-**2.12a** (5 mol%) in toluene/xylene solvent at 140 °C with moderate to good yields. The scope of the reaction is quite decent, allowing for the synthesis of substituted desired products having aryl and heteroaromatic groups.



Chapter 1

The Acceptorless Dehydrogenation and Borrowing Hydrogen Catalysis via Metal-ligand Cooperation

1.1. Introduction:

Advancement of fundamental theories and reactivity in chemistry has enabled chemists to develop new synthetic processes to meet human needs. The formation of useful building blocks through carbon-carbon or carbon-heteroatom bond formation and functionalization of suitable atom to different functional groups is a special tool in organic synthesis. Despite enormous progress in the fulfilment of human necessities, future challenges remain in the development of new chemical processes by inventing new reactions, which can lessen environmental impact by minimizing waste generation and the use of renewable feedstock. In this perspective, the acceptorless dehydrogenative coupling (ADC) reaction and Borrowing Hydrogen (BH) catalysis are the extremely powerful approaches to synthesize a diverse range of useful organic building blocks.

1.2. Acceptorless dehydrogenation:

The abstraction of hydrogen atoms from the adjacent atomic position of an organic substrate is a thermodynamically uphill process. Conventionally, this could be achieved by the use of stoichiometric amounts of inorganic oxidants such as dichromate,[1] permanganate ions in the presence of strong mineral acids,[2] silver oxide[3] and lead tetraacetate.[4] Alternatively, catalytic transfer hydrogenation strategy using stoichiometric amounts of sacrificial organic acceptor[5] has also been practiced to achieve this process. Both the methods generate copious stoichiometric toxic waste[6] and thereby causing adverse effect on the environment. On the contrary, ADC reactions are well-recognized sustainable processes, as they do not need any external oxidant or prefunctionalization of the substrates. Acceptorless dehydrogenation (AD) reactions perform not only the simple removal of hydrogen gas from various substrates but also develop efficient and environmentally benign synthetic methodologies by the involvement of intermediates resulting from dehydrogenation process in further reaction process. Therefore, catalytic acceptorless dehydrogenation has become an expedient process for the manufacturing of vendible chemicals.[7]

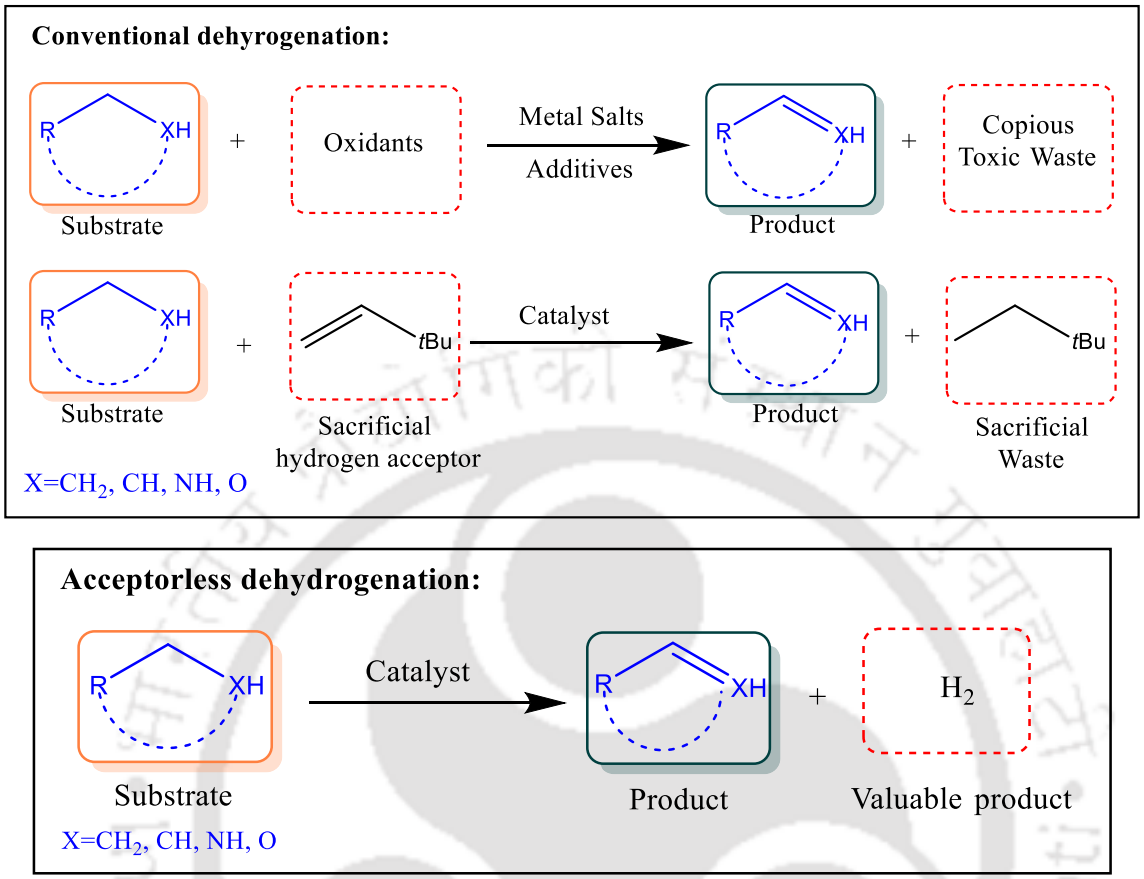


Figure 1: (a) Conventional dehydrogenation reactions, (b) Acceptorless dehydrogenation reaction.

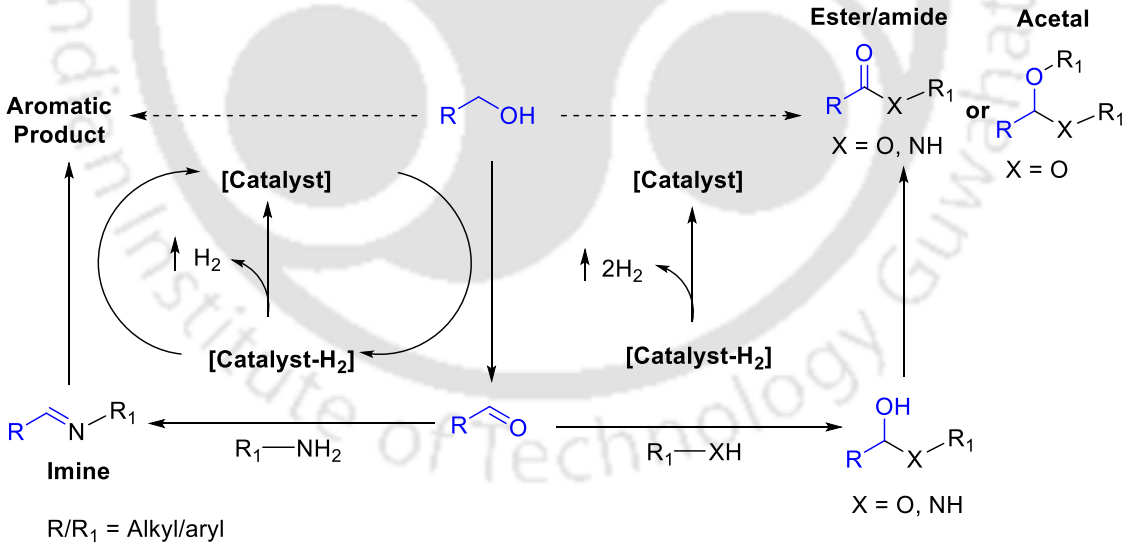
In ongoing research, acceptorless dehydrogenation methodology mainly involves **alcohol dehydrogenation**, **amine dehydrogenation** and **alkane dehydrogenation**, which appears to serve a significant role in synthetic organic chemistry. In many cases, the reaction proceeds *via* metal-ligand cooperativity.

1.2.1. Alcohol dehydrogenation:

Conventionally the oxidation of alcohols is performed by the use of stoichiometric amount of strong toxic oxidants such as chromium-based,[8] manganese-based,[9] silver based[10] and DMSO-based reagents.[11] Alcohol oxidation was also carried out in the presence of other different oxidants such as Dess-Martin Periodinane,[12] *o*-iodoxybenzoic acid (IBX),[13] sodium hypochlorite (NaOCl),[14] TEMPO (2,2,6,6-tetramethyl-1-piperidinyloxy)[15] etc. Although the high significance and wide application of these processes proved their efficacy in the organic synthesis, they often suffer from

the generation of substantial amounts of side products or wastes. Recently, greener approaches for oxidation reaction have been accomplished.[16]

In this regards, acceptorless dehydrogenation of alcohols has attracted significant attention, as the process is green, atom-economical and the alcohols are easily available either by different industrial processes or can be obtained renewably from lignocellulose.[17] Additionally, the emitted hydrogen gas itself a valuable product. In this strategy, first alcohol is transformed into more reactive aldehyde/ketone and the in situ formed carbonyl compound is coupled with different nucleophile resulted in the formation of new carbon-carbon or carbon-heteroatom bond. Here, the transition metal catalyst plays an important role to activate the alcohol molecules to form aldehyde or ketone. First, the transfer of two H atoms from the alcohol moiety to the catalyst occurs, where one H atom is transferred from a CH bond adjacent to the -OH group and another H atom from the alcoholic -OH group. Then the hydrogen enriched Catalyst-H_2 returns back to its original active catalytic species by elimination of a hydrogen molecule (**Scheme 1.1**). Here, a brief overview of the field is discussed.



Scheme 1.1: General overview of acceptorless dehydrogenation of alcohol.

1.2.2. Dehydrogenation of alcohols to form aldehyde/ketone:

During the last three decades, various homogenous catalysts have been employed for the dehydrogenation of alcohol to form aldehyde or ketone with the concomitant

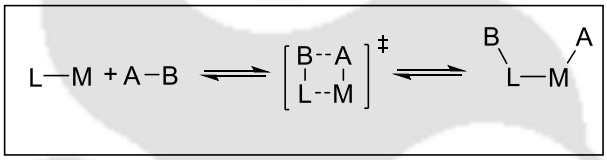
generation of molecular hydrogen in absence of any hydrogen acceptor. *Dobson and Robinson*[18] in their pioneering work demonstrated $[Ru(OCOCF_3)_2(CO)(PPh_3)_2]$ catalysed dehydrogenation of primary and secondary alcohol. Here first, in presence of excess alcohol (RCH_2OH), the alkoxide complex $[Ru(OCH_2R)(OCOCF_3)(CO)(PPh_3)_2]$ is generated with the simultaneous liberation of CF_3CO_2H. Next, the β-hydride elimination will lead to the formation of hydride complex $[RuH(OCOCF_3)(CO)(PPh_3)_2]$ and the corresponding aldehyde (for secondary alcohol ketone). Finally, excess CF_3CO_2H is required to regenerate the original catalyst with the liberation of H_2 and hence this protocol is termed as 'acid-promoted' strategy. *Jung and Garrou* also reported dehydrogenation of alcohol utilizing the similar concept and they also performed the mechanistic studies.[19] *Hulshof and co-workers* also shed light on the dehydrogenation process and illustrated that the dehydrogenation of primary alcohols is complicated by the decarbonylation process which leads to the catalyst deactivation.[20] *Morton and Cole-Hamilton* revealed the efficacy of various ruthenium and rhodium complexes toward the dehydrogenation of ethanol, propanol and isopropanol. These base promoted protocols showed hydrogen production from lower molecular weight alcohols with reasonable rate.[21] *Wilkinson's* catalyst in presence of triethylamine is also effective for the dehydrogenation of isopropanol.[22] *Beller and co-workers* illustrated the catalytic efficiency of $[RuCl_3.xH_2O]$ and $[RuCl_2(p\text{-cymene})]_2$ toward alcohol dehydrogenation in presence of PCy_3.[23] Subsequently, various different ligand derived metal Ru and Ir metal complexes were also found to be active for this process.[24]

Conventionally the acceptorless alcohol dehydrogenation proceeds through the oxidative addition, which will lead to the formation of metal hydride complex. Next, the β-hydride elimination forms the carbonyl compound together with metal dihydride species which upon reductive elimination liberates H_2 with simultaneous regeneration of the original active catalyst. There are several drawbacks associated with the classical method of alcohol dehydrogenation. During the catalytic process, the redox adjustment of the metal centre is energetically highly unfavourable. Hence, a very high temperature is usually required for effective catalysis. Generally, these processes occurred under basic condition, which leads to the formation of aldol type side products and thereby

limits of the yield of desired product and complicates the product separation. Furthermore, the stability of the metal-alkoxide complex sometimes make the β-hydride elimination process difficult. To overcome these shortcomings, recently metal-ligand cooperativity has attracted considerable attention. Here, I present a brief introduction about the Metal-Ligand cooperation.

1.2.3. Metal Ligand Cooperation:

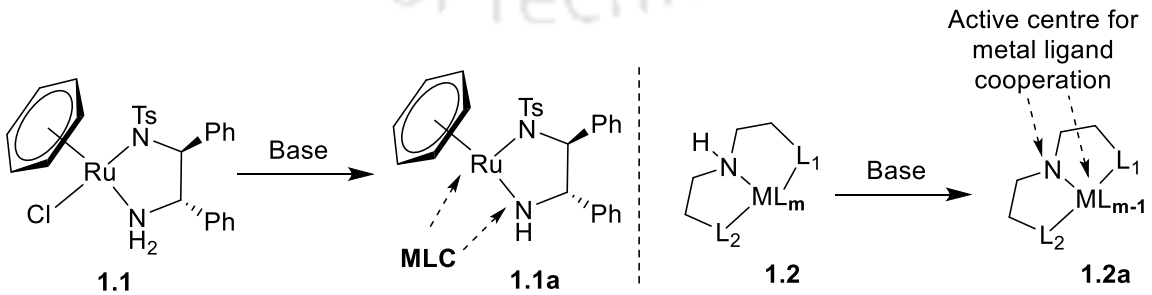
Conventionally, transition metal catalysis depends only on the activity of metal centres, where the ligands play an important role to tune the steric and the electronic requirement of the metal centre but the ligands are not directly involved in the bond activation. In Metal-ligand cooperation (MLC),[25] both the metal and the ligand are directly participated in the bond activation processes and their interplay facilitates chemical processes avoiding the oxidative addition and reductive elimination steps.

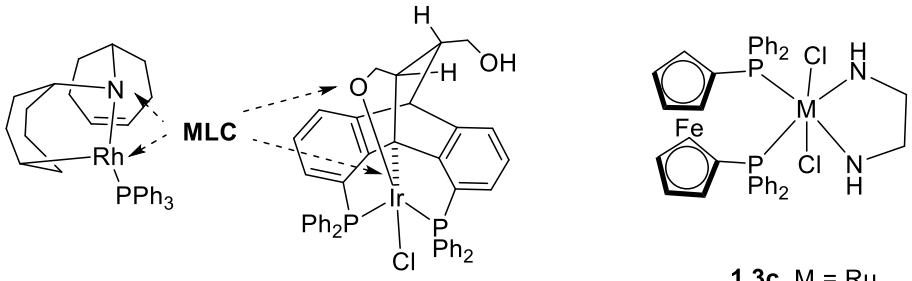


Scheme 1.2: Metal-ligand cooperative bond activation process.

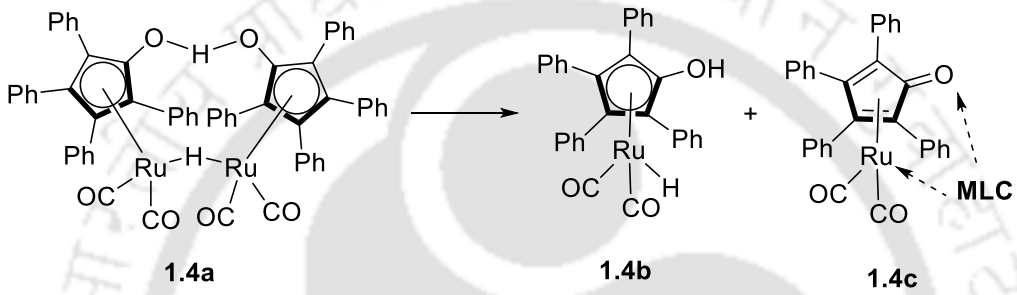
The MLC catalyst consists of a basic site (Lewis basic) which is located at appropriate place of the ligand framework and metal centre behave as a lewis acidic site. These two sites cooperate in synergistic manner to activate the alcohol molecule. MLC catalyst can be classified into three categories (α–, β– and γ– protic) according to the position of lewis basic site with respect to the metal centre.[26]

α-Protic Metal-Ligand Cooperative Catalyst:

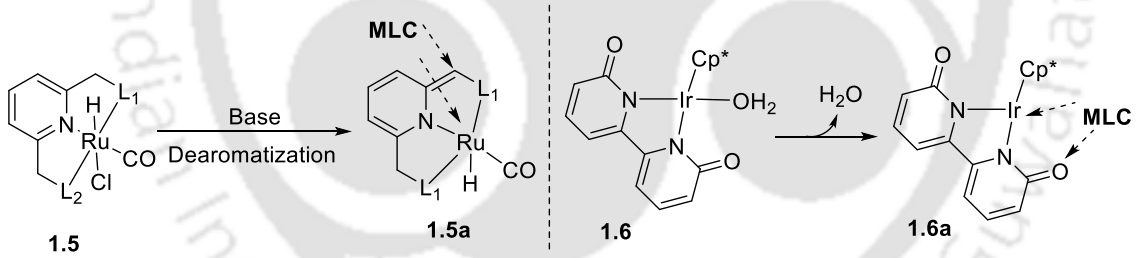




β-Protic Metal-Ligand Cooperative Catalyst:



γ-Protic Metal-Ligand Cooperative Catalyst:

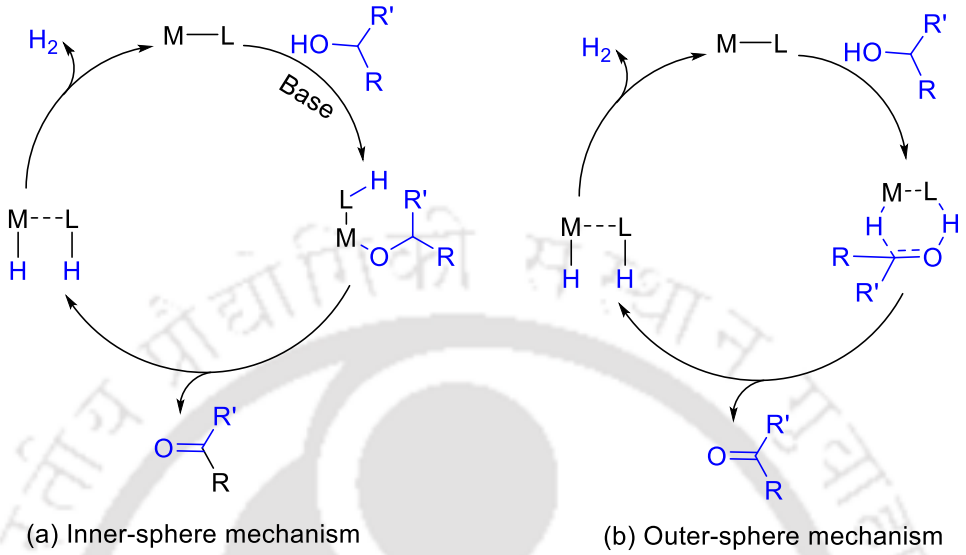


Scheme 1.3: Different types of metal-ligand cooperation reactions.

Some important MLC catalysts and the active sites for metal-ligand cooperation are shown **Scheme 1.3**.

The catalysis proceeds either through inner-sphere mechanism or *via* outer sphere mechanism. In the inner-sphere mechanism, the alcohol directly binds to metal centre and it involves β-hydride elimination whereas in the outer-sphere mechanism, transfer of proton and hydride happens in concerted manner *via* six-membered cyclic transition states. By the help of metal-ligand cooperation not only O-H bond are activated but also

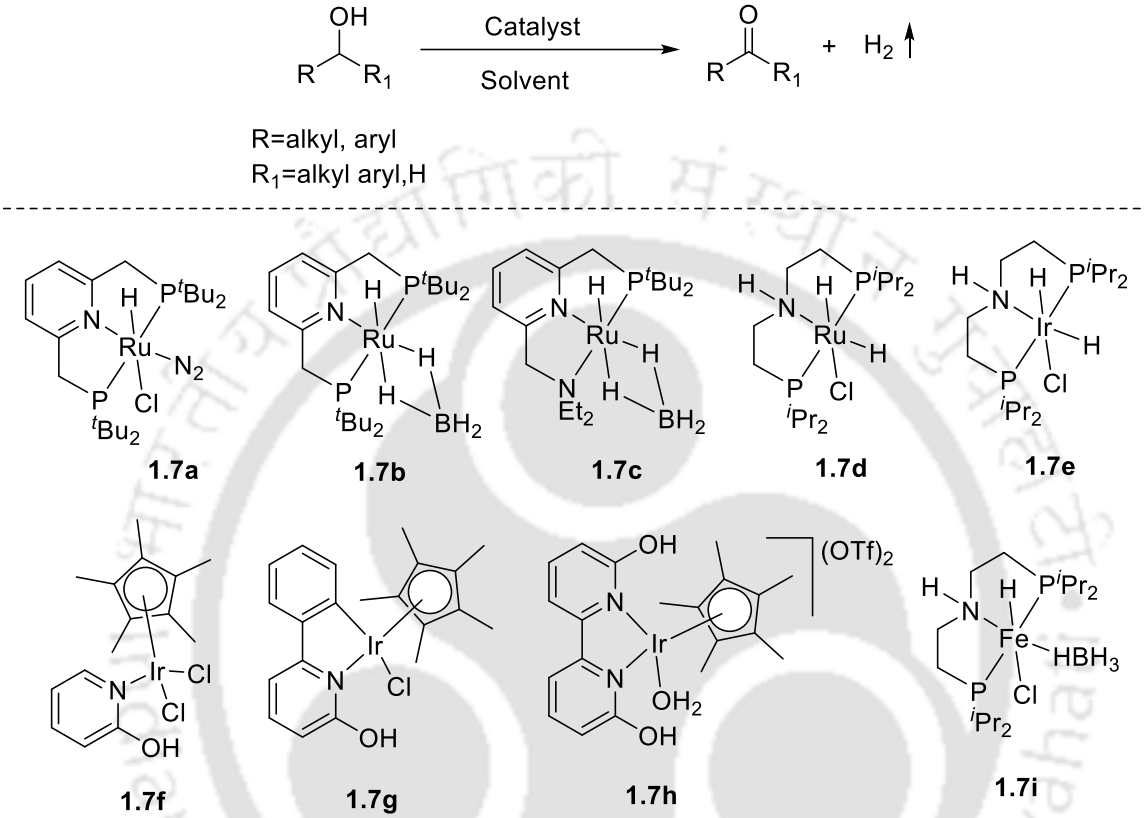
different other bonds like N-H, H-H, B-H and Si-H can be activated which will lead to various useful organic transformations.[25]



Scheme 1.4: General mechanistic pathway for (a) inner-sphere and (b) outer-sphere mechanism.

In 2004, the *Milstein group* reported the pyridine based ruthenium PNP [2,6-bis-(di-*tert*-butylphosphinomethyl)pyridine] pincer complex **1.7a** which showed excellent catalytic activity toward the dehydrogenation of secondary alcohols with low catalyst loading in presence of base.[27] But, their catalyst failed to dehydrogenate primary alcohols. Later the same group showed that the modified catalysts **1.7b** and **1.7c** which can also dehydrogenate the secondary alcohols in absence of base. The catalyst **1.7c** was found to be more reactive than **1.7b** and 93% conversion of 1-phenylethanol to the corresponding ketone was achieved with 0.1 mol% catalyst **1.7b.**[28] In the year 2007, *Yamaguchi and co-workers* applied the iridium complex **1.7f**[29] to catalyse the dehydrogenation of secondary alcohols. Benzyl alcohol gave only 24% benzaldehyde even with 1 mol% catalyst loading. The study of the catalytic efficiency of the complex **1.7d** and **1.7e**, toward the dehydrogenation of isopropanol in the presence of varied amounts of base was reported by *Beller and co-workers* in 2011.[30] Recently, *Fujita and Yamaguchi* presented the iridium catalyst **1.7g** for catalytic dehydrogenation of both primary and secondary alcohols to obtain the corresponding aldehydes or ketones in good yield. Similar type of dehydrogenation in water medium was also achieved with the

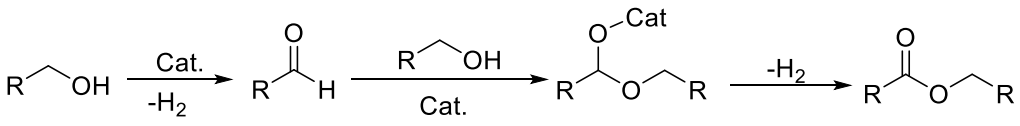
water-soluble catalyst **1.7h.**[31] Very recently, *Beller and co-workers* applied earth-abundant transition metal complex **1.7i** for the dehydrogenation of secondary alcohols to ketones.[32]



Scheme 1.5: The dehydrogenation of alcohols by well-defined metal complexes.

1.2.4. Dehydrogenative ester formation reaction:

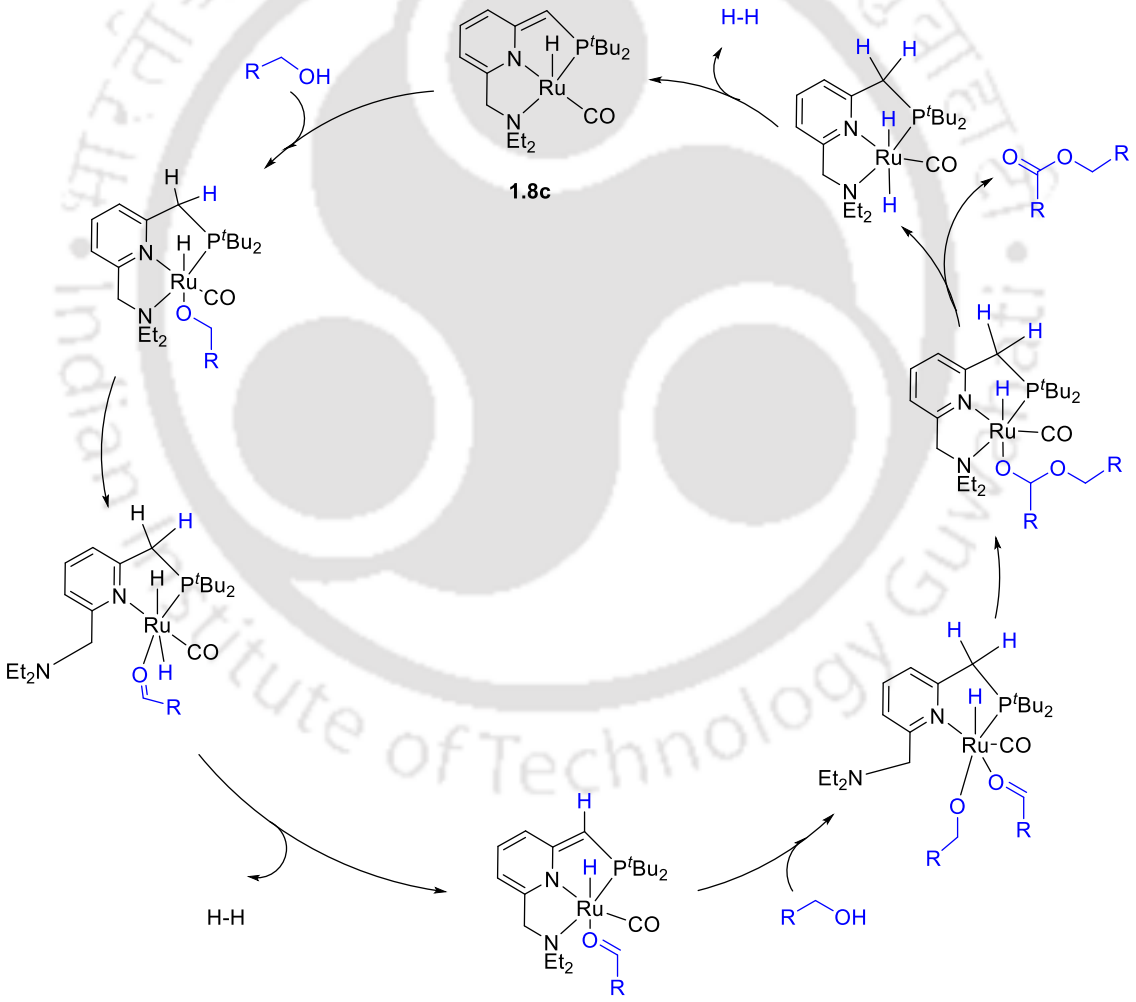
The esterification of alcohols is considered to be one of the most useful organic reactions due to its wide synthetic application in the production of many bioactive



Scheme 1.6: Plausible mechanism for the synthesis of ester via acceptorless dehydrogenation.

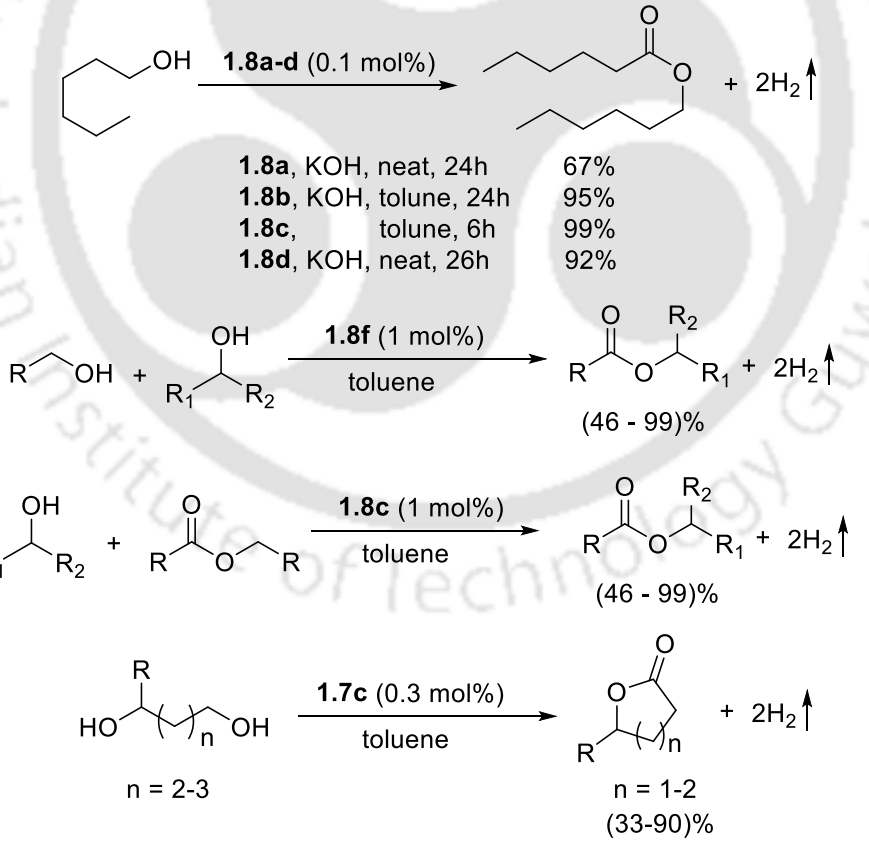
compounds, pharmaceuticals, fragrances, polymers, biodiesels and paints.[33] Typically, the reaction of carboxylic acid and its derivatives with the appropriate alcohols are used for the preparation of the different ester compounds. In recent years, alternative green strategies for the synthesis of esters were established *via* the dehydrogenative coupling of alcohols.

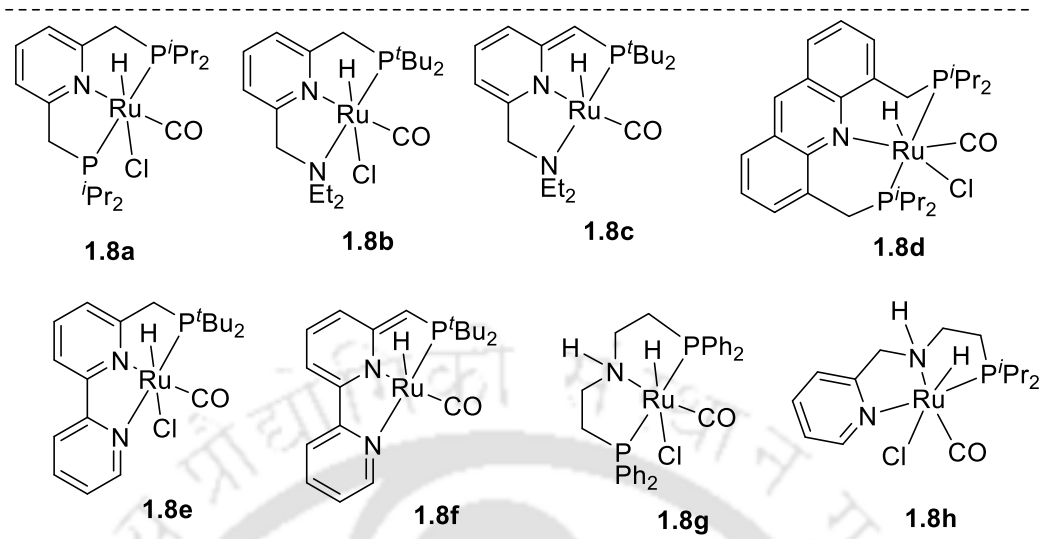
Initially, *Shvo and co-workers* demonstrated ruthenium catalysed dehydrogenative coupling of alcohols to esters.[34] *Murahashi and co-workers* utilized 2 mol% $RuH_2(PPh_3)_3$ for the effective conversion of alcohols to esters at very high temperature 180 °C in absence of hydrogen acceptor.[35] Their protocol is also effective



Scheme 1.7*:* Plausible catalytic cycle for the dehydrogenative coupling of alcohols to form esters catalysed by Ru-PNN complex.

for the synthesis of lactones from 1,4- or 1,5-diol and their study revealed that the presence of acceptor significantly enhances the lactonization process. In 2005, *Milstein and co-workers* illustrated the applicability of the MLC for the efficient conversion of alcohol to the corresponding ester.[36] Both the precatalyst **1.8a** and **1.8b** are effective in presence of catalytic amount of base. The hemilability of the amine "arm" plays an important role and makes the precatalyst **1.8b** more effective compared to **1.8a**. Actually, in presence of catalytic amount of base pre-catalyst **1.8b** converted to the corresponding dearomatised catalyst **1.8c** which is equally active in the absence of base. The mechanism of the reaction is depicted in **Scheme 1.7**. They also established the dehydrogenative lactonisation process.[28] In the year 2012, *Beller and co-workers* applied Ru-MACHO precatalyst **1.8g** for the synthesis of ethylacetate in bulk scale.[37] In the same year, *Gusev and his group* explored the impressive activity of complex **1.8g** toward dehydrogenative coupling of ethanol.[38] Cross dehydrogenative coupling of primary and

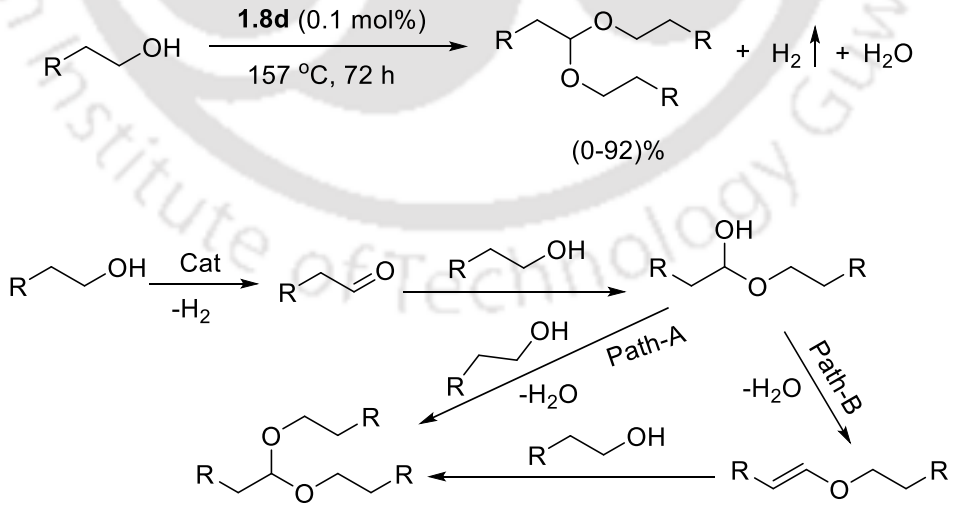




Scheme 1.8: The dehydrogenative synthesis of ester by noble metal catalyst.

secondary alcohols to form mix-ester was also developed.[39] The selectivity toward the cross product was found to be moderate (79%) when equimolar amount of primary and secondary alcohol was taken, which was further enhanced to 93% increasing the ratio from 1:1 to 1:2.5. Very recently, earth-abundant transition metal such as Co[40] and Mn[41] have been used to explore this kind of reaction.

1.2.5. Dehydrogenative coupling of alcohols to form acetals:

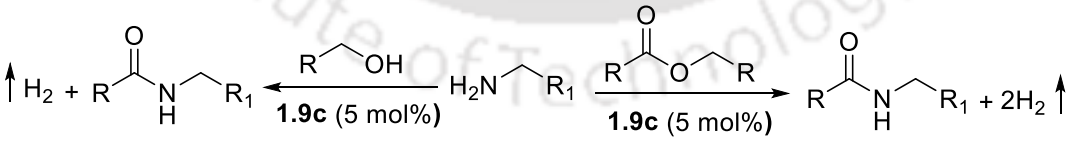


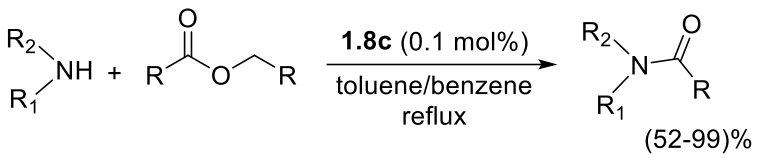
Scheme 1.9*:* Plausible mechanism for acetalization.

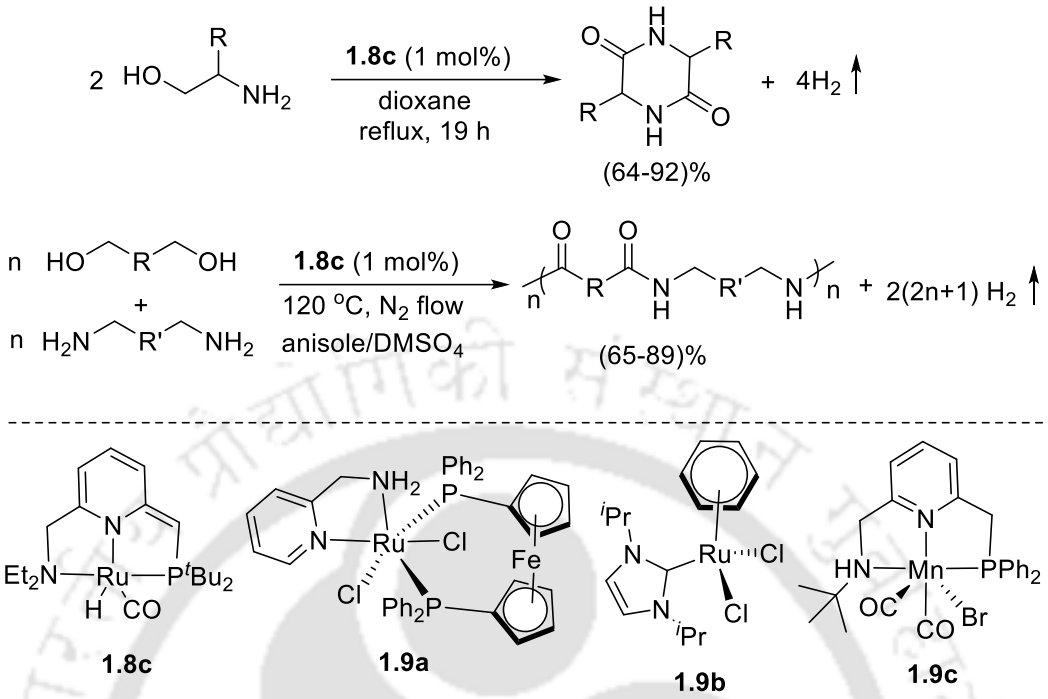
Acetals are conventionally prepared through the acid catalysed reaction of aldehyde/ketone with the alcohols.[42] *Murahashi and co-workers* first demonstrated a greener approach to access acetal directly from alcohol with 24 TON.[43] In 2009, the group of *Milstein* illustrated an efficient dehydrogenative synthesis of ester by the help of long-range MLC. Linear primary alcohol gave good yield of the acetal product in the presence of 0.1 mol% of Acr-PNP Ru-complex **1.8d** under heating condition (**Scheme 1.9**).[44] Small amounts of esters formation was also detected. It was observed that alcohols without *β*-hydrogen such as benzyl alcohol did not undergo an acetal formation.

1.2.6. Dehydrogenative coupling of alcohols with amines to form amides:

Amide is considered to be an important functional group in organic chemistry because of its wide application in biology as well as chemistry.[45] The synthesis of amide under neutral condition is highly challenging.[46] Recently, dehydrogenative synthesis of amides has attracted lot of attention as this could be performed under neutral condition. *Gunanathan and Milstein*, in their pioneering work, reported a new strategy to synthesize amide directly from amine and alcohol. The reaction is catalysed by 0.1 mol% **1.8c** and it generates molecular H_2.[47] The strategy is further extended to achieve the synthesis of peptides and polyamides directly from diols and diamines.[48] Afterwards, other Ru-complexes are also applied to catalyse this transformation.[49] Furthermore, amino alcohols are also applied to synthesize linear or polypeptides.[50] It is worth mentioning that chiral amino-alcohols gave cyclic peptide with retention in configuration. The dehydrogenative synthesis of amide by the reaction of ester and amine was also reported.[51]





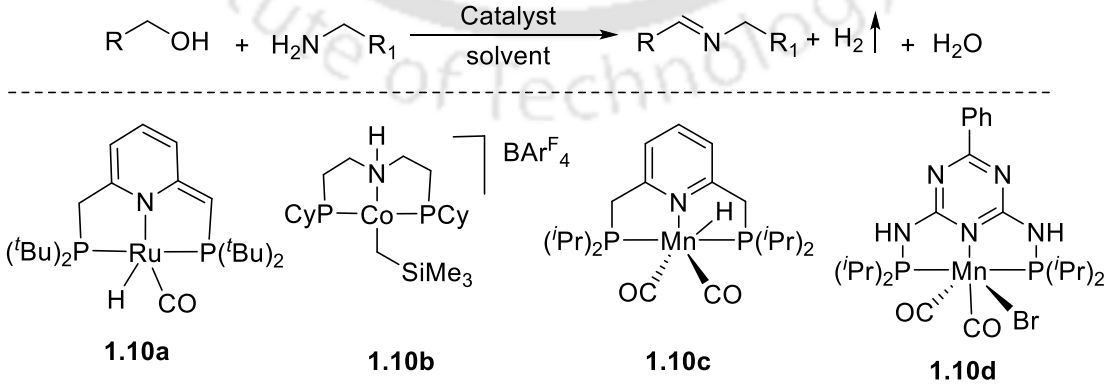


Scheme 1.10: The synthesis amides through dehydrogenative coupling reaction.

Of late, *Milstein and co-workers* have applied Mn-complex **1.9c** for the synthesis of amides by the coupling of primary amines with either alcohols or esters.[52] Fe-complexes were also utilized for the synthesis of amides.[53]

1.2.7. Dehydrogenative coupling of alcohols with amines to form imines:

Dehydrogenative coupling of alcohol and amine is a promising environmentally benign approach to synthesize imines. In 2010, the *Milstein group* first reported the

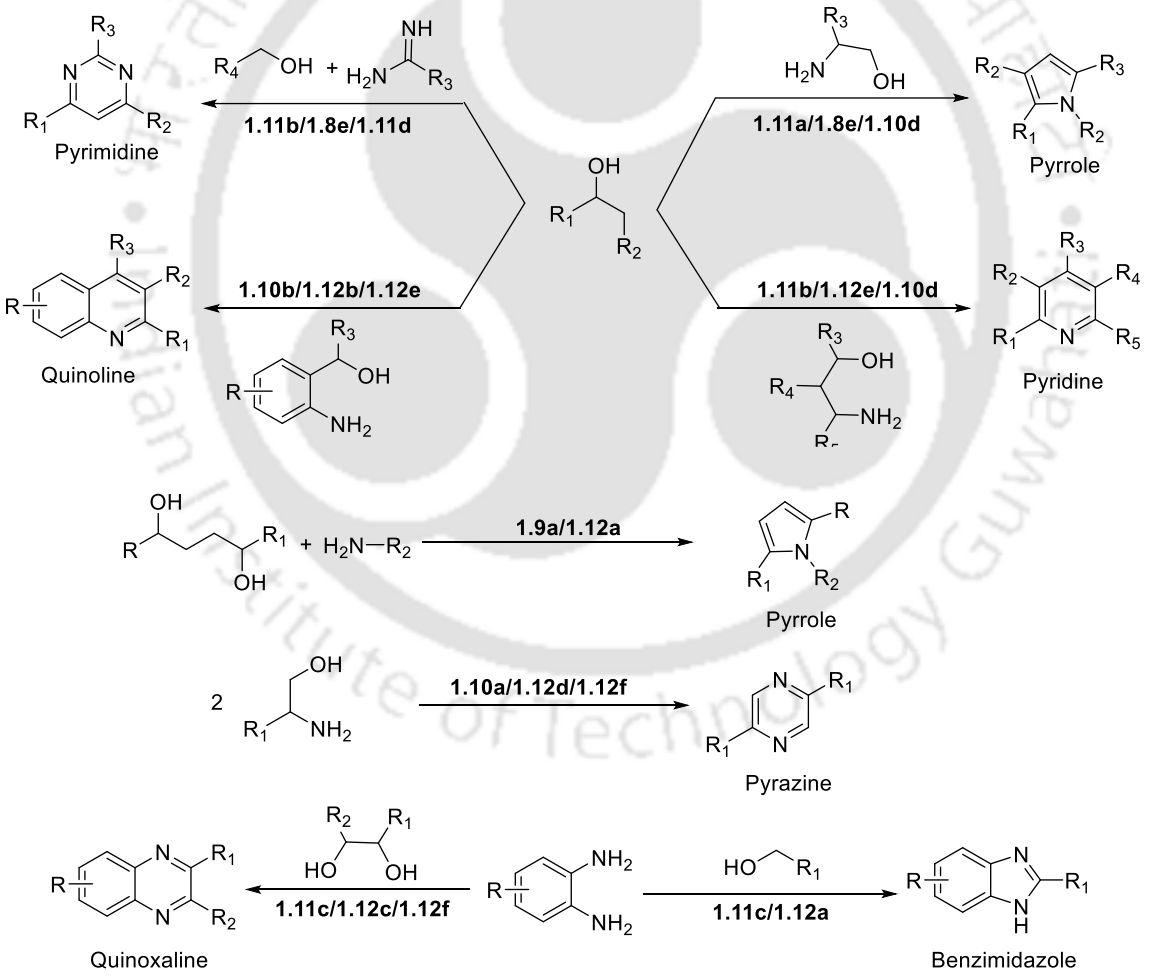


Scheme 1.11: The synthesis of imines *via* dehydrogenative coupling of alcohols with imines.

ruthenium catalysed acceptorless dehydrogenative synthesis of imines from the reaction between alcohols and amines.[54] Following this report, several other noble metal-based catalytic systems for imine synthesis have been developed.[55] In 2013, *Zhang and Hanson* first utilized cobalt complex **1.10b** for such transformation.[56] Recently, the group of *Milstein*[57] and *Kempe*[58] independently reported earth-abundant Mn-Complex (**1.10c**, **1.10d**) catalysed dehydrogenative imine synthesis.

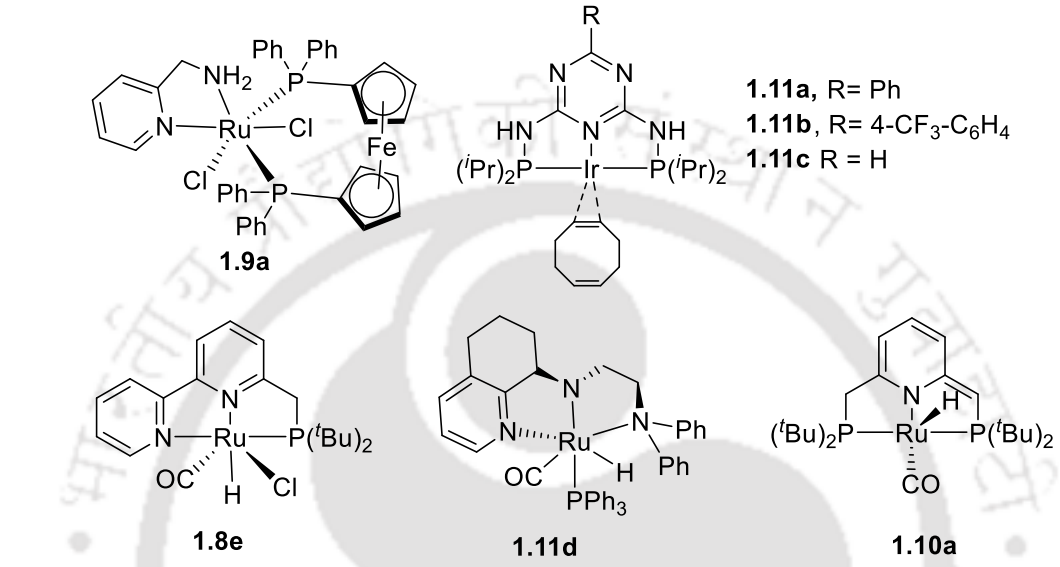
1.2.8. Dehydrogenative coupling of alcohols to form heteroaromatic compounds:

Development of sustainable synthesis of *N*-heterocycles directly from alcohols has attracted considerable attention (**Scheme 1.12)** as these compounds are present in a

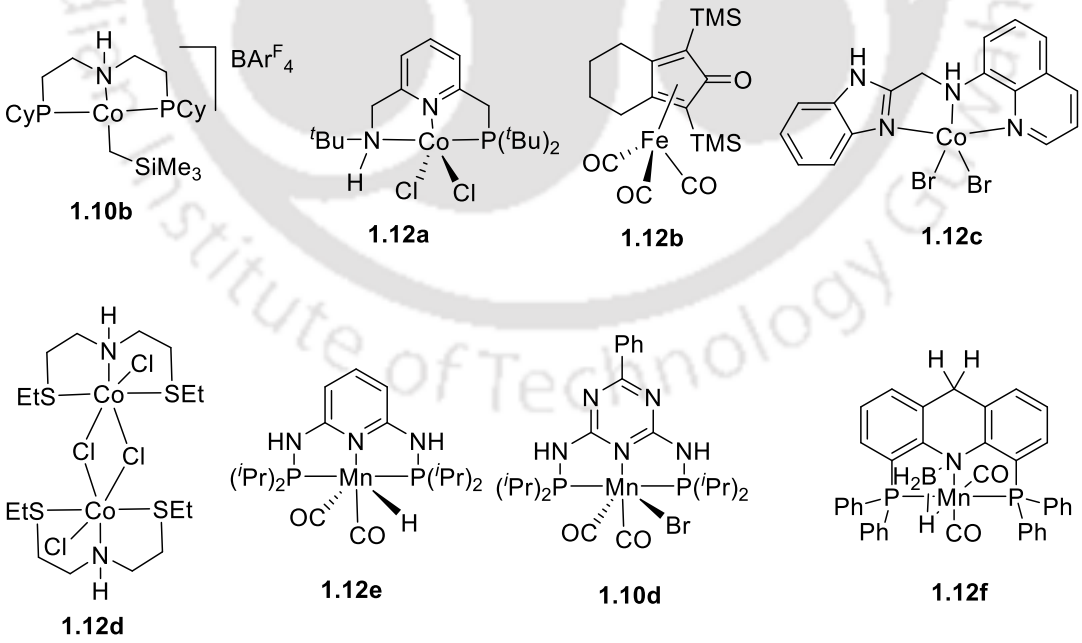


Scheme 1.12: Sustainable synthesis of *N*-heterocycles *via* dehydrogenative coupling of alcohols.

large number of bioactive molecules,[59] natural products,[60] drugs,[61] vitamins,[62] agrochemicals,[63] dyes[64] and flavors.[65] The strategy involved sequence of multiple dehydrogenation and condensation reaction. Varieties of noble-metal catalysts have been employed to catalyse such types of reaction.



Scheme 1.13: Some noble metal complexes that are used for synthesis of N-heterocycles.



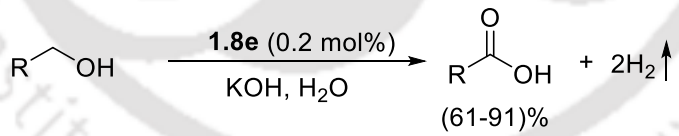
Scheme 1.14: Some earth-abundant transition metals complexes that are used for synthesis of *N*-heterocycles.

A ruthenium catalysed sustainable synthesis of pyrrole directly from 1,4-diol and amines was developed by the *Crabtree group*.[66] In 2013, the group of *Kempe, Milstein* and *Saito* independently developed the dehydrogenative coupling *β*-amino alcohols with secondary alcohols to synthesize functionalized pyrroles.[67]

Later, this strategy has been extended to synthesize pyridines from *γ*-amino alcohols and secondary alcohols [68] and quinoline from 2-aminobenzyl alcohol and secondary alcohol. [69] The homocoupling of *β*-amino alcohols also leads to the formation of pyrazine molecule.[70] Dehydrogenative synthesis of quinaxoline and benzimidazole was also achieved by the reaction of 1,2-diaminobenzene.[71] In 2013, *Beller and co-workers* also developed an elegant synthesis of pyrroles *via* three-component coupling catalysed by ruthenium.[72] Subsequently, the noble metal catalysed synthesis of a wide variety of heterocycles was reported.[73] Very recently, earth-abundant transitions metals such as Co,[74] Fe,[75] Mn[76] and Ni[77] complexes have also been applied for heterocycles synthesis.

1.2.9. Dehydrogenative synthesis of acid from alcohol:

The conversion of alcohols to carboxylic acids is an important industrial reaction to synthesize many bulks and fine chemicals.[78] Conventionally, stoichiometric oxidants

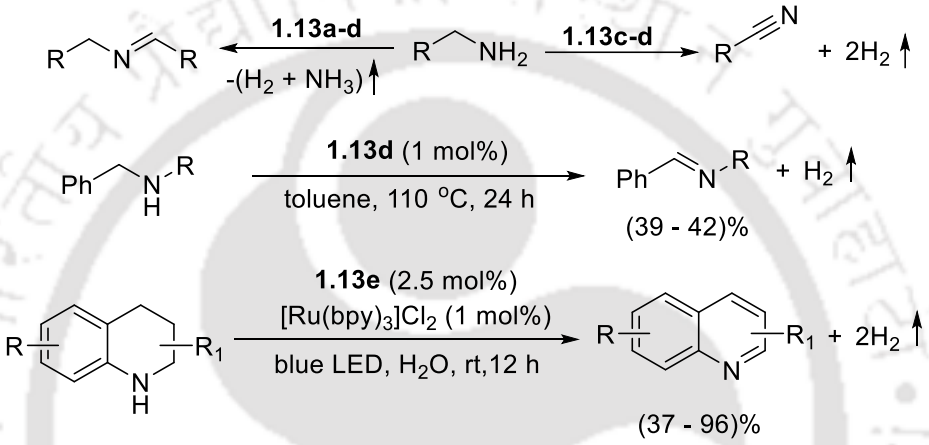


Scheme 1.15: The dehydrogenative synthesis of acid from alcohol.

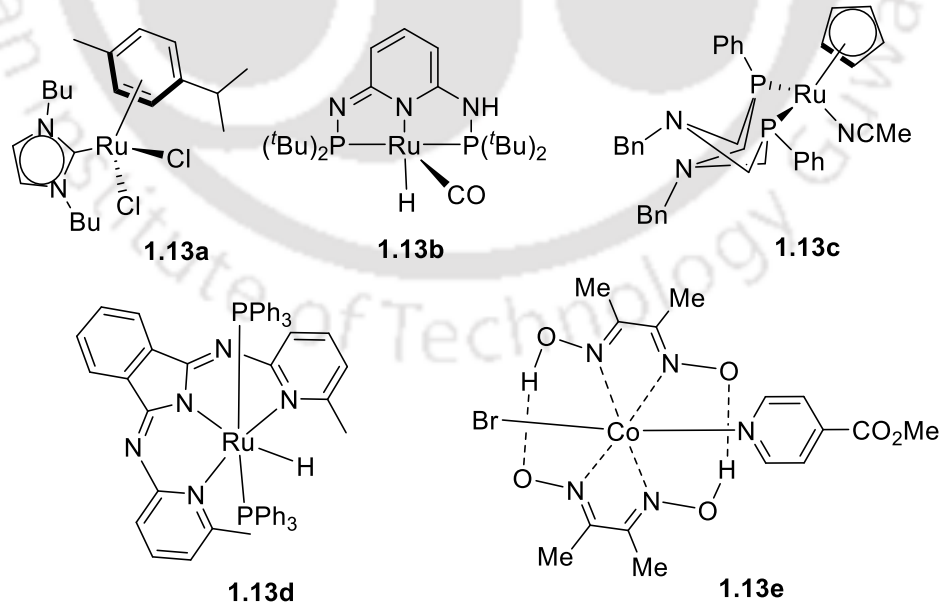
and chlorinated solvents are used to accomplish this transformation.[78b-d] Recently, metal-catalysts such as Rh[79] and Ru[80] has also been applied to catalyse the transformation of alcohols to carboxylic acids without any traditional oxidants.

1.2.10. Dehydrogenation of amines:

In comparison to alcohol-dehydrogenation, the amine-dehydrogenation is much less documented. Excess amount of base, high temperature or the presences of acceptors have been employed in this process.[81] In 2011, *Peris and Albrecht* reported ruthenium catalysed homo-coupling of amines to form imines at high temperature (150 °C).[82] Successively catalyst **1.13b**[83] and catalyst **1.13c**[84] have been employed to catalyse the



Scheme 1.16: Synthesis of imine, nitrile, *N*-heterocycle through acceptorless dehydrogenation of amines.

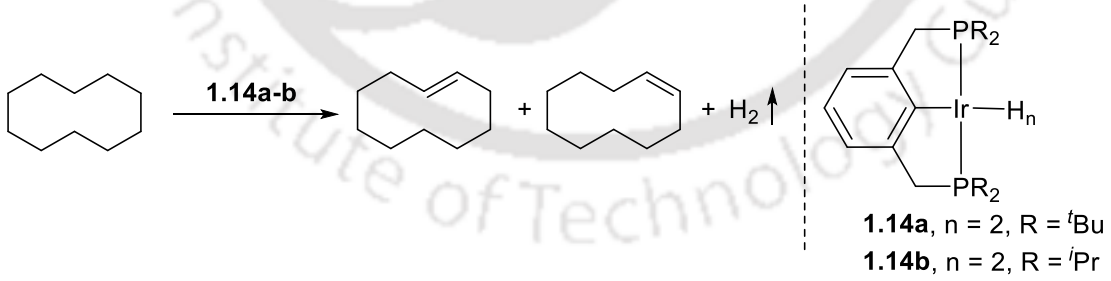


Scheme 1.17: Some metal catalysts that are used for dehydrogenation reaction of amines.

similar types of reaction under relatively milder condition. In 2013, the group of *Szymczak* developed catalyst **1.13d** for the selective dehydrogenation of primary amine to nitrile and secondary amine to imine product.[85] In 2019, *Balaraman and co-workers* demonstrated the catalytic dehydrogenation of cyclic amines in water. Both the photoredox catalyst $[Ru(bpy)_3]_2+$ and the proton-reduction catalyst **1.13e** are essential for this process.[86]

1.2.11. Alkane dehydrogenation:

The alkanes are the most abundant and inexpensive organic resource in the chemical industry. Thus, the utilization of alkane in various chemical transformations is a paramount goal in catalysis. But alkanes are typically too stable to participate in chemical reactions. In contrary, alkenes are highly reactive and olefins can be easily converted to various different compounds including ketone, aldehyde, alcohol, acids, amines, alkyl halides etc. Thus, the conversion of alkane to the alkene in selective manner is highly important area of research. The pioneering work of *Crabtree and co-workers* reported the dehydrogenation of cyclopentane or cyclooctane in presence of $[IrH_2(O_2CCF_2CF_3)(PCy_3)]$ and tertbutylethylene.[87] In 1999, *Jensen, Goldman and co-workers* reported first acceptorless dehyrogenation of cyclodecane in presence of Ir(PCP) pincer complex **1.14a** at very high temperature (200 °C).[88a] Afterwards, the sterically



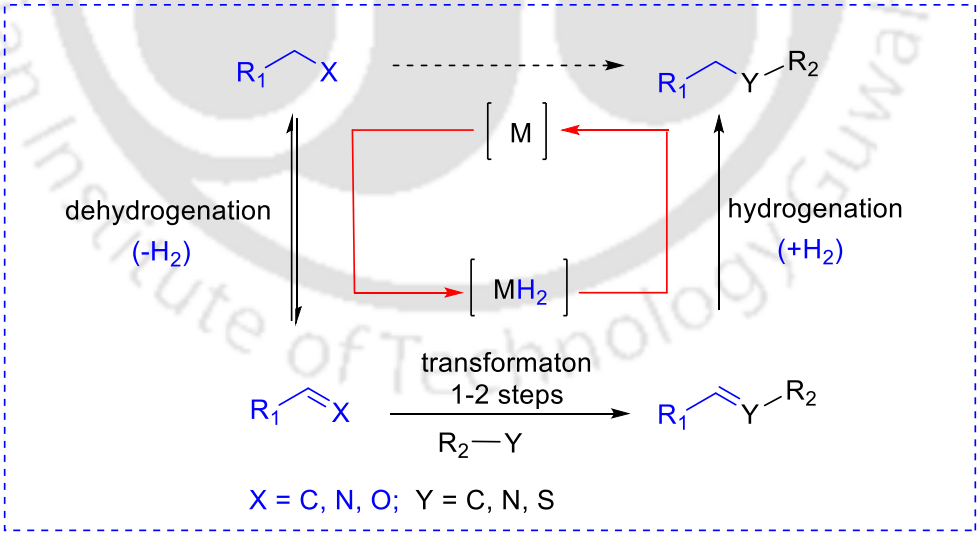
Scheme 1.18: Iridium catalysed dehydrogenative reaction of alkane.

less-crowded complex **1.14b** was found to be more reactive. Furthermore, the catalyst **1.14b** was also effective toward acceptorless dehydrogenation of *n*-alkanes.[88b]

Subsequently, a series of different catalysts was developed to catalyse alkane dehydrogenation processes.[88c]

1.3. Borrowing Hydrogen Catalysis:

The 'borrowing hydrogen' (BH) method is a unique strategy, in which catalysts temporarily store the hydrogen released from a donor molecule and finally that will be utilised in the hydrogenation step. Therefore, this approach is also termed as hydrogen-autotransfer (HA) process. The strategy consists of three distinct steps, (a) dehydrogenation reaction, (b) intermediate reaction and (c) the hydrogenation reaction (**Scheme 1.19**). In the dehydrogenation step, less reactive donor molecule such as alkane, alcohol or amine is temporarily transformed to a more reactive substrate such as alkene, aldehyde/ ketone or imine with the formation of metal hydride. Next, the reactive substrate will undergo further transformation to generate activated intermediate. In the final step, an activated intermediate is hydrogenated by the intervention of the metal hydride formed in the first step. Thus, the approach is highly useful in terms of synthetic, economic and environmental aspect.



Scheme 1.19: Basic scheme of the BH methodology.

The borrowing hydrogen methodology has been used in many homogeneous and heterogeneous catalysis and it mainly provides a useful alternative way to construct C-C

and C-N bonds. Here, I mostly discussed the synthetic applicability of BH method in homogeneous catalysis. The discussion is divided into three parts depending upon the structure of the hydrogen-donor substrate.

1.3.1. Activation of alcohols

1.3.2. Activation of amines

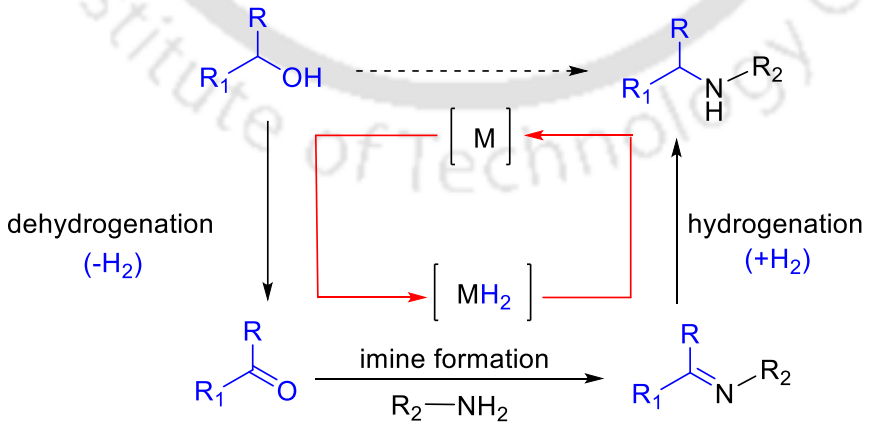
1.3.3. Activation of alkanes

1.3.1. Activation of alcohols:

In this approach, first the alcohol is converted to a more reactive carbonyl compound, which further reacts with nitrogen nucleophile or carbon nucleophile to generate an activated intermediate. The final product is formed *via* the hydrogenation of the activated intermediate.[89]

1.3.1.1. Amination of alcohols:

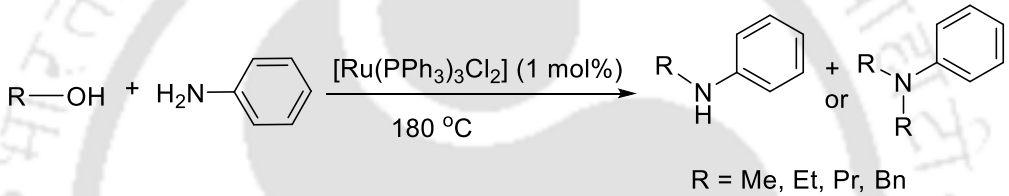
Usually, the alkylation of amines is achieved by the reaction of amines with various alkylating agents such as alkyl halides, triflates, tosylates, or mesylates. These alkylating agents can be obtained from alcohols by functional group transformations. Thus conventional approaches use hazardous reagents and lengthy work-up procedures,



Scheme 1.20: General concept of the borrowing hydrogen for amination reaction.

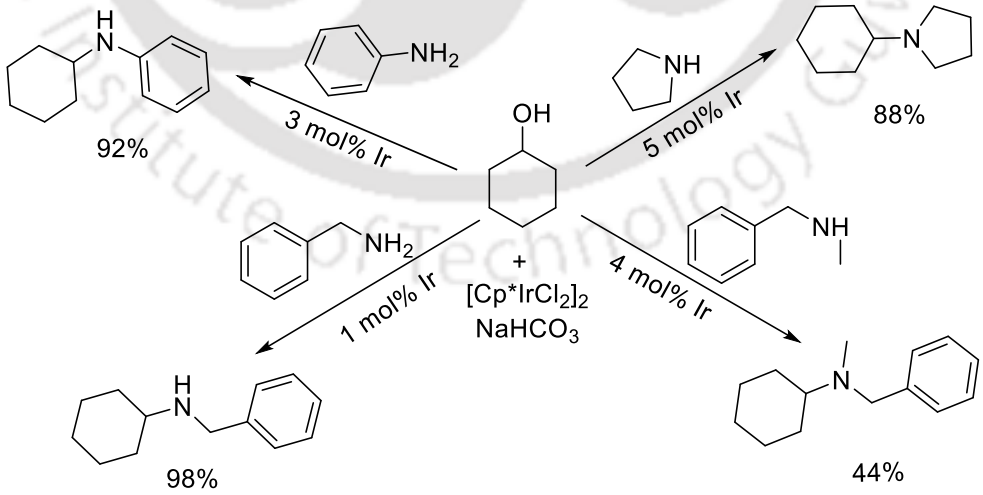
which eventually causes a large amount of waste.[90] They also suffer from poor atom economy[91] and a low level of selectivity. To overcome these drawbacks, new catalytic protocols involving direct *N*-alkylation of amines by alcohol using "hydrogen autotransfer" (HA) or "borrowing hydrogen" (BH) strategies have been developed.[92] The reaction sequence involves alcohol dehydrogenation, imine formation and the conversion of imine to amine *via* hydrogenation.

The pioneering work on the *N*-alkylation of amines by alcohols were described independently by *Watanabe*[93] and *Grigg*[94] at the beginning of 1980s. *Grigg and co-workers* disclosed the catalytic efficiency of $[RhH(PPh_3)_4]$ toward the *N*-alkylation. The group of *Watanabe* illustrated the first $[Ru(PPh_3)_3Cl_2]$ catalysed *N*-alkyaltion reaction.



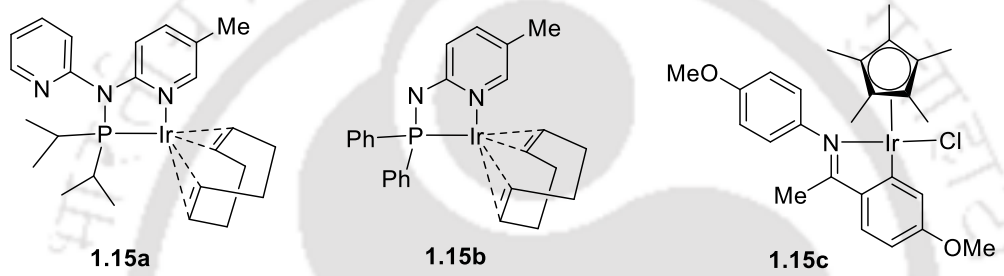
Scheme 1.21: First *N*-alkylation of aryl amines with alcohols by Watanabe.

Mixtures of mono- and di-alkylated products were formed by the reaction of primary amine and the primary alcohol which create a limitation of their protocol. In 2003, the

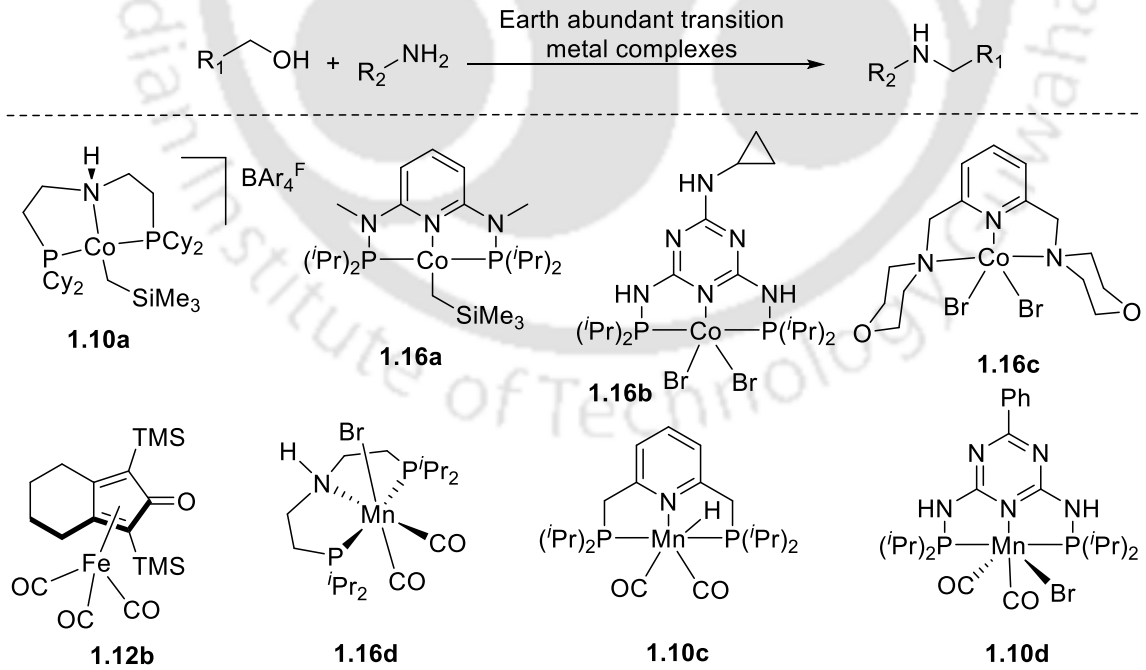


Scheme 1.22: *N*-alkylation reaction of secondary alcohols with amines by $[Cp^*IrCl_2]_2$.

group of *Yamaguchi* introduced the activity of $[Cp^*IrCl_2]_2$ in the *N*-alkylation of alcohols.[95] Subsequently, they disclosed the scope of the reaction with respect to different amines (**Scheme 1.22**).[96] *Willam and co-workers* also demonstrated such type of reaction in presence of different iridium- and ruthenium-catalysts.[97] In 2010, *Kempe and his group* reported iridium complex **1.15a** catalysed *N*-alkylation of different types of anilines with various primary alcohols.[98] The authors observed the selective formation of monoalkylated product with very low catalyst loading (0.05%) at 70 °C. *Xiao and co-workers* also reported iridium complex **1.15b** catalysed *N*-alkylation of primary amines



Scheme 1.23: *N*-alkylation reaction of primary alcohols with primary amines by Ir catalyst.



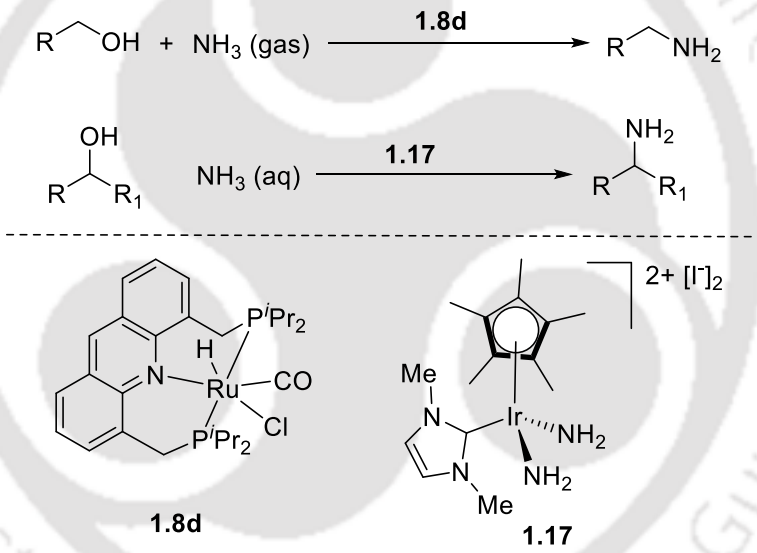
Scheme 1.24: *N*-alkylation reaction of alcohols with amines by earth-abundant metal catalysts.

with primary alcohols with relatively weaker base (K_2CO_3).[99] *Li and Andersson* illustrated such alkylation even at room temperature under neat condition using phosphine-based iridium catalyst **1.15c**.[100] Subsequently, ruthenium catalysed *N*-alkylation at room temperature was also reported.[101]

Very recently, the capability of earth-abundant 3d transition metal complexes such as Fe,[102] Co,[103] Mn[41a, 57,104] have been explored to catalyse such type of reactions.

1.3.1.2. Synthesis of amines from alcohols and ammonia:

The transition metal catalysed synthesis of primary amines from an alcohol and ammonia (gaseous or liquid) is highly desirable, as it does not generate any toxic by-product. In 2008, *Gunanathan and Milstein* demonstrated the selective synthesis of

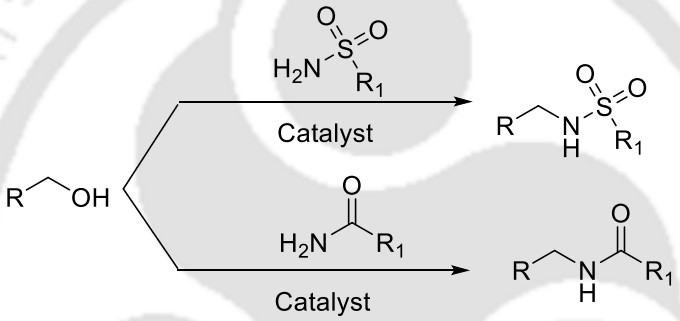


Scheme 1.25: The dehydrogenative amine synthesis from primary/secondary alcohol by noble metal catalyst.

primary amines by the coupling primary alcohols and ammonia gas in presence of acridine-based Ru-pincer complex **1.8d** (**Scheme1.15**).[105] After that, *Beller and Vogt* independently reported the synthesis of primary amines from secondary alcohols and ammonia using $Ru_3(CO)_{12}$/2-(dicyclohexylphosphino)-1-phenyl-1*H*-pyrrole system.[106] Recently, the *Yamaguchi group* reported an elegant way to synthesize new water-soluble iridium *N*-heterocyclic complex **1.17** for the *N*-alkylation of aqueous ammonia with alcohols to give primary amines.[107]

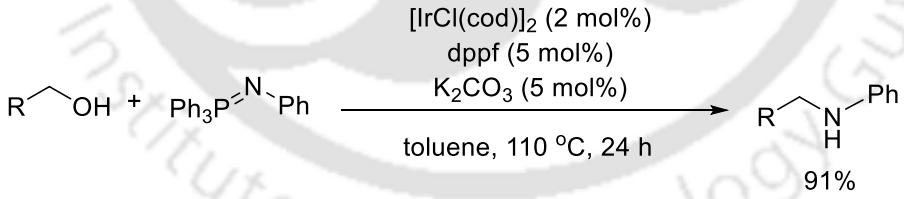
1.3.1.3. Amidation of alcohols:

N-Alkylation of amides and sulfamide is an active area of research due to the structural importance of these compounds in agrochemical and pharmaceutical chemistry.[108] The *N*-alkylation of amides and sulfamide is more challenging compared to the amines as the nucleophilicity of these compounds are less than the amines. In 1983, *Watanabe* described the first ruthenium $RuCl_2(PPh_3)_3$ catalyzed *N*-alkylation of amides from alcohols using borrowing hydrogen technique at very high temperature (180 ^oC).[109] During last two decades, different protocols for the *N*-alkylation amides[110] or sulfamides[110,111] have been established.



Scheme 1.26: *N*-Alkylation reaction of alcohol with amides or sulfamide.

1.3.1.4. Aza-Wittig reaction:



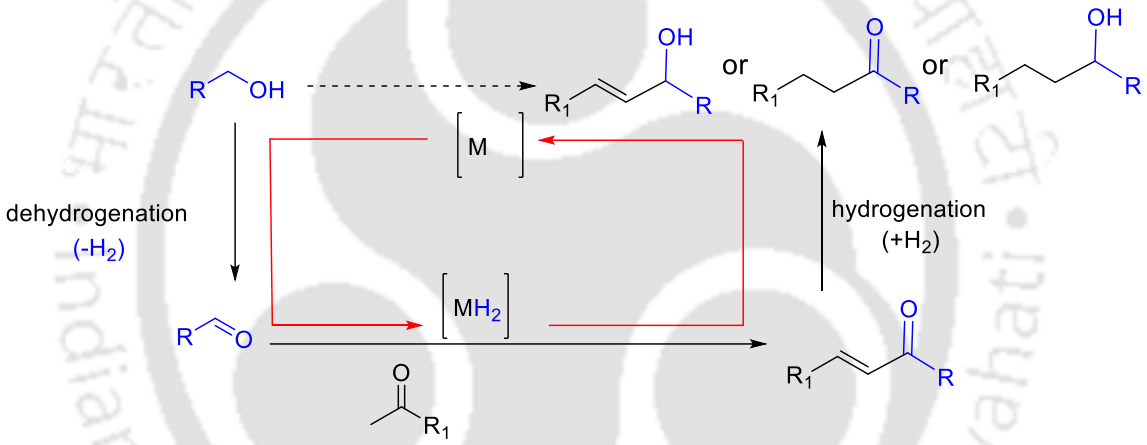
Scheme 1.27: Indirect Aza-Wittig reaction with iminophosphoranes.

The construction C-N bond was achieved *via* Aza-Wittig type reaction. *Williams and co-worker*[97a] developed a method to convert alcohols into *N*-alkyl anilines *via* such type reaction[112] in the presence of iridium catalyst.

1.3.1.5. C-C bond formation via condensation with carbon nucleophiles:

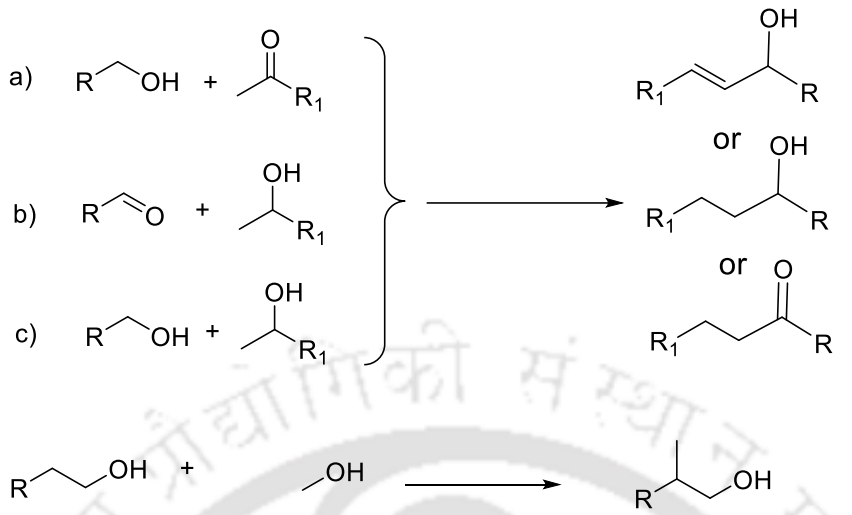
The aldol condensation is one of the most widely applied organic reaction to construct carbon-carbon bonds in synthetic organic chemistry. The reaction leads

to the formation of *α,β*-unsaturated compounds through the condensation of an aldehyde or ketone in presence of acid/base.[113] Combining the concept of BH principle together with aldol condensation more complex ketone or alcohol could be obtained starting from simple alcohols. The steps involved are i) the dehydrogenation of an alcohol to form aldehyde or ketone ii) aldol condensation iii) Full/partial hydrogenation of the formed unsaturated compound (**Scheme 1.28**). In this approach, one or both the coupling partner could be alcohol and the product distribution depends on the selectivity in the hydrogenation step. Depending on the nature of coupling partner, reaction can be categorised as a) *α*-alkylation of ketone, b) *β*-alkylation of primary and secondary alcohol.

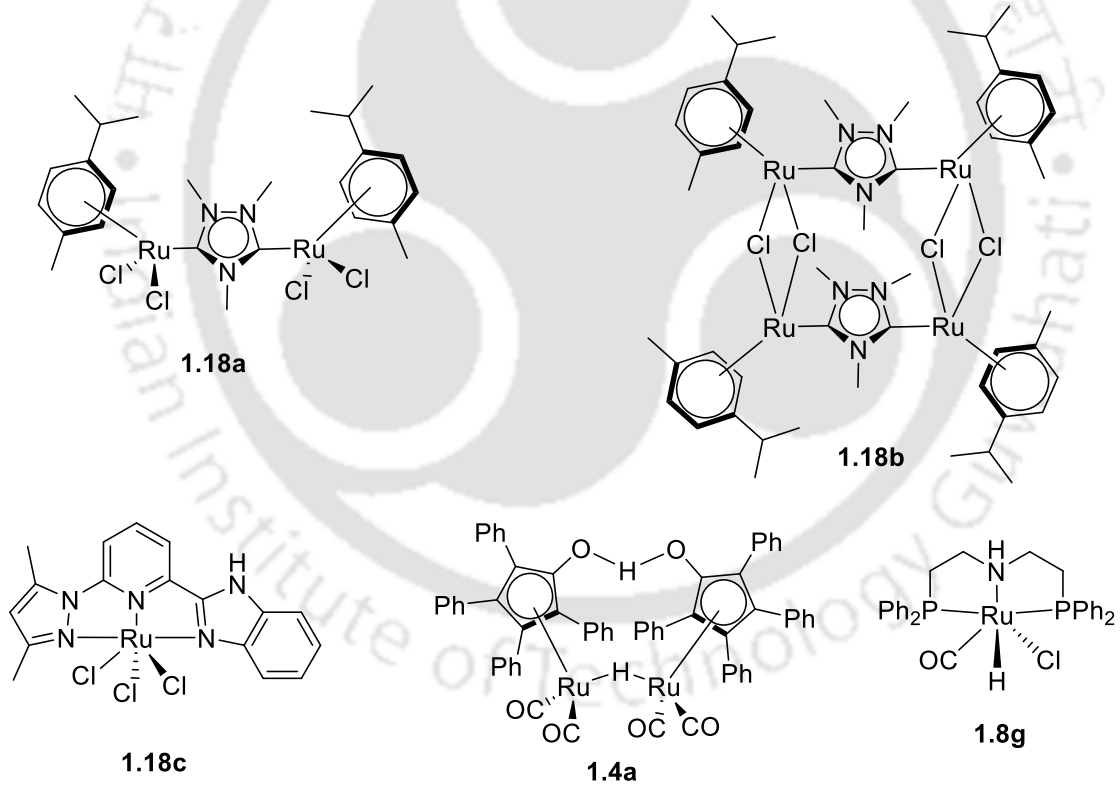


Scheme 1.28: General concept of the borrowing hydrogen for aldol condensation reaction.

The scope and limitation of this reaction with respect to a series of different catalysts are well documented.[114] Among them, $RuCl_2(DMSO)_4$ [115] and $[Cp^*IrCl_2]_2$ [108] can be highlighted due to their excellent catalytic activity in the *α*-alkylation of ketones and *β*-alkylation of secondary alcohols. Subsequently, highly active ruthenium complexes have been developed by the group of *Peris*[116] and *Wanga*[117] to catalyse *β*-alkylation of secondary alcohols with primary alcohols. *Beller and co-workers* reported methylation of secondary alcohols by the combination of **1.8g** and **1.4a** catalyst.[118]



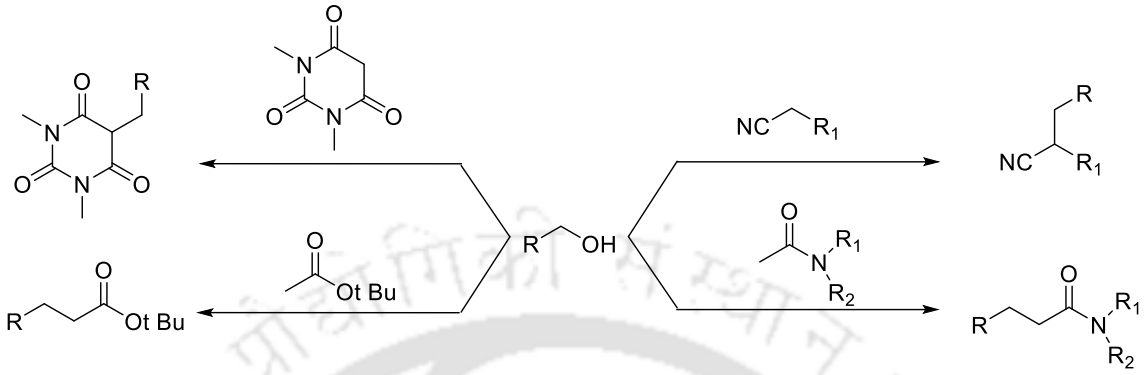
Scheme 1.29: Different types of α-alkylation or β-alkylation reactions.



Scheme 1.30: Some Ru-catalysts that are used for α-alkylation or β-alkylation reaction of alcohols.

Furthermore, using the similar strategy the α-alkylation of ester,[120] amide[120a, 121] and nitrile[122] have been accomplished. In recent year, earth-abundant transition metals

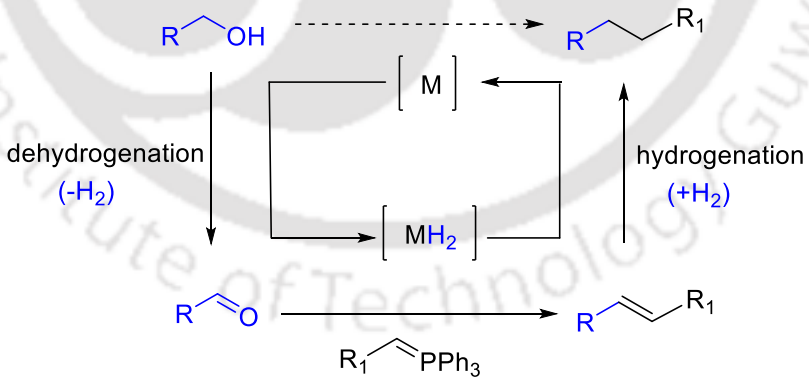
such as Co,[123] Fe[124] and Mn[125] based complexes have been employed for such type of alkylation reaction.



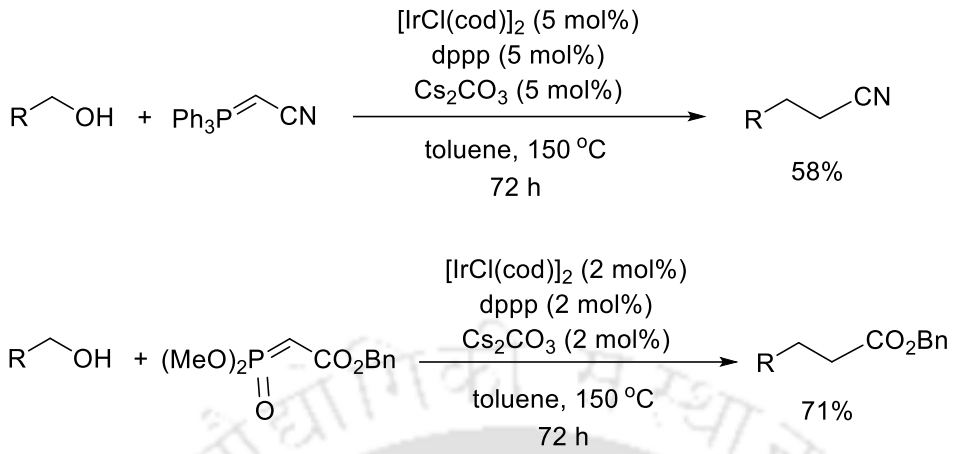
Scheme 1.31: α-alkylation reaction of ester, amide and nitrile with alcohol.

1.3.1.6. Wittig reaction:

The synthesis of an olefin is easily achieved by the reaction of an aldehyde/ketone with a phosphonium ylide, which is known as Wittig olefination reaction. Thus, merging Wittig reaction and BH approach alkane can be synthesized directly from alcohols. *William and co-workers* extensively worked on the synthesis of alkane directly from alcohol *via* modified Wittig-type reaction.[126] *N*-heterocyclic carbene based Ru-complexes were also utilized to synthesise alkanes *via* this type of indirect Wittig reaction.[127]



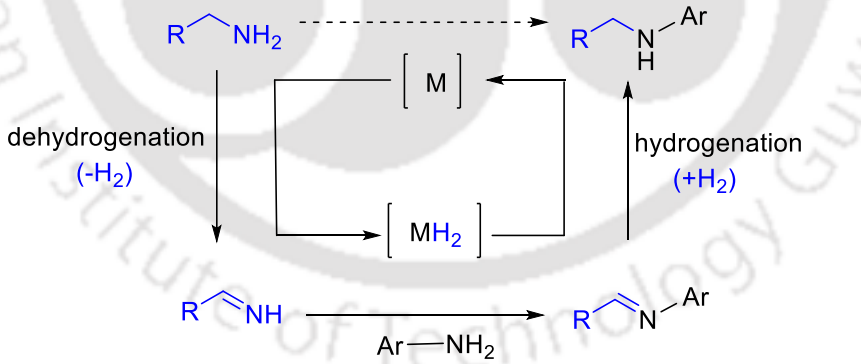
Scheme 1.32: Indirect Wittig reaction using alcohols.



Scheme 1.33: Iridium catalysed modified Wittig-type reaction.

1.3.2. Activation of amines:

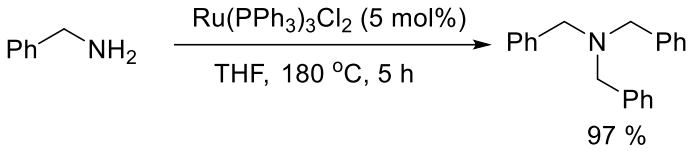
Amines having α-hydrogens are also exploited in the BH methodology. In this approach first primary amine converted to the reactive imine *via* oxidation. Then, the nucleophilic addition of aryl amine to the intermediate imine will lead to the generation of secondary imine that subsequently hydrogenate to form the secondary amine. When the nucleophilic amine used is secondary amine, tertiary amine would be the final product.

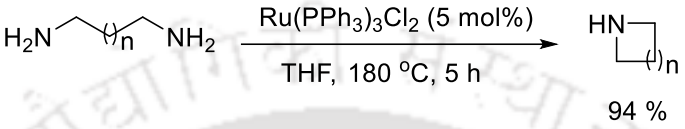


Scheme 1.34: The dehydrogenative activation of amines via borrowing hydrogen method.

The first homogeneous catalyst for such reactions was reported by *Porzi et al.*[128] The ruthenium catalyst [$RuCl_2(PPh_3)_3$] was used to convert primary amines to the symmetrical tertiary amines and primary diamines to secondary cycloamine at high

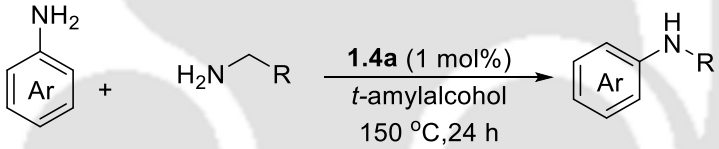
temperature of 180 °C. Another two groups, *Garrou et al.*[129] and *Watanabe et al.*[130] developed Ru-catalyst for similar kinds of reactions.



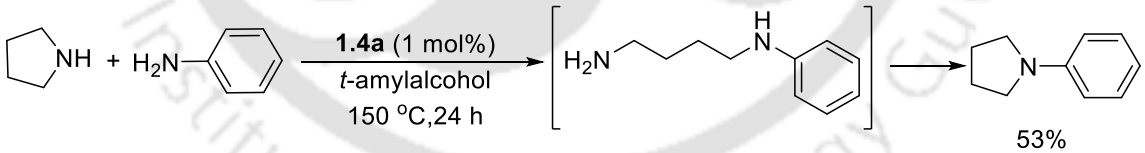


Scheme 1.35: First homogeneous catalyzed condensation of amines.

In 2007, *Beller and co-workers* reported alkylation of various aniline derivatives with alkyl amines by the help of *Shvo* catalyst.[131] They have also demonstrated arylation of pyrrolidines and piperidines.[132]



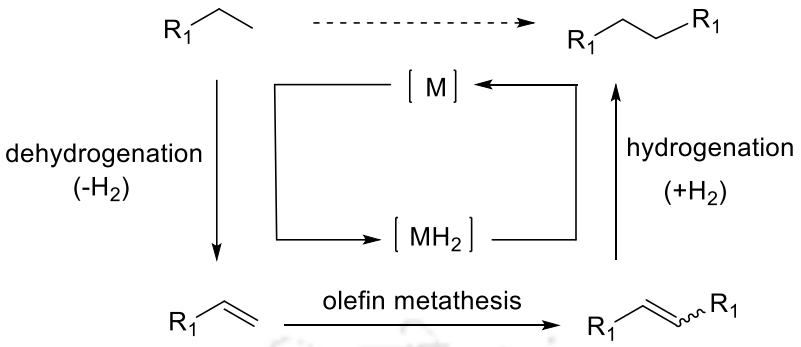
Scheme 1.36: Amination of aniline with different alkyl amines.



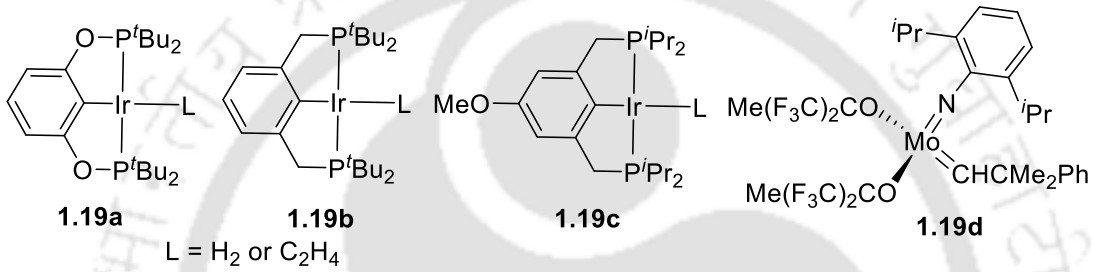
Scheme 1.37: Arylation of cyclic aliphatic amines (pyrrolidine).

1.3.3. Activation of alkanes:

Goldmann and co-workers in their pioneering work illustrated a unique strategy to convert lower alkane to its higher homologue utilizing BH strategy.[133] In this approach first the alkane is dehydrogenated to alkene which undergoes olefin metathesis to form higher alkene. Finally, hydrogenation of the metathesis product leads to the formation of the higher alkane analogue. The reaction was achieved through the utilization of the dehydrogenation/catalyst and olefin metathesis catalyst.



Scheme 1.38: BH strategy to convert alkane to its higher analogue.



Scheme 1.39: Some dehydrogenation/hydrogenation catalysts (**1.19a-c**) and olefin metathesis catalyst (**1.19d**) that are used for alkane activation via BH strategy.

1.4. Concluding remarks:

The application of acceptorless dehydrogenation and borrowing hydrogen principle has been extensively investigated with noble metal catalysts. The demonstration of selective example gives a general idea about the designing of co-operative catalysts and their applicability to achieve such type of processes. Various metal complexes with different ligand frameworks are highly important to get the desired selectivity and effectiveness. The application of earth-abundant transition metals for acceptorless dehydrogenation and borrowing hydrogen catalysis is in the nascent stage. Thus, there is an ample scope to develop new earth-abundant transition metal complexes to study their scope and limitation in various de(hydrogenative) transformations. In the present thesis, new air stable tridentate ligand derived manganese metal complexes have been developed to investigate their applicability and shortcomings towards different de(hydrogenative) processes.

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Chapter 2

Synthesis of Well-defined NNS-Mn(I) Complexes and their Catalytic Application for the Synthesis of Amine and Imine via Hydrogen-autotransfer or Acceptorless Dehydrogenative Coupling of Amine and Alcohol

2.1. Introduction:

In this chapter, I have mainly discussed the synthesis of new well-defined NNS-Mn(I) complexes and explored their applicability in acceptorless dehydrogenation and borrowing hydrogen catalysis. In view of sustainable and cost-effective development, I am particularly interested in the use of earth-abundant biocompatible manganese metal and non-phosphine ligand system. The syntheses of amines, imines and 2,3-dihydro-1*H*-perimidine were achieved using the catalytic efficacy of these manganese complexes.

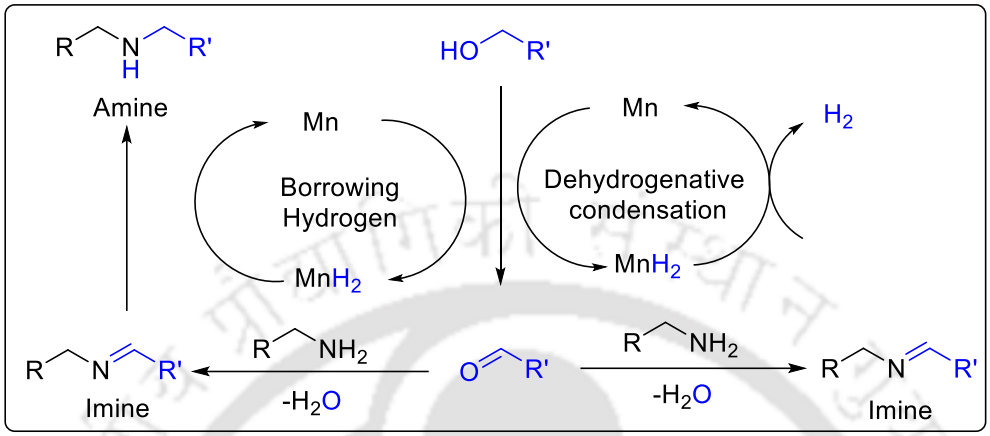
Nitrogenous compounds such as amines and imines are known for their valuable application in chemistry.[1] They are ubiquitous in many natural products and widely used as dyes, pharmaceuticals, agrochemicals, lubricants and surfactants.[2] The two most widely used methods for the synthesis of amines are the *Buchwald-Hartwig amination*[3] and *Ullmann reactions*.[4] Although these methods are most significant in the organic synthesis, they often suffer from the generation of substantial amounts of side products or wastes. In recent year, much focus has been attributed to the conversion of alcohols to amines, as the alcohols are easily available either by different industrial processes or can be obtained renewably from lignocellulose[5]. The classical way to form C-N bond from alcohols is converting first the alcohol functionality to a suitable leaving group such as halides, triflates, tosylates, or mesylates and then reacting with primary amines to get the *N*-alkylated product.[6] These multistep strategies use hazardous reagents and lengthy work-up procedures, which generates a large amount of waste.[7] To overcome these drawbacks, new catalytic protocols involving direct *N*-alkylation of amines by alcohol using hydrogen autotransfer or borrowing hydrogen strategies have been developed.

The catalytic cycle involves three steps:

i) Dehydrogenation of an alcohol to form an aldehyde/ketone

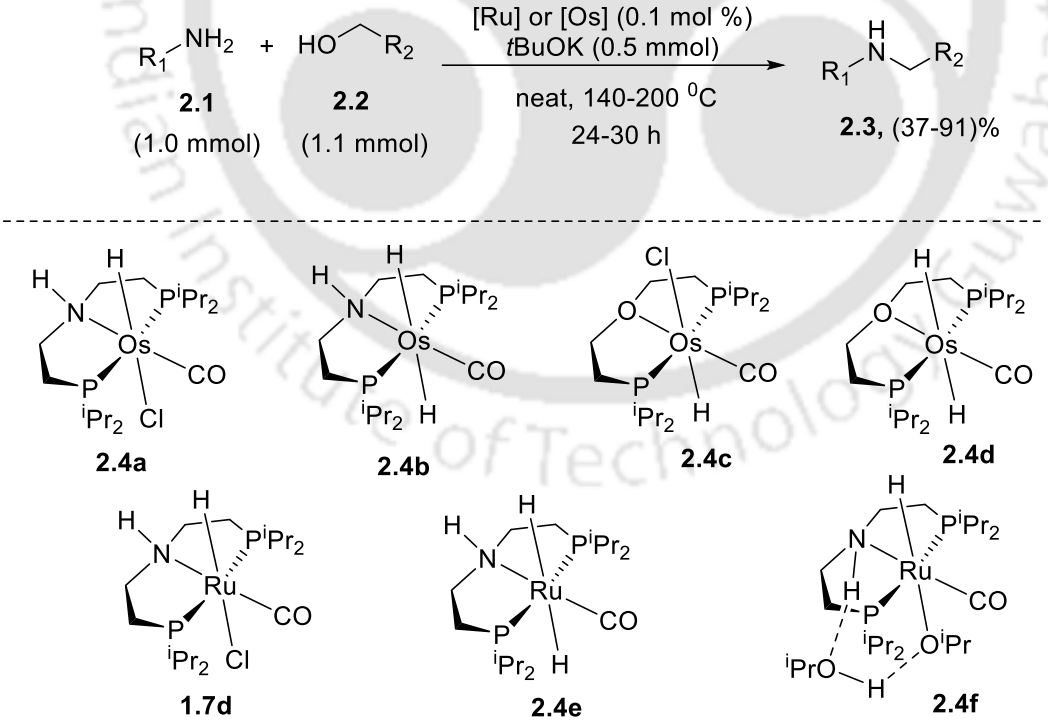
ii) Imine formation *via* condensation of amine and the in situ formed aldehyde/ketone

iii) Hydrogenation of the imine to form amine (hydrogen auto-transfer or borrowing hydrogen).



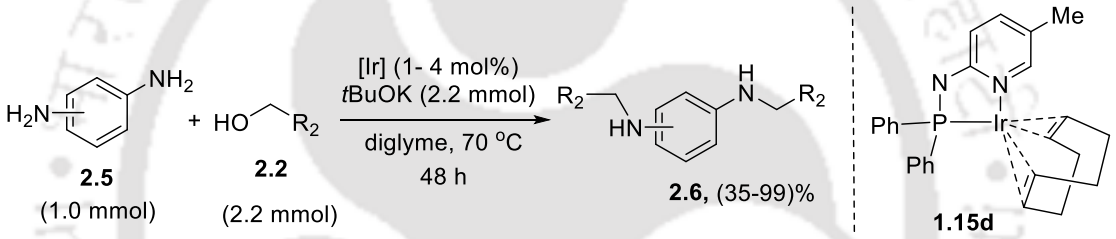
Scheme 2.1: Synthesis of amine and imine through borrowing hydrogen or acceptorless dehydrogenation.

Initially, the pioneering works on the *N*-alkylation of amines by alcohols were described independently by *Watanabe*[8] and *Grigg*[9] at the beginning of the 1980s, the



Scheme 2.2: Synthesis of amine catalysed by Ru/Os-pincer complexes.

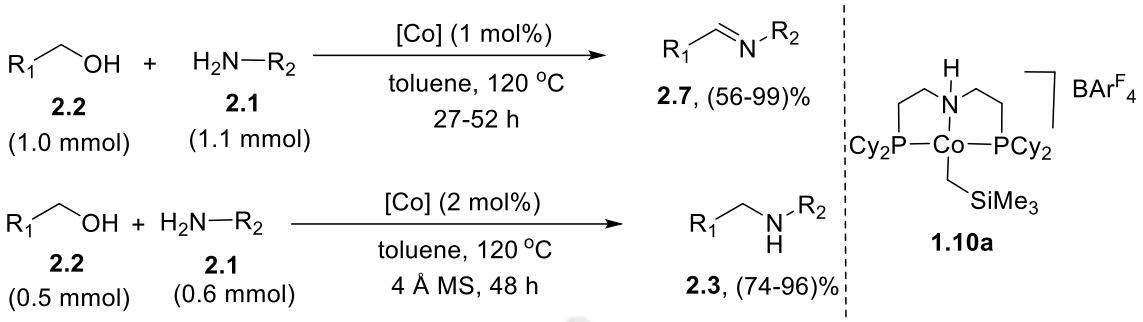
significant progress has been achieved only after 2000 using precious noble metals.[10-14] Some of the noble metal catalyzed *N*-alkylation reactions have been discussed here. In 2011, *Gusev and co-workers*[12] reported various phosphine containing pincer-type complexes of Os and Ru and studied their catalytic activities toward *N*-alkylation of amines with alcohols. The reaction occurred at higher temperature (140-200 °C). They have noticed that the dihydride complexes of PNP[=HN($C_2H_4P^iPr_2)_2$] are more reactive than POP[=O($C_2H_4P^iPr_2)_2$] dihydride complexes (**Scheme 2.2**). In 2012, the group of *Kempe* demonstrated an iridium catalyzed[11l] synthesis of symmetrical and unsymmetrical monoalkylation of *ortho*-, *meta*- and *para*-benzenediamines (**Scheme 2.3**) *via* hydrogen auto-transfer reaction in presence of excess *t*BuOK (2.2 mmol).



Scheme 2.3: Synthesis of di-alkylated amine catalysed by Ir-pincer complex.

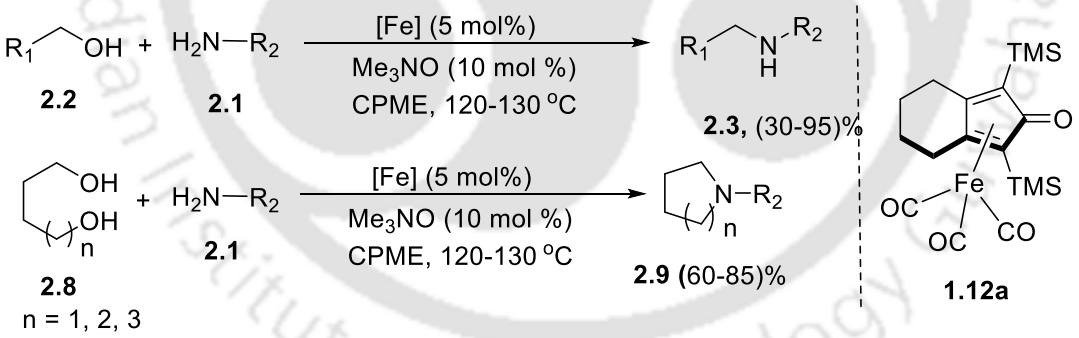
The replacement of precious noble metal such as ruthenium, rhodium, iridium, and osmium by eco-friendly, non-precious, earth-abundant 3d transition metals[15] is a key challenge in the homogeneous catalysis. In recent years, explosive growth in the catalysis by base metals has been observed.

In 2013, *Hanson and co-workers* explored the applicability of cobalt(II) alkyl complex [(PNP)Co(CH_2SiMe_3)]$BArF_4$ toward the dehydrogenative synthesis of imines[16a] directly from alcohol and amine. The reaction was performed in the presence of cobalt precatalyst **1.10a** (1 mol%) in toluene at 120 °C. *Zhang and co-workers*[16b] have utilized the same cobalt complex for the efficient *N*-alkylation reaction of both aromatic and aliphatic amines with alcohol derivatives *via* borrowing hydrogen catalysis and they were able to isolate selectively amine products (74-96%). The reaction of



Scheme 2.4: Selective synthesis of imine and amine catalysed by Co-PNP complex.

primary amines and alcohols were performed in presence of cobalt precatalyst **1.10a** (1 mol%) and 4 Å MS in toluene at 120 °C. In 2014, *Feringa and Barta* reported[17] base free *N*-alkylation of amine in presence of a bifunctional air-stable Fe-precatalyst **1.12a** and Me_3NO. The *N*-alkylation reaction was performed in cyclopentyl methyl ether (CPME) solvent at 120 °C. A wide range of functional groups was well tolerated under the reaction condition. They have also reported the synthesis of different ring sized *N*-heterocycles by the reaction of amines with various diols (**Scheme 2.5**).

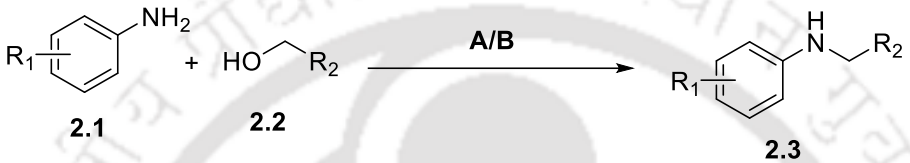


Scheme 2.5: *N*-alkylation of amine catalysed by Fe-PNP pincer complex.

The first example of nickel catalysed *N*-alkylation reaction followed by the borrowing hydrogen concept was reported in 1932 with aliphatic amines and primary alcohols.[18]

After that, the pioneering work of *N*-alkylation reaction was developed based on the heterogeneous nickel catalysts.[19-21] Nickel catalysed homogenous *N*-alkylation of aryl amines and hydrazides were introduced by *Zhou and co-workers*[22a] in the year 2017.

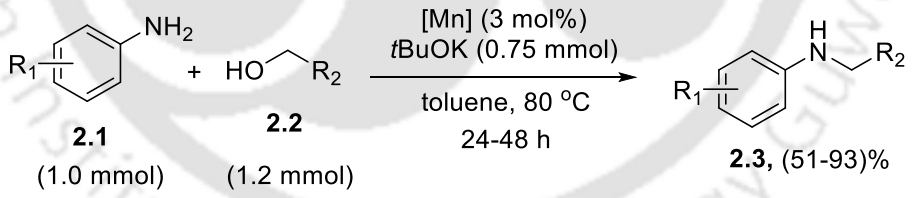
They showed that 2 mol% $Ni(OTf)_2$, 2.5 mol% dcpp [1,3-bis(dicyclohexylphosphino)-propane], and molecular sieves are essential for the reaction (**Scheme 2.6**, condition A). Recently, *Banerjee and co-workers* also reported nickel catalysed monoalkylation of aniline[22b] with various primary alcohols. The reaction is catalyzed by 10 mol% $NiBr_2$ with 20 mol% 1,10-phenanthroline in the presence of 100 mol% *t*BuOK as a base (**Scheme 2.6**, condition B). They have shown a wide range of functional group tolerance including hydroxyl, alkene, nitrile and nitro to establish the utility of their protocol.

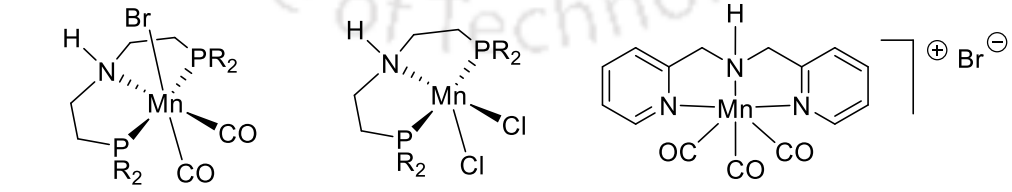


A = 2 mol% $Ni(OTf)_2$ + 2.5 mol% dppc + *t*-amyl alcohol/HFIP (1:1) + MS, 120 °C, 30 h
B = 10 mol% $NiBr_2$ + 20 mol% 1,10-phenanthroline + 100 mol% *t*BuOK + toluene, 120 °C, 48 h

Scheme 2.6: Synthesis of amine catalysed by Ni-complexes.

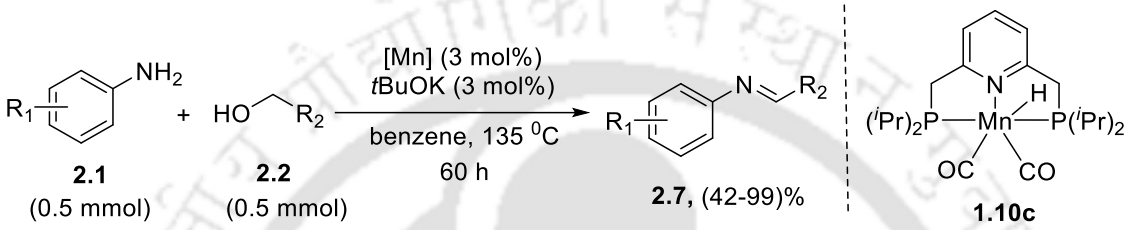
In the year 2016, manganese was first used towards the *N*-alkylation of alcohols with amine[23a] and the dehydrogenative synthesis of imines from alcohol and amine.[23b] In this year, *Beller and coworker* first demonstrated the efficient *N*-alkylation of alcohol





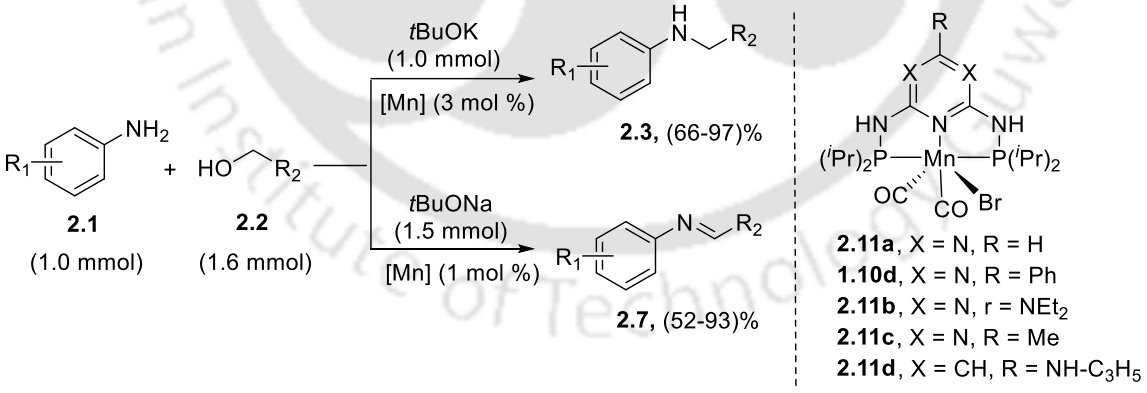
Scheme 2.7: Synthesis of amine catalysed by Mn-PNP pincer complexes.

using Mn-PNP Pincer complexes.[23a] Among these Mn-complexes, complex **1.16a** was found to be the best catalyst for the amine synthesis in presence of 0.75 equivalent *t*BuOK at 80 °C temperature (**Scheme 2.7**). In the same year, *Milstein and co-workers* reported the first imine synthesis through the dehydrogenative coupling of alcohols and amines catalyzed by pyridine based Mn-PNP pincer complex (**1.10c**)[23b] in the presence of catalytic amount of *t*BuOK (3 mol%) (**Scheme 2.8**).



Scheme 2.8: Synthesis of imine catalysed by Mn-PNP pincer complexes.

Very recently, in 2018, *Kempe and co-workers* reported selective manganese-catalyzed[23c] synthesis of *N*-alkylated amines *via* borrowing hydrogen/hydrogen autotransfer and dehydrogenative imine synthesis. The reaction is catalysed by triazine based Mn-PNP pincer complex (**Scheme 2.9**).



Scheme 2.9: Selective amine and imine catalysed by Mn-PNP pincer complexes.

The literature reports emphasize that the methods for preparation amine and imines *via* borrowing hydrogen method/acceptorless dehydrogenation is highly important because of its usefulness. Hence, the development of new, selective, economically beneficial and environmentally benign catalytic protocols for these types

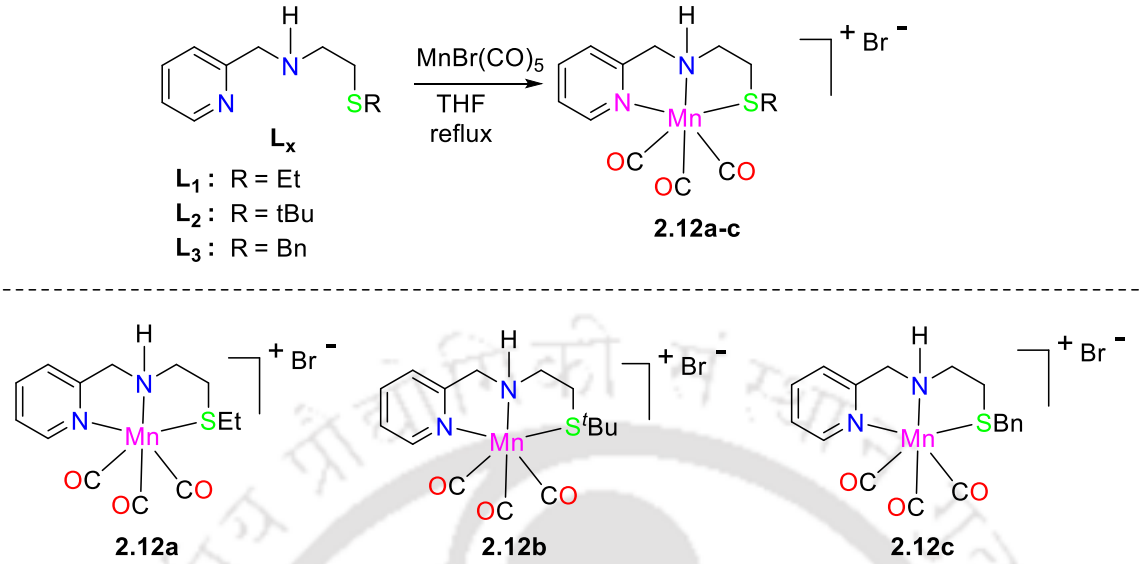
of processes is highly desirable. The reported manganese complexes are mainly derived from phosphine based ligand systems. Although phosphine ligands are recognized for the significant applications in the homogeneous catalysis, still, there are some drawbacks associated with their air and moisture sensitivities, complex synthetic procedures and relatively high cost. Herein, I am interested to study the coordination behavior of phosphine free SNS ligand systems with manganese precursor and investigate the applicability of the new metal complexes in acceptorless dehydrogenation and borrowing hydrogen catalysis.

2.2. Present Work:

Chapter 2 discusses the synthesis, purification and characterization of SNS ligand derived Mn-complexes. The efficacy of the new manganese complexes was examined toward *N*-alkylation of amines using alcohols for dehydrogenative imine synthesis. The selective synthesis *N*-alkylated amines or imines are achieved by using a single pre-catalyst, just by tuning the reaction condition. In addition, the dehydrogenative synthesis of structurally important 2,3-dihydro-1*H*-perimidine derivatives has also been demonstrated.

2.2.1. Synthesis of NNS-Mn Complexes and Characterizations:

At the outset, the NNS-non phosphine ligands, $\mathbf{L_x}$ {$\mathbf{L_1}$ = 2-(ethylthio)-*N*-(pyridin-2-ylmethyl)ethan-1-amine, $\mathbf{L_2}$ = 2-(*tert*-butylthio)-*N*-(pyridin-2-ylmethyl)ethan-1-amine, $\mathbf{L_3}$ = 2-(benzylthio)-*N*-(pyridin-2-ylmethyl)ethan-1-amine} were synthesized following an earlier reported procedure[24] (Experimental section 2.5). Initially, I tried to prepare new manganese complexes by refluxing $MnBr(CO)_5$ and the ligand $\mathbf{L_x}$ in dry toluene solvent. The yield was found inferior compared to the yield in the THF solvent. Thus, when a mixture of $MnBr(CO)_5$ and $\mathbf{L_x}$ in dry THF solvent was refluxed for overnight under argon atmosphere (Experimental section 2.5), complexes (**2.12a-c**) were obtained in excellent yield (92-95%). Single crystal was made by layering THF solution of the complex with toluene (complex **2.12a** & **2.12c**) or $CHCl_3$ solution of the complex with hexane (complex **2.12b**).



Scheme 2.10: Synthesis of NNS-Mn complexes.

The Mn-complexes were characterised by spectroscopic analyses such as FT-IR, NMR (^{1}H and ^{13}C) and ESI-mass spectrometry (Experimental section). In the FT-IR spectrum which was taken in presence of KBr plate, three new stretching frequencies that are ranged from 1920 cm^{-1} to 2032 cm^{-1} was observed which is assignable to the CO stretching modes. The formation of the complexes was further confirmed by single crystal X-ray structure determination. The crystallographic data (Experimental section) and ORTEP diagram of complex **2.12a**, **2.12b** and **2.12c** are shown in Figure 2.1. The crystal structure of $[Mn(NNS)(CO)_3]^+$ is more like octahedral geometry around Mn-center which is connected through two N atoms and one S atom from ligand and three carbonyl groups. The crystal structure reveals that both the N atoms and the S atom are *cis* to each other and the three carbonyls are *cis* to each other.

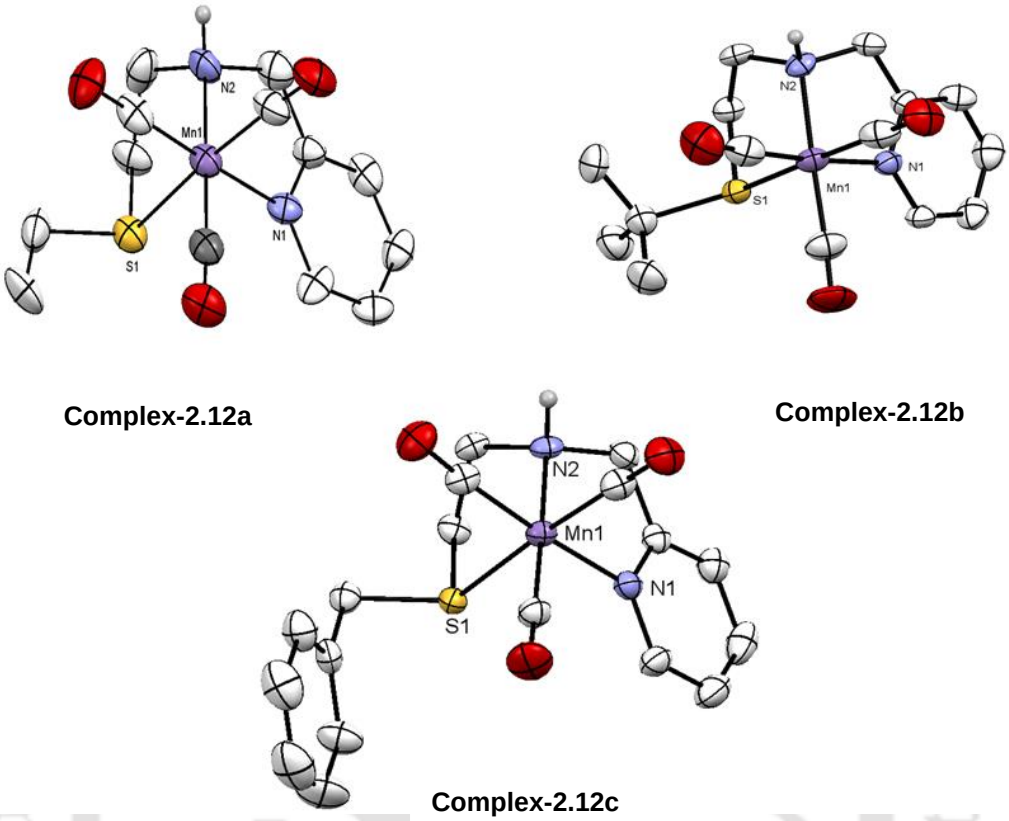


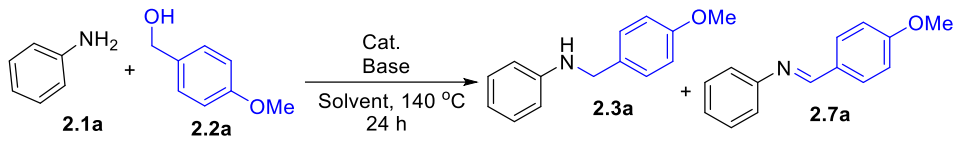
Figure-2.1: Molecular structure of complexes $[Mn(NNS)(CO)_3]^+$ with thermal ellipsoid 30% probability level (all the hydrogens except N_2 are not shown for the clarity).

After complete characterization, these Mn-complexes were applied for *N*-alkylation reaction of amines by alcohol using borrowing hydrogen strategy and the synthesis of imine through acceptorless dehydrogenation.

2.2.2. Optimization of reaction conditions:

Initially, the catalytic applicability of complexes **2.12a-c** towards the *N*-alkylation reaction of amines with alcohols were investigated. Aniline and 4-methoxybenzyl alcohol were taken as model substrates to optimize the reaction condition. When a toluene solution containing aniline (1.0 mmol), 4-methoxybenzyl alcohol (1.1 mmol) and *t*BuOK (1.2 mmol) was refluxed for 24 h in the presence of 5 mol% cat **2.12a**, *N*-(4-methoxybenzyl)aniline **2.3a** was obtained in 85% yield (**Table 2.1**, entry 1). Keeping the other conditions unaltered when xylene was used, the yield of the *N*-alkylated product was dropped to 34% (**Table 2.1**, entry 2).

Table 2.1: **Screening Table**:[a,b]



Exp. No.	Catalyst (mmol)	Base (mmol)	Solvent (2ml)	Amine : Alcohol (mmol)	% of Yield[b] **2.3a**	**2.7a**
1	Cat **2.12a**	*t*BuOK-1.2	toluene	1 : 1.1	85	6
2	Cat **2.12a**	*t*BuOK-1.2	xylene	1 : 1.1	34	58
3	Cat **2.12b**	*t*BuOK-1.2	toluene	1 : 1.1	79	6
4	Cat **2.12b**	*t*BuOK-1.2	xylene	1 : 1.1	31	40
5	Cat **2.12c**	*t*BuOK-1.2	toluene	1 : 1.1	48	37
6	Cat **2.12a**	***t*BuOK-1.2**	**toluene**	**1 : 1.2**	**98**	**0**
7	Cat **2.12a**	*t*BuOK-1.2	toluene	1 : 1.3	96	0
8	Cat **2.12a**	*t*BuOK-1.0	toluene	1 : 1.2	77	27
9	Cat **2.12a**	*t*BuOK-0.75	toluene	1 : 1.2	49	50
10	Cat **2.12a**	*t*BuOK-1.5	toluene	1 : 1.2	42	37
11[c]	Cat **2.12a**	*t*BuOK-1.2	toluene	1 : 1.2	71	0
12[d]	Cat **2.12a**	*t*BuOK-1.2	toluene	1 : 1.2	80	10
13[e]	Cat **2.12a**	*t*BuOK-1.2	toluene	1 : 1.2	33	12
14	Cat **2.12a**	KOH-1.2	toluene	1 : 1.2	50	50
15	Cat **2.12a**	KOH-0.5	toluene	1 : 1.2	33	59
16[f]	Cat **2.12a**	KOH-0.5	toluene	1 : 1.2	24	75
17[f]	Cat **2.12a**	**KOH-0.3**	**toluene**	**1 : 1.2**	**10**	**88**
18	Cat **2.12a**	K_2CO_3-1.2	toluene	1 : 1.2	27	38
19	$Mn(CO)_5Br$	*t*BuOK-1.2	toluene	1 : 1.2	20	20

[a] Reaction conditions: Cat (5 mol %), aniline (1 mmol), 4-Methoxy benzyl alcohol (1.1-1.3 mmol), base (0.75-1.5 mmol.) 140 °C (oil bath temperature), 24 h, Solvent (2 mL), under argon ballon, [b] NMR yield using CH_3CN as internal standard. [c] 2.5 mol%. [d] 12 h. [e] 100 °C, [f] under argon flow.

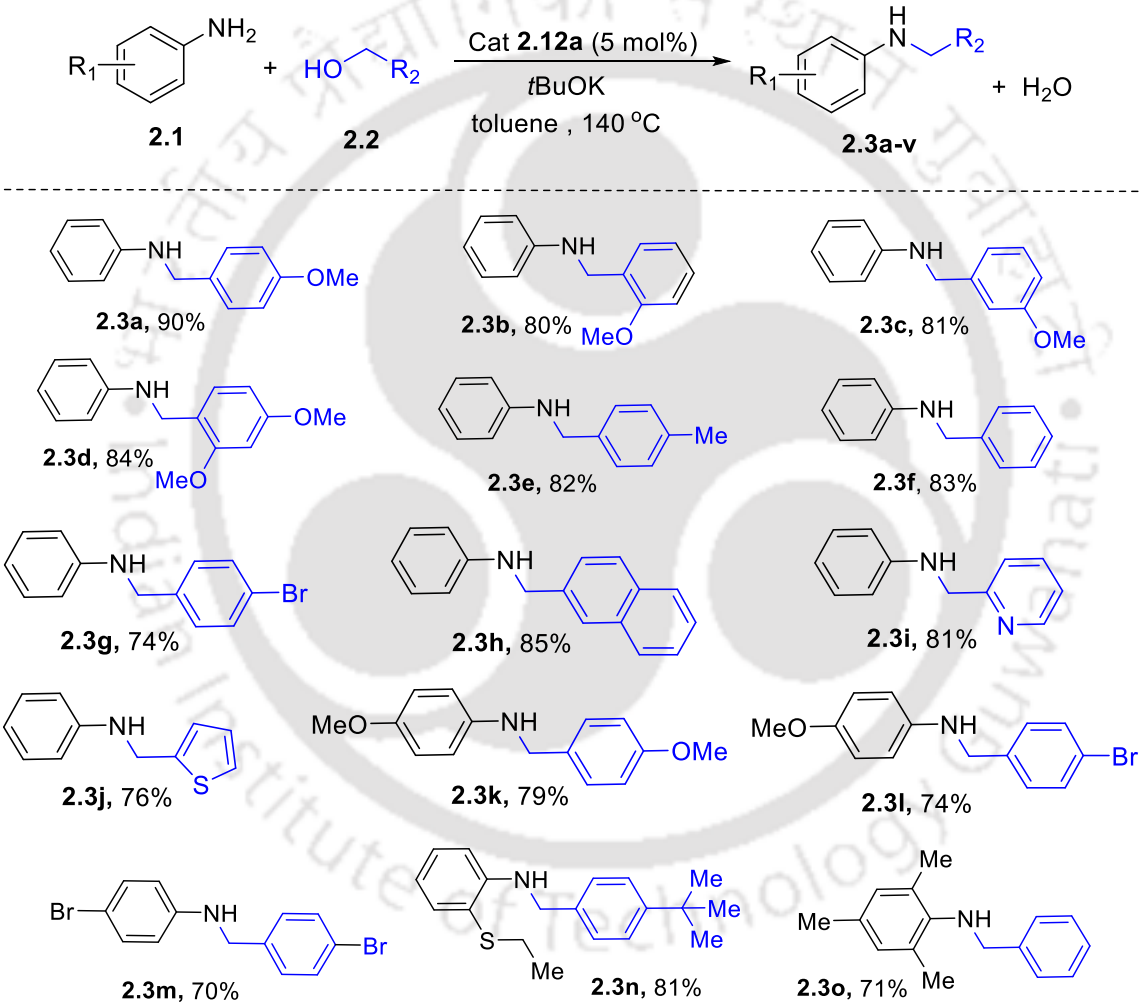
Next, I studied the catalytic activity of the cat **2.12b**; under the similar reaction condition using toluene solvent, cat **2.12b** gave 79% desired product yield (**Table 2.1**, entry 3) and in xylene solvent the yield was 31%. When the cat **2.12c** was employed the yield of product decreased to 48% (**Table 2.1**, entry 5). Gratifyingly, the yield of *N*-alkylated product was further improved to 98% when aniline and 4-methoxybenzyl alcohol were taken in 1:1.2 ratio (**Table 2.1**, entry 6) in presence of cat **2.12a**. The yield of desired *N*-(4-methoxybenzyl) aniline was decreased with a lower amount of catalyst loading (**Table 2.1**, entry 11) or lower amount of *t*BuOK (**Table 2.1**, entries 8 and 9) or by using weaker base such as KOH or K_2CO_3 (**Table 2.1**, entries 14 and 18). Lower temperature or the shorter reaction time was found to have a detrimental effect on the yield of the reaction (**Table 2.1**, entries12 and 13). $MnBr(CO)_5$ gave only 20% of the desired amine under the optimized reaction condition (**Table 2.1**, entry 19). Without changing the other parameters when the amount of KOH was decreased from 1.2 mmol to 0.3 mmol, imine was obtained as major product. Delightfully, when the reaction was performed in presence of 0.3 eq. of KOH under argon flow maximum yield of the imine product was obtained (**Table 2.1**, entry 17).

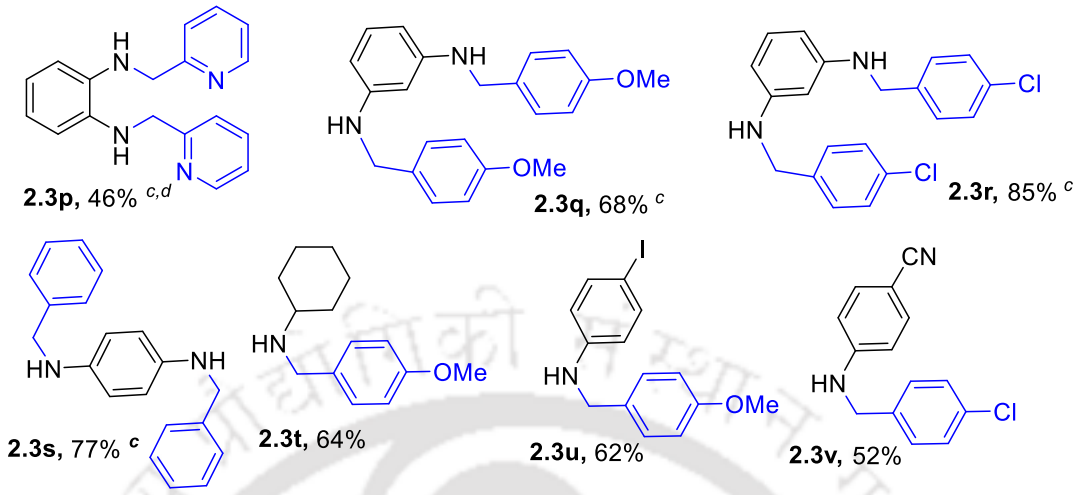
2.2.3. Substrate scope:

After identifying the optimized conditions, the scope of the *N*-alkylation reaction was first studied. I investigated a wide range of substrate scope to demonstrate the generality of the reaction. At the outset, differently substituted aniline and alcohols were tested. Substrates having the electron-donating or electron-withdrawing group in the aryl of aniline or benzyl alcohols were reacted smoothly under the optimized condition to afford *N*-monoalkylated product in high yields. Even the sterically hindered aniline such as 2-(ethylthio)aniline and 2,4,6-trimethylaniline underwent *N*-alkylation smoothly, affording the corresponding *N*-monoalkylated product in good yields (**Table 2.2**). Alcohols possessing heteroaromatic moieties or naphthyl moieties also worked well. Furthermore, the *N*-alkylation of diaminobenzene was investigated. There is a possibility of formation of dialkylated (*N*-alkyalation of both the NH_2 and mono-alkylated (*N*-alkylation of one of the NH_2) product. Indeed, when, 1,3-diamino benzene and benzyl

alcohol were taken in 1:2.4 ratio, mixture of mono- and dialkylated- product was formed (29%) and increasing the ratio to 1:3, the dialkylated product was isolated 85% yield. In the case of 1,2-diaminobenzene, only 46% desired dialkylated product was obtained due to the formation of 1,2-disubstituted benzimidazole as side product. Pure aliphatic amine like cyclohexyl amine reacted smoothly under the reaction condition.

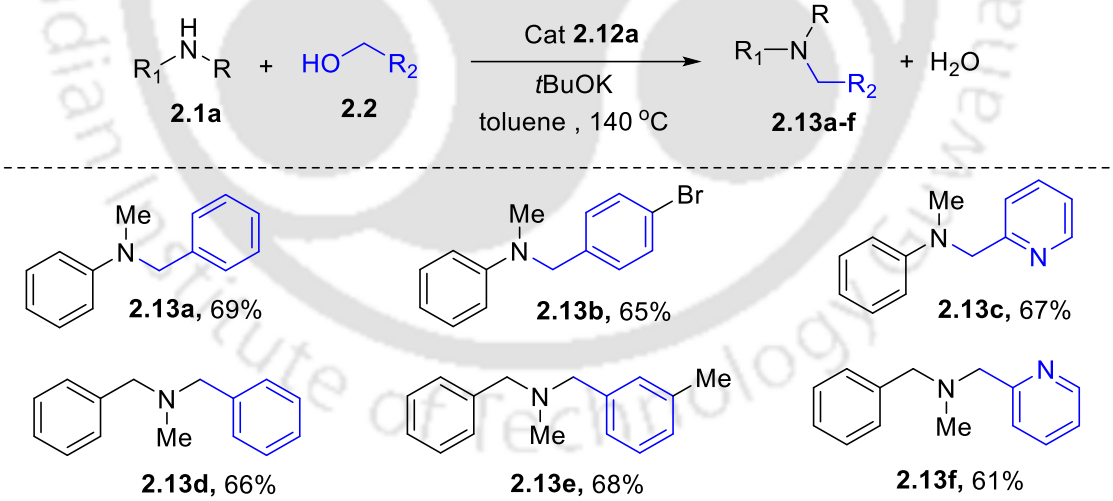
Table 2.2: Scope of *N*-alkylation reaction of aniline derivatives with benzyl alcohol derivatives[a,b]





[a] Reaction conditions: Cat 2.**12a** (5 mol %), amine (1 mmol), alcohol (1.2 mmol), *t*BuOK (1.2 mmol.) 140 °C (oil bath temperature), 24 h, toluene (2 mL), [b] isolated yield, [c] diaminobenzene (0.5 mmol), alcohol (1.5 mmol), 36 h, [d] 18 h.

Table 2.3: Scope of *N*-alkylation reaction of secondary amines with benzyl alcohol derivatives[a,b]



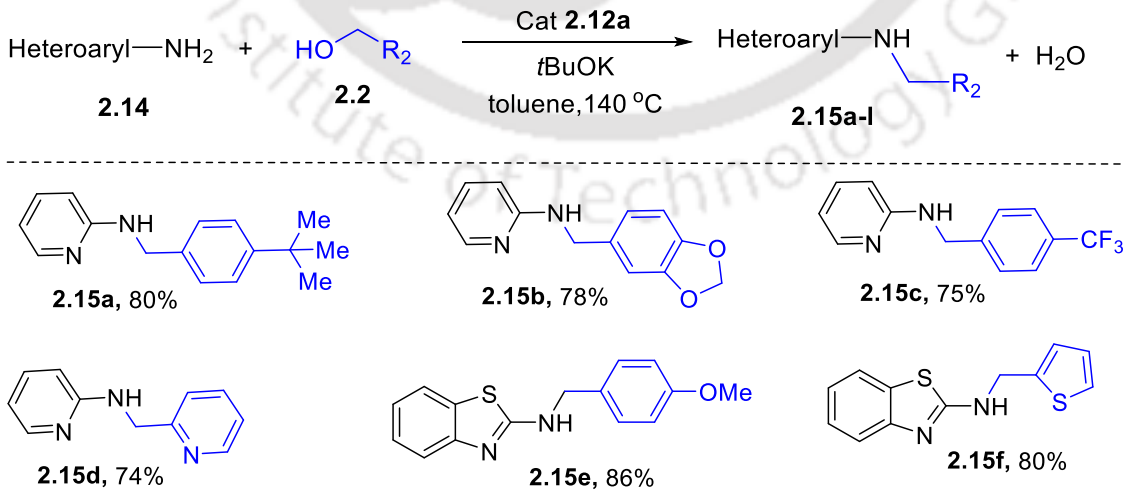
[a] Reaction conditions: Cat **2.12a** (5 mol %), amine (1 mmol), alcohol (1.2 mmol), *t*BuOK (1.2 mmol.) 140 °C (oil bath temperature), 24 h, toluene (2 mL), [b] isolated yield.

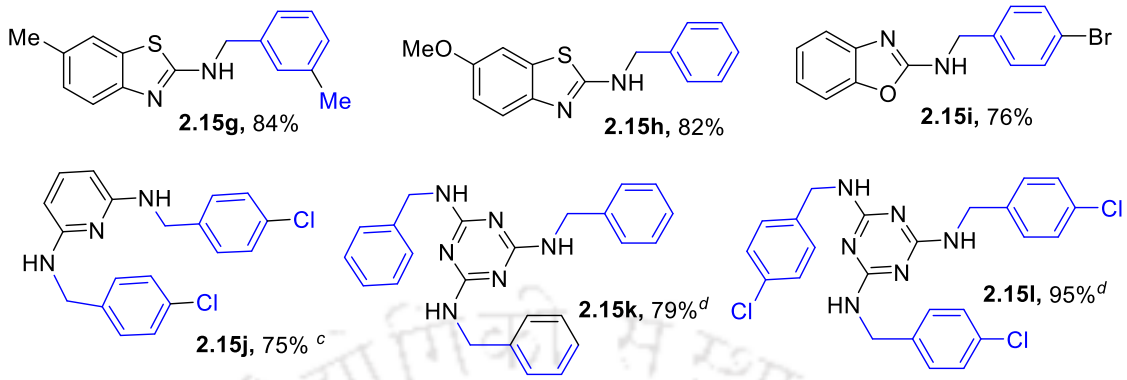
To demonstrate the usefulness of the present protocol, the *N*-alkylation of secondary amine to synthesize unsymmetrically substituted tertiary amine (**Table 2.3**) were explored. The challenging substrates like *N*-methylaniline[22b] and less basic *N*-methylbenzylamine reacted well with different benzylic and heteroaryl alcohols, which to the best of my knowledge are not yet reported with any manganese catalyst.

To illustrate the synthetic utility, the scope of *N*-alkylation reaction with regard to different heterocyclic amines was investigated further. 2-(*N*-alkylamino)benzothiazoles are structurally important units in many bioactive compounds,[25] and have a broad range of physiological and pharmacological activities.[26] Thus, initially, the *N*-alkylation of 2-aminobenzothiazole with different alcohols were studied; gratifyingly *N*-exosubstituted 2-(*N*-alkylamino)benzothiazoles were obtained in high yield (**Table 2.4**). The reaction catalyzed by Mn-complex is completely regioselective towards *N*-exosubstituted 2-(*N*-alkylamino)benzothiazoles whereas *N*-alkylation of 2-aminobenzothiazoles with alkyl halides give *N*-endosubstituted 3-alkyl-2-iminobenzothiazolines.[27]

Next, I interested to investigate the *N*-alkylation of aminopyridines as the selective *N*-alkylation of the amino-pyridine is a challenging as amides can be formed as byproducts.[28] Delightfully, the *N*-alkylation of aminopyridines proceeds well to afford the desired *N*-alkylated product in good yield (**Table 2.4**). Next, I am interested in

Table 2.4: Scope of *N*-alkylation reaction of heterocyclic amines with benzyl alcohol derivatives[a,b]



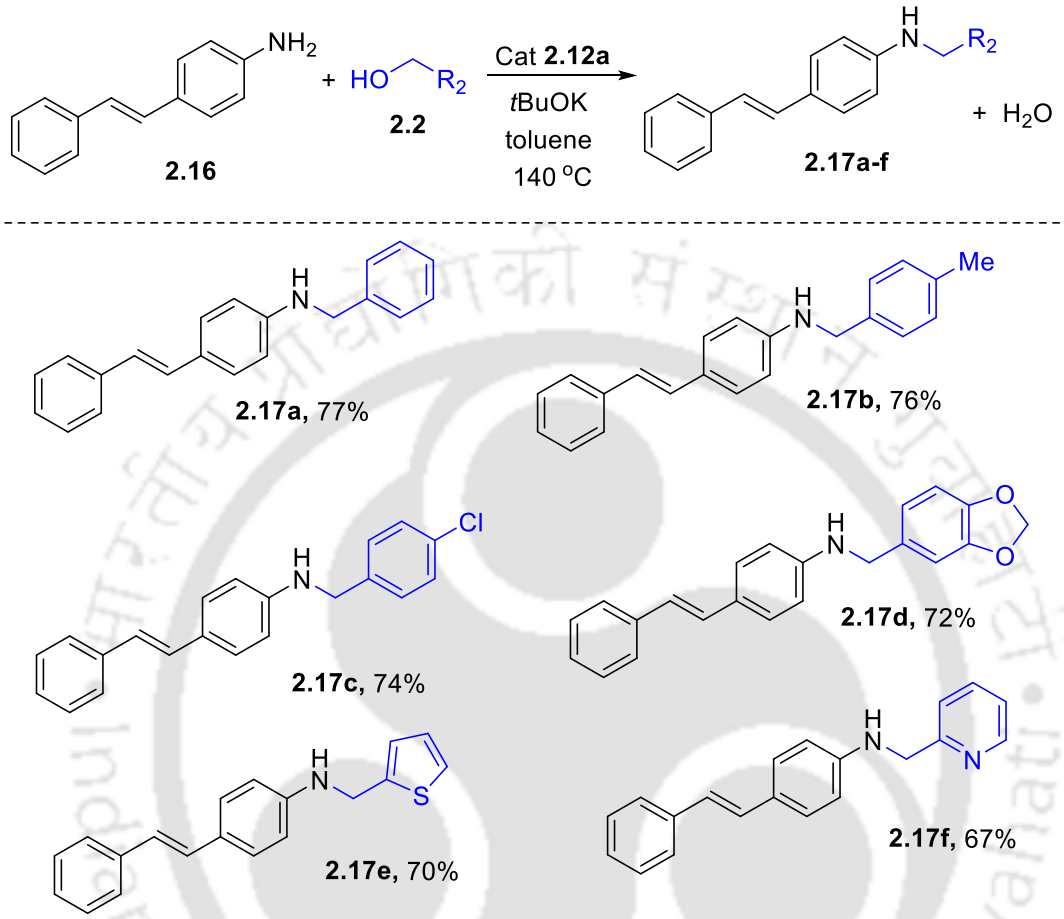


[a] Reaction conditions: Cat **2.12a** (5 mol %), amine (1 mmol), alcohol (1.2 mmol), *t*BuOK (1.2 mmol.) 140 °C (oil bath temperature), 24 h, toluene (2 mL), [b] isolated yield, [c] diaminobenzene (0.5 mmol), alcohol (1.5 mmol), 36 h, [d] melamine (0.5 mmol), alcohol (2.25 mmol), cat **2.12a** (0.08 mmol)), *t*BuOK (1.6 mmol), 52 h.

the tri *N*-alkylation of melamine as substituted *s*-triazine derivatives are known to have different biological activities.[29] Thus, the reaction of melamine with different benzyl alcohols was studied. Upon refluxing melamine (0.5 mmol) with 4-chlorobenzyl alcohol (2.25 mmol) in toluene led to the formation of corresponding trialkyalted product in 58% yield after 36 h, which was further improved to 95% just by increasing the reaction time (52 h).

Next, I have applied this protocol for the chemoselective *N*-alkylation 4-aminostilbene with different alcohols to afford Resveratrol derivatives (**Table 2.5**) in good isolated yield, as resveratrol-derived amines are known for their activity towards the treatment of Alzheimer's disease.[30]

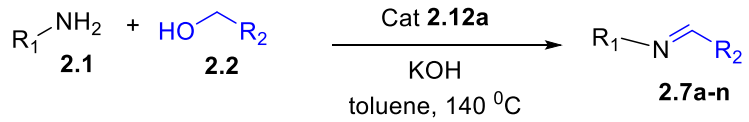
Table 2.5: Scope of the reaction to synthesize resveratrol derivatives from (*E*)-4-styrylaniline and benzyl alcohol derivatives[a,b]

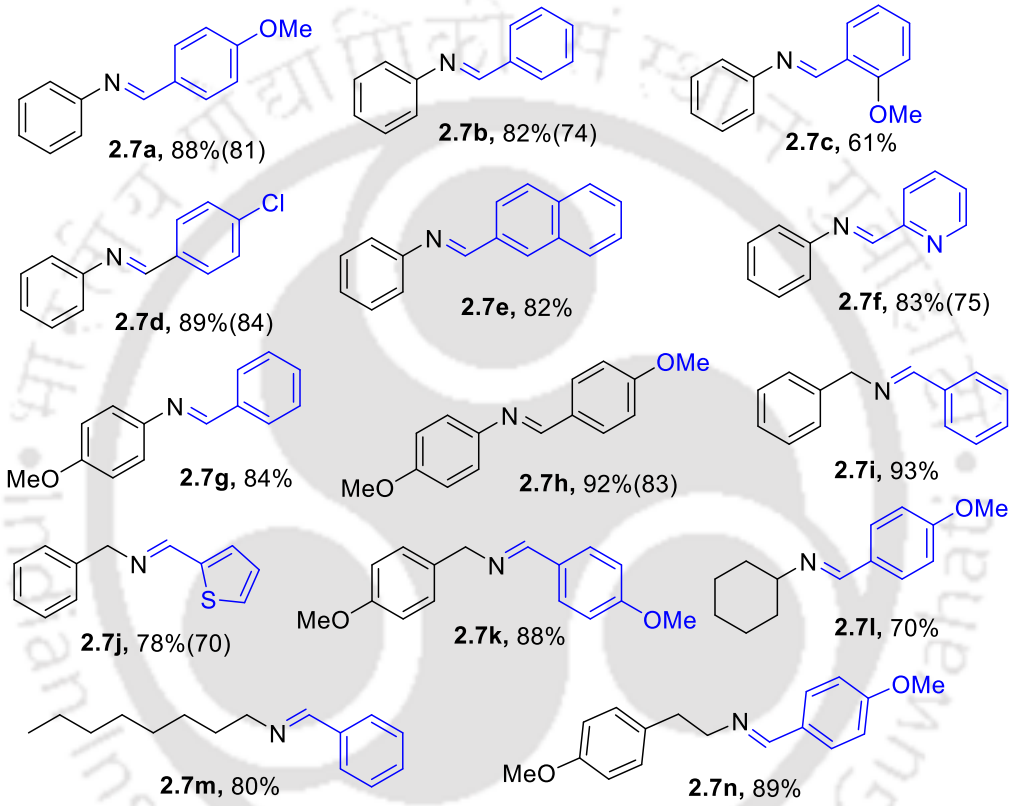


[a] Reaction conditions: Cat **2.12a** (5 mol %), 4-aminostilbene (1 mmol), alcohol (1.2 mmol), *t*BuOK (1.2 mmol) 140 °C (oil bath temperature), 24 h, toluene (2 mL), [b] isolated yield.

Then, I am interested to synthesize imine directly from the alcohol and amines using these Mn-complexes just by tuning the reaction condition. From the optimization **Table**, it was found that the nature and amount of the base are very important to get the desired selectivity towards imine (**Table 2.1**, entry 18, 19). Thus, when a toluene solution having aniline (1.0 mmol) and 4-methoxybenzyl alcohol (1.2 mmol) was refluxed in presence of KOH (0.5 mmol) and 5 mol% cat **2.12a** under argon flow, the desired imine was obtained in 75% yield which was further improved to 88% when 0.3 mmol KOH has been used. The substrate scope of the reaction is summarized in the **Table 2.6**.

Table 2.6: Scope of the reaction to synthesize imines derivatives from primary amine and primary alcohol derivatives[a,b]



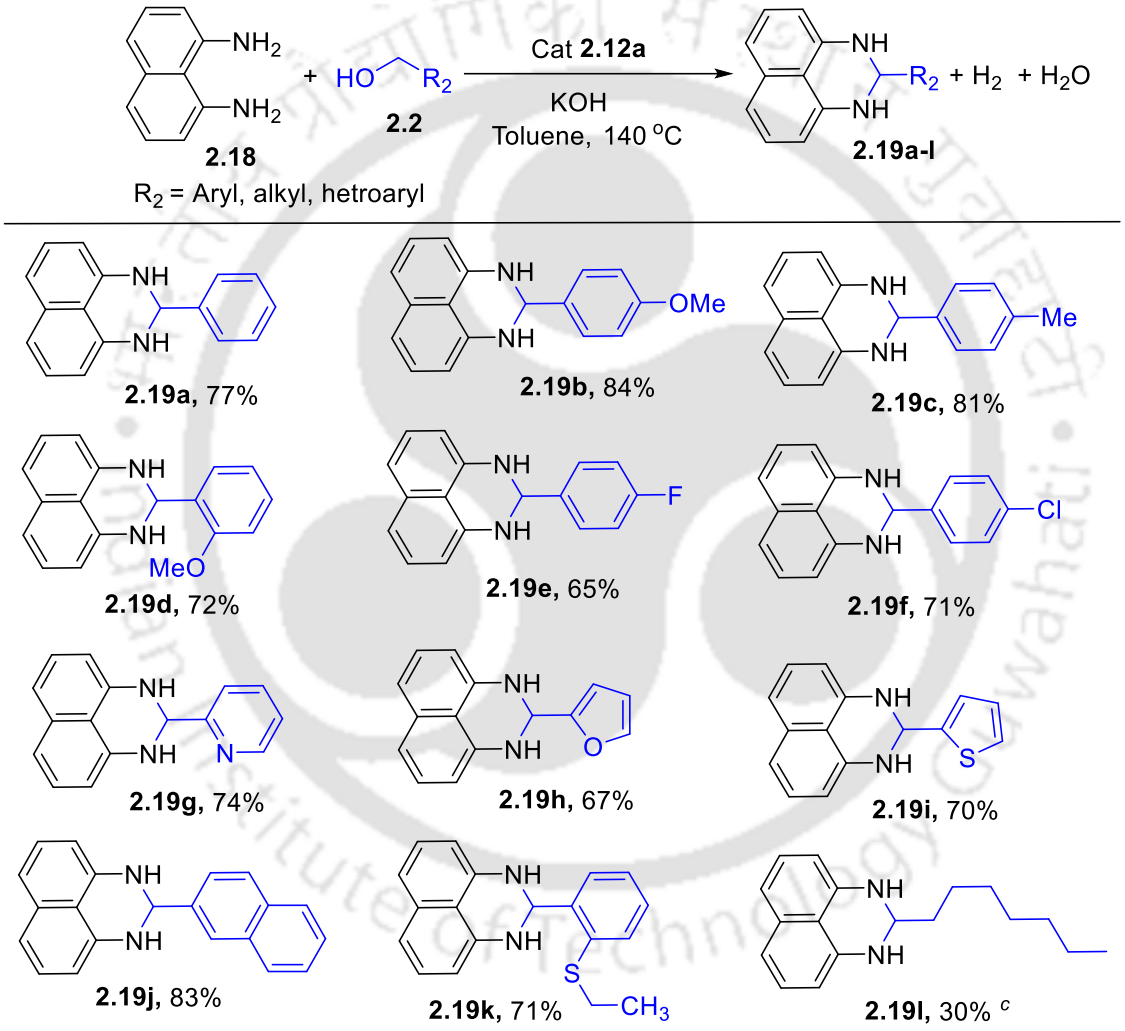


[a] Reaction conditions: Cat **2.12a** (5 mol %), amine (1.0 mmol), alcohol (1.2 mmol), KOH (0.3 mmol), 140 °C (oil bath temperature), 24 h, toluene (2 mL). [b] the NMR yield (the yield in the parenthesis is the isolated yield).

Encouraged by the versatility of this current catalytic system, I tried to apply this protocol to synthesize 2,3-dihydro-1*H*-perimidines as they are important class of compounds having useful biological activity.[31] Thus, when 1.0 mmol of 1,8-diaminonaphthalene is reacted with 1.2 mmol of primary alcohol in presence of 5 mol% of cat **2.12a** and 0.3 mmol of KOH, corresponding 2,3-dihydro-1*H*-perimidines derivatives were obtained in good yields. Different kinds of alcohol derivatives such as

electron-withdrawing, electron donating as well as heterocyclic alcohol undergo this reaction to produce good to excellent yield (**Table 2.7**). Octanol gave only 30% yield of the desired product after 72 h.

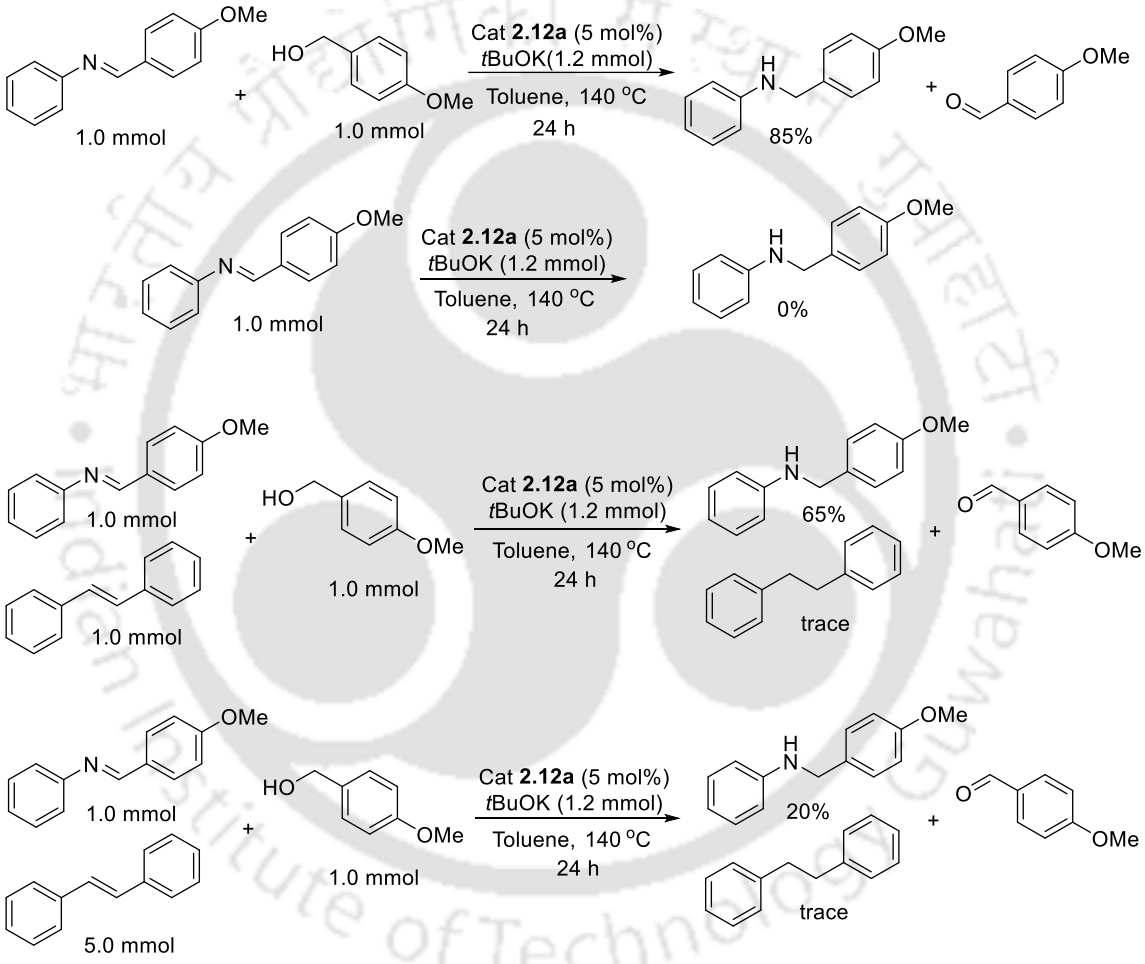
Table 2.7: Scope of the reaction to synthesize 2,3-dihydro-1*H*-perimidine derivatives from naphthalene-1,8-diamine and primary alcohol derivatives[a,b]



[a] Reaction conditions: Cat **2.12a** (5 mol %), 1,8-diaminonaphthalene (1.0 mmol), alcohol (1.2 mmol), KOH (0.3 mmol), 140 °C, 24 h, toluene (2 mL). [b] isolated yield. [c] alcohol (2.0 mmol), KOH (0.5 mmol), 72 h.

2.3. Plausible mechanism:

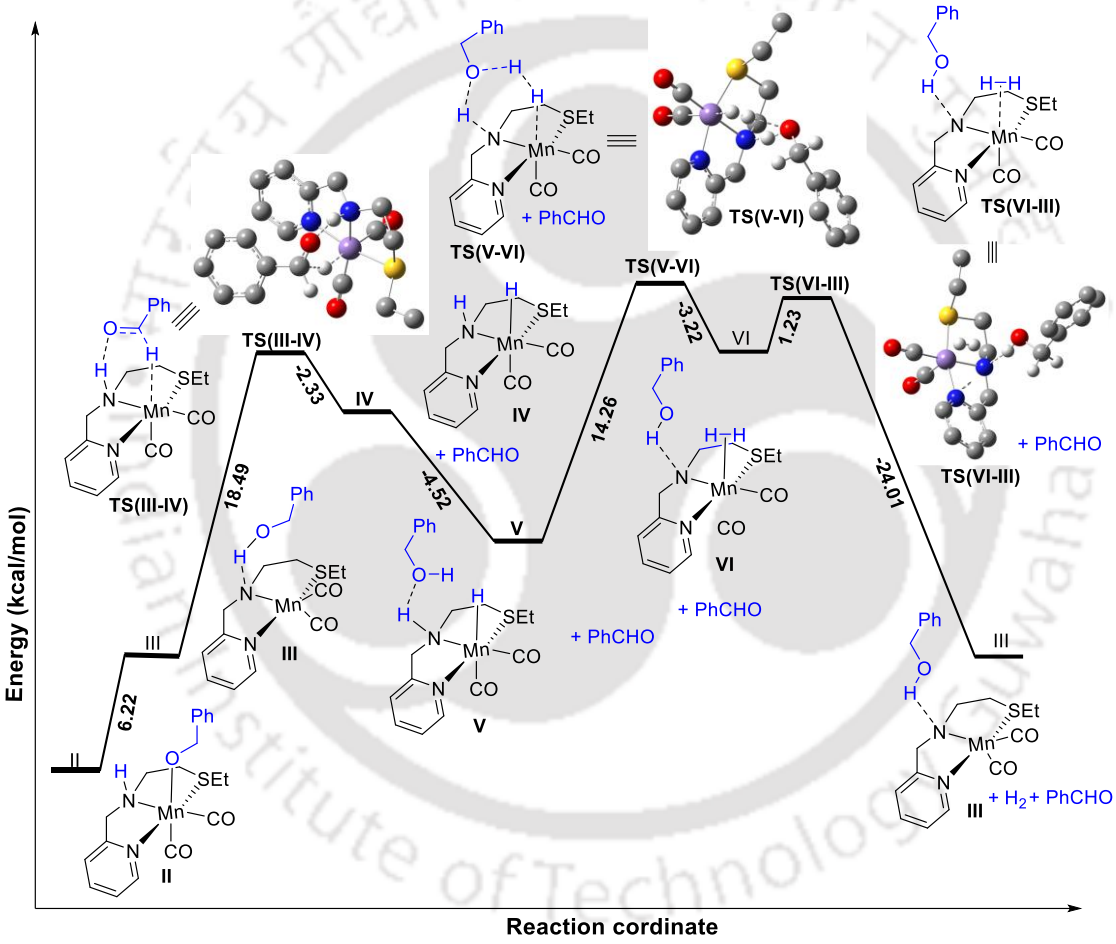
To gain a mechanistic insight, some control experiments were performed (**Scheme 2.11**). When an equimolar mixture of (*E*)-1-(4-methoxyphenyl)-*N*-phenylmethanimine and 4-methoxybenzyl alcohol was treated with catalyst **2.12a** in the presence of *t*BuOK (1.2 mmol), *N*-(4-methoxybenzyl)aniline was obtained in an 85% yield, whereas when



Scheme 2.11: Control experiments.

the reaction was done under the similar condition in the absence of the alcohol, no conversion of the imine to the corresponding amine was observed. Next, the hydrogen autotransfer reaction in the presence of alkene was studied. Thus, when an equimolar mixture of (*E*)-1-(4-methoxyphenyl)-*N*-phenylmethanimine, *trans*-stilbene, and 4-

methoxybenzyl alcohol was treated under the optimized reaction condition of hydrogen autotransfer, 65% of corresponding amine was detected, and stilbene was not hydrogenated. Furthermore, when a mixture of (*E*)-1-(4-methoxyphenyl)-*N*-phenylmethanimine and *trans*-stilbene in a 1:5 ratio is treated with 4-methoxybenzyl alcohol (1 mmol) under the similar reaction condition, the yield of the desired amine dropped to 20%. Thus, the excess amount of alkene found to retard the hydrogen autotransfer reaction of imine.



Scheme 2.12: The plausible mechanism.

On the basis of the previous reports,[32] and with the help of DFT calculations,[33] the plausible mechanism has been proposed and is presented in **Scheme 2.12.** Benzyl alcohol was taken as a model substrate to investigate the manganese (catalyst **2.12a**) catalyzed dehydrogenation reaction. First, the cationic complex in the presence of base

and under heating condition gave the five-coordinated amide complex I [$PyCH_2NCH_2CH_2Mn(CO)_2$]. The catalysis commences with the adduct formation III through the hydrogen bonding between complex I and benzyl alcohol. The complex II was selected as a reference point, which is more stable than complex III by 6.22 kcal/mol. Next, benzaldehyde was formed together with the manganese hydride complex IV *via* the hydride transfer of the *α*-methylene group of benzyl alcohol onto the metal centre. This is going through the transition state TS(III-IV), and the activation barrier for this reaction is 18.49 kcal/mol. This is the rate-determining step, and it is in accordance with the previous report.[32c]

Next, the barrier was calculated for the release of H_2 from the complex IV with the involvement of benzyl alcohol. The first step is the generation of the adduct complex V *via* hydrogen bonding between N-H of the complex IV and O of benzyl alcohol. Then, it leads to the formation of the manganese-coordinated η^2-H_2 complex VI through TS(V-VI). The activation barrier for this formation is 14.26 kcal/mol. The stabilization for complex VI is 3.22 kcal/mol compared to the TS(V-VI). Finally, dissociation of the H_2 molecule has an activation barrier of only ~1 kcal/mol to regenerate complex III, which shows a high stabilization of 24.01 kcal/mol from the TS as presented clearly in **Scheme 2.12**. The effect of various DFT methods, basis sets, dispersion corrections, etc. on the energy profile of the reaction was tested (Experimental section). The level of the calculation does not affect the overall trend of the results. Changes in geometry of these complexes along the path of the reaction are summarized (Experimental section).

2.4. Conclusion:

In conclusion, the first phosphine-free Mn-based protocol to synthesize both amine and imine from the same set of alcohol and amine is demonstrated. It is observed that a wide range of functional group tolerance and a broad range of substrate scope for both the reaction under the optimized reaction condition. The nature and stoichiometry of the applied base are crucial to obtain the maximum selectivity. This effective protocol has also been applied to synthesize the 2,3-dihydro-1*H*-perimidines derivatives.

Unfortunately, after the reaction the catalytic activity of Mn(I) complexes are destroyed. Hence these catalysts cannot be recycled.

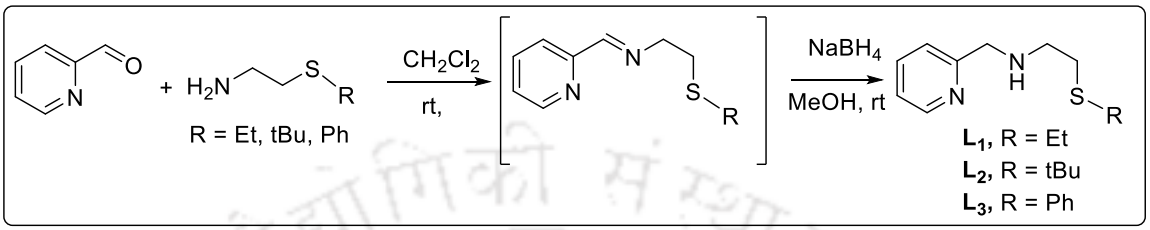
2.5. Experimental section:

General information

All chemicals were purchased from common commercial sources and used without any further purification. All solvents were dried by using standard procedures. The preparation of catalyst was carried out under argon atmosphere with freshly distilled THF. All catalytic reactions were carried out with air and/or under argon atmosphere using dried glassware and standard syringe/septa techniques. DRX-400 Varian spectrometer and Bruker Avance III 600 and 400 spectrometers were used for recording NMR (^{1}H and ^{13}C) spectra using $CDCl_3$ as solvent and TMS as an internal standard. Chemical shifts (δ) and spin-spin coupling constant (J) are reported in ppm and in Hz respectively, and other data are reported as follows: s = singlet, d = doublet, t = triplet, m = multiplet, q = quartet, and br s = broad singlet. FTIR were collected on PerkinElmer IR spectrometer. Q-Tof ESI-MS instrument (model HAB 273) was used for recording mass spectra. X-ray crystallographic data were collected using Agilent Super Nova (Single source at offset, Eos) diffractometer. Data refinement and cell reduction were carried out by CrysAlisPro. Structures were solved by direct methods using SHELXS-97 and refined by full-matrix least-squares on F^2 using SHELXL-97. All of the non-H atoms were refined anisotropically. SQUEEZE was used to reduce contribution of dichloromethane to the overall electron density. The purity determination of the substrates and reaction monitoring were accomplished by TLC on silica-gel 60 F254 plates (from Merck Company) and SRL silica gel (100-200 mesh) for column chromatography were used.

A. General experimental procedure for the synthesis of Ligands and Complexes:

1) Synthesis of Ligands:[24]



Scheme 2.13: Synthesis of NNS-ligands.

Pyridine-2-carboxaldehyde (15.76 mmol) and amino-thiol compound (15.0 mmol) were dissolved in dry DCM (35 mL) and the resulting suspension was stirred at room temperature (25 °C) for overnight in presence of Na_2SO_4 (16.9 mmol). Then, the reaction mixture was filtered and solvent was removed by rota-evaporator. The residue was dissolved in methanol (30 ml) and $NaBH_4$ (53.6 mmol) was added portion wise in stirring condition at 0 °C and the stirring was continued for overnight at room temperature. Then the solvent was evaporated and 40 ml water was added and neutralised by 10% HCl. After that, it was extracted by DCM (200 mL×3) and the combined organic phase was dried over Na_2SO_4. Then the solvent was evaporated to get the crude product, which was purified further by silica gel column chromatography using 20-40 % ethyl acetate in hexane.

2) Synthesis of NNS-Mn Complexes:

Ligand [$(PyCH_2)HN(CH_2CH_2SR)$, R= Et, tBu, Bn] (5.0 mmol) was taken in 20 mL dry THF and was added dropwise to the orange-yellow suspension of [$MnBr(CO)_5$] (5.0 mmol) in 12 mL degassed dry THF. Then, the suspension was refluxed for overnight under argon atmosphere. After cooling it down to the room temperature, the solvent was evaporated to obtain the residue, which was further washed with hexane and dried under vacuum to get yellow solid of Mn-complex (**Scheme 2.10**). The single crystal was grown by slow diffusion of toluene in the THF solution of the complex.

B. General experimental procedure for the synthesis of secondary and tertiary amines with different primary alcohol and aniline derivatives:

A mixture of aniline derivatives (1.0 mmol), primary alcohol (1.2 mmol), *t*BuOK (1.2 mmol), and catalyst **2.12a** (0.05 mmol) was refluxed with 2 mL of toluene at 140 °C for 24 h under an argon balloon. After cooling, chloroform was added to dilute the mixture and filtered through Celite. The filtrate was concentrated under reduced pressure, and the residue was purified using silica gel column chromatography with 2−20% ethyl acetate in hexane as an eluent.

C. General experimental procedure for the synthesis of imine derivatives:

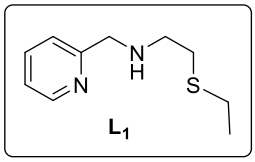
A mixture of amine (1.0 mmol), primary alcohol (1.2 mmol), KOH (0.3 mmol), and catalyst **2.12a** (0.05 mmol) was refluxed with 2 mL of toluene at 140 °C for 24 h in an open system under an argon flow. After cooling, chloroform was added to dilute the mixture and filtered through Celite. The filtrate was concentrated under reduced pressure, and the residue was purified using silica gel column chromatography with 2-20% ethyl acetate in hexane as an eluent to get a pure compound.

D. General experimental procedure for the synthesis of 2,3-dihydro-1*H*-perimidines derivatives:

A mixture of naphthalene-1,8-diamine (1.0 mmol), primary alcohol (1.2 mmol), KOH (0.3 mmol), and catalyst **2.12a** (0.05 mmol) was refluxed with 2 mL of toluene at 140 °C for 24 h in an open system under an argon balloon. After cooling, chloroform was added to dilute the mixture and filtered through Celite. The filtrate was concentrated under reduced pressure, and the residue was purified by silica gel column chromatography with 2-20% ethyl acetate in hexane as an eluent to get a pure compound.

2.6. Characterization data of products:

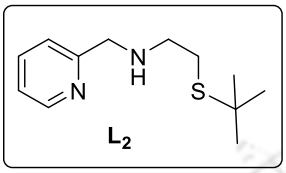
a) 2-(ethylthio)-N-(pyridin-2-ylmethyl)ethan-1-amine (L_1):[24a]



Brown oil (3.077 g, 92%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.52-8.51 (m, 1H), 7.60 (td, *J* = 7.6, 1.2 Hz, 1H), 7.29 (d, *J* = 7.8 Hz, 1H), 7.13-7.11 (m, 1H), 3.90 (s, 2H), 2.84-2.81 (m, 2H), 2.70-2.68 (m,

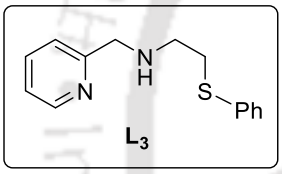
2H), 2.50 (q, *J* = 7.4 Hz, 2H), 2.35 (br s, 1H), 1.21 (t, *J* = 7.4 Hz, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 159.7, 149.4, 136.5, 122.2, 122.0, 55.0, 48.3, 32.0, 25.8, 14.9.

b) 2-(tert-butylthio)-N-(pyridin-2-ylmethyl)ethan-1-amine (L_2):[24b]



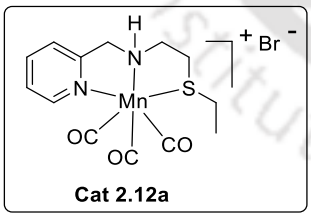
Brown oil (2.949 g, 88%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.55 - 8.53 (m, 1H), 7.63 (td, *J* = 7.6, 1.7 Hz, 1H), 7.31 (d, *J* = 7.8 Hz, 1H), 7.15 (dd, *J* = 7.5, 4.9 Hz, 1H), 3.93 (s, 2H), 2.86 (t, *J* = 6.8 Hz, 2H), 2.73 (t, *J* = 6.8 Hz, 2H), 2.34 (s, 1H), 1.31 (s, 9H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 159.7, 149.4, 136.6, 122.3, 122.1, 55.0, 49.3, 42.2, 31.2, 28.9.

c) 2-(benzylthio)-N-(pyridin-2-ylmethyl)ethan-1-amine (L_3):[24c]



Brown oil (1.388 g, 91%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.48 (d, *J* = 4.8 Hz, 1H), 7.56 (td, *J* = 7.7, 1.6 Hz, 1H), 7.22 - 7.21 (m, 5H), 7.15 (dt, *J* = 8.6, 4.4 Hz, 1H), 7.08 (dd, *J* = 7.3, 5.1 Hz, 1H), 3.81 (s, 2H), 3.62 (s, 2H), 2.73 (t, *J* = 6.6 Hz, 2H), 2.54 (t, *J* = 6.6 Hz, 2H), 2.10 (s, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 159.7, 149.4, 138.4, 136.6, 128.9, 128.6, 127.1, 122.3, 122.0, 54.9, 47.9, 36.0, 31.6.

Complex-2.12a:

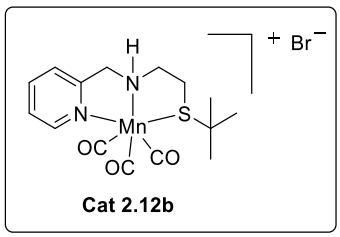


Yellow solid (1.980 g, 95%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.69 (br s, 1H), 8.26 (br s, 1H), 7.87 (br s, 1H), 7.71 (br s, 1H), 7.40 (br s, 1H), 4.81(br s, 1H), 4.58 (br s, 1H), 3.39-3.35 (m, 2H), 2.98-2.87 (m, 2H), 2.05 (br s, 2H), 1.45 (br s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) *δ* 218.9, 216.6, 161.9, 152.6, 139.6, 125.2, 122.7, 60.4, 54.6, 33.1, 31.8, 13.4.

IR (cm^{-1}): 3059, 2920, 2875, 2030, 1946, 1920, 1609, 1462, 1286, 1196, 1083, 949, 910, 821, 769, 689, 637.

HRMS (ESI) calcd for $C_{13}H_{16}MnN_2O_3S$ [M +]: 335.0262; found, 335.0263

Complex-2.12b:



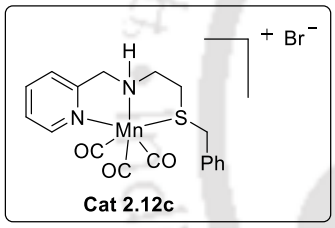
Cat 2.12b

Yellow solid (1.670 g, 92%), ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.65 (s, 1H), 8.24 (s, 1H), 7.81 (s, 1H), 7.64 (s, 1H), 7.20 (s, 1H), 4.62 (d, *J* = 144.5 Hz, 2H), 3.23 (s, 2H), 2.81- 2.04 (m, 2H), 1.43 (s, 9H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 219.8, 217.0, 161.9, 153.1, 139.4, 125.4, 122.6, 60.4, 55.9, 49.7, 30.7, 29.9.

IR (cm^{-1}): 3409, 3071, 2960, 2924, 2032, 1943, 1925, 1605, 1442, 1365, 1264, 1159, 1015, 766, 634, 533.

HRMS (ESI) calcd for $C_{15}H_{20}MnN_2O_3S$ [M]$^{+}$: 363.0575; found, 363.0579.

Complex-2.12c:



Cat 2.12c

Yellow solid (1.151 g, 89%),^{1}H NMR (600 MHz, CDCl3) δ 8.29 (s, 1H), 7.89 (s, 1H), 7.51 (s, 1H), 7.37 (s, 1H), 6.98 (s, 6H), 4.34 (d, *J* = 93.6 Hz, 2H), 3.69 (d, *J* = 31.4 Hz, 2H), 3.06 (s, 2H), 2.45 (s, 2H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 219.0, 218.6, 216.9, 162.1, 152.8, 139.5, 133.7, 129.4, 129.2, 128.8, 125.3, 122.7, 60.0, 53.9, 41.7, 32.1.

IR (cm^{-1}): 3420, 3072, 2914, 2033, 1926, 1631, 1422, 1291, 1073, 768, 704, 685, 633, 532.

HRMS (ESI) calcd for $C_{18}H_{18}MnN_2O_3S$ [M]$^{+}$: 397.0419; found, 397.0413.

Crystal data of complex 2.12a, 2.12b and 2.12c:

Crystal parameters	**Cat. 2.12a**	**Cat. 2.12b**	**Cat. 2.12c**
Empirical formula	C13 H16 Br Mn N2 O3 S	C33 H50 Br2 Cl Mn2 N3 O12 S2	C18 H18 Br Mn N2 O3 S
CCDC	1831616	1881759	1855184
Formula weight	415.18	1050.03	477.25
Temperature, T	293 K	293 K	293 K

Crystal system	monoclinic	triclinic	orthorhombic
Space group	P 21/c	'P -1'	'P b c a'
Unit cell dimensions	a=7.9663(16) α=90° b=14.830(3) Å β=96.629(18)° c=14.187(2) Å γ=90°	a=11.5216(4)Å α=108° b=14.0105(6)Å β=99° c=15.3047(8) Å γ=90°	a=16.5242(15) Å α=90° b=9.5030(8) β=90° c=26.035(3) Å γ=90°
Volume, V (Å^3)	1664.9(5)	2312.85(18)	4088.2(7)
Z	4	2	8
Density (calculated), Mg·m^{-3}	1.656	1.508	1.551
Absorption coefficient, μ (mm^{-1})	3.327	2.477	2.721
F(000)	832.0	1068	1920.0
Crystal size, mm^3	0.34 × 0.32 × 0.32	0.32 × 0.28 × 0.22	0.34 × 0.31 × 0.29
Theta range for data collection	2.92 to 24.50	2.30 to 25.00	2.92to 25.00
Index ranges	-5 ≤ h ≤ 9, -17 ≤ k ≤ 8, -16 ≤ l ≤ 16	-13 ≤ h ≤ 13, -10 ≤ k ≤ 16, -18 ≤ l ≤ 18	-19 ≤ h ≤ 14, -11 ≤ k ≤ 10, -25 ≤ l ≤ 30
Reflections collected	6124	3186	2262
Independent reflections	2766	8149	3597
Completeness to theta	0.9963	0.999	0.999
Absorption	Multi-scan	Multi-scan	Multi-scan

correction			
Max. and min. transmission	1.00000 and 0.29978	1.00000 and 0.62569	1.00000 and 0.57204
Refinement method	'SHELXL-97(Sheldrick, 1997)'	'SHELXL-97(Sheldrick, 1997)'	'SHELXL-97(Sheldrick, 1997)'
Data / restraints / parameters	2766/0/191	8149 /0/421	3597 /0/235
Goodness-of-fit on F^2	0.903	0.943	0.956
Final R indices [I>2sigma(I)]	R1 = 0.0923, wR2 = 0.1579	R1 = 0.0530(4333), wR=0.1471(8149)	R1 = 0.0448(2444), wR=2 0.1531(3597)
R indices (all data)	R1 = 0.2034, wR2 = 0.2151	R1 = 0.1005, wR=0.1471	R1 = 0.0816, wR=2 0.1273
Extinction coefficient	3.327	2.477	2.721
Largest diff. peak and hole	0.973 and -0.500 e·Å^{-3}	0.669and -0.465e·Å^{-3}	0.473 and -0.530 e·Å^{-3}

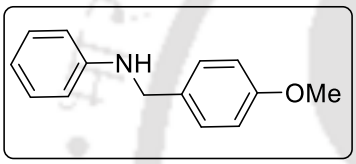
Selected Bond length [Å]

Cat. 2.12a	**Cat. 2.12b**	**Cat. 2.12c**
Mn1-N1 2.064(11)	Mn1 N1 2.053(5)	Mn1-N1 2.058(4)
Mn1-N2 2.091(12)	Mn1 N2 2.066(4)	Mn1-N2 2.081(4)
Mn1- S1 2.358(4)	Mn1 S1 2.3865(16)	Mn1- S1 2.3617(15)
Mn1- C11 1.780(17)	Mn1 C13 1.795(8)	Mn1- C16 1.811(6)
Mn1-C12 1.753(19),	Mn1 C14 1.810(8)	Mn1-C17 1.806(6)
Mn1-C13 1.782(19)	Mn1 C15 1.809(8)	Mn1-C18 1.807(6)

Selected Bond angles [°]

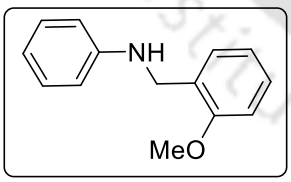
Cat. 2.12a	Cat. 2.12b	Cat. 2.12c
N1 Mn1 S1 82.3(3)	N1 Mn1 S1 80.75(12)	N1 Mn1 S1 81.01(12)
N2 Mn1 S1 83.9(4)	N2 Mn1 S1 84.70(12)	N2 Mn1 S1 84.23(12)
N1 Mn1 N2 80.8(5)	N1 Mn1 N2 80.46(18)	N1 Mn1 N2 80.65(18)
C12 Mn1 S1 92.1(5)	C13 Mn1 N1 175.5(3)	C16 Mn1 S1 173.8(2)
C11 Mn1 S1 95.6(5)	C14 Mn1 S1 92.7(2)	C17 Mn1 S1 92.61(19)
C13 Mn1 S1 172.6(5)	C15 Mn1 S1 171.9(2)	C18 Mn1 S1 96.81(18)

***N*-(4-methoxybenzyl)aniline (2.3a):**[34]



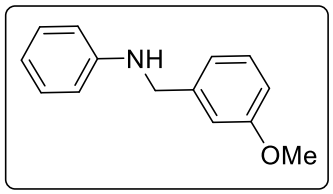
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow solid (192 mg, 90%), ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.34 (d, *J* = 8.4 Hz, 2H), 7.23 (app. t, *J* = 7.8 Hz, 2H), 6.93 (d, *J* = 8.4 Hz, 2H), 6.77 (app. t, *J* = 7.3 Hz, 1H), 6.68 (d, *J* = 8.0 Hz, 2H), 4.29 (s, 2H), 3.99 (s, 1H), 3.84 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 158.9, 148.3, 131.5, 129.3, 128.9, 117.5, 114.1, 112.9, 55.4, 47.8.

***N*-(2-methoxybenzyl)aniline (2.3b):** [34]



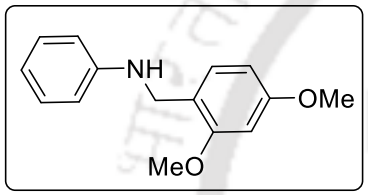
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (171 mg, 80%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.22 (d, *J* = 7.4 Hz, 1H), 7.15 (app. t, *J* = 8.3 Hz, 1H), 7.09 - 7.05 (m, 2H), 6.84 - 6.78 (m, 2H), 6.62 - 6.55 (m, 3H), 4.25 (s, 2H), 4.02 (s, 1H), 3.77 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.5, 148.5, 129.3, 129.0, 128.4, 127.5, 120.6, 117.4, 113.2, 110.4, 55.4, 43.6.

_N_-(3-methoxybenzyl)aniline (2.3c): [34]



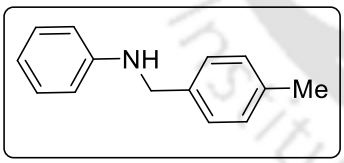
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow solid (173 mg, 81%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.18 (app. t, *J* = 7.9 Hz, 1H), 7.10 (app. t, *J* = 7.9 Hz, 2H), 6.89 - 6.85 (m, 2H), 6.74 (dd, *J* = 8.2, 2.3 Hz, 1H), 6.64 (app. t, *J* = 7.3 Hz, 1H), 6.56 (d, *J* = 8.5 Hz, 2H), 4.23 (s, 2H), 3.95 (s, 1H), 3.72 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.1, 148.3, 141.3, 129.8, 129.4, 119.9, 117.7, 113.2, 113.0, 112.8, 55.4, 48.5.

_N_-(2,4-dimethoxybenzyl)aniline (2.3d): [35]



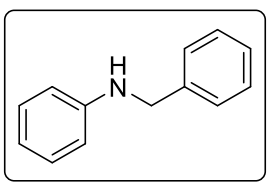
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow solid (204 mg, 84%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.22 - 7.15 (m, 3H), 6.72 - 6.65 (m, 3H), 6.49 - 6.47 (m, 1H), 6.44 (dd, *J* = 8.2, 2.4 Hz, 1H), 4.26 (s, 2H), 4.05 (s, 1H), 3.84 (s, 3H), 3.80 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.3, 158.6, 148.6, 129.8, 129.3, 119.9, 117.4, 113.2, 104.0, 98.8, 55.5, 55.5, 43.3.

_N_-(4-methylbenzyl)aniline (2.3e): [34]



This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (162 mg, 82%), ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.28 (d, *J* = 7.6 Hz, 2H), 7.20 - 7.16 (m, 4H), 6.73 (app. t, *J* = 7.3 Hz, 1H), 6.65 (d, *J* = 8.5 Hz, 2H), 4.30 (s, 2H), 3.99 (s, 1H), 2.36 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 148.3, 137.0, 136.4, 129.4, 129.4, 127.6, 117.6, 112.9, 48.2, 21.2.

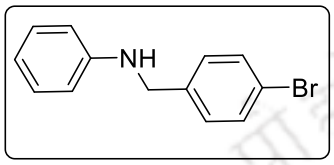
_N_-benzylaniline (2.3f): [34]



This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Colourless liquid (152 mg, 83%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 - 7.35 (m, 4H), 7.32 -

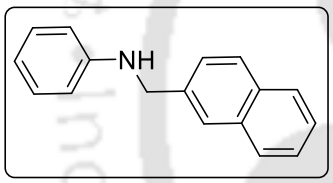
7.29 (m, 1H), 7.22 - 7.18 (m, 2H), 6.75 (app. t, *J* = 7.3 Hz, 1H), 6.67 (d, *J* = 7.3 Hz, 2H), 4.36 (s, 2H), 4.04 (s, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 148.2, 139.5, 129.3, 128.7, 127.6, 127.3, 117.6, 112.9, 48.3.

***N*-(4-bromobenzyl)aniline (2.3g):** [36]



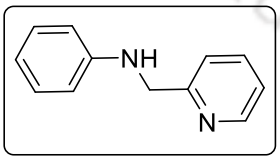
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (194 mg, 74%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 (d, *J* = 8.4 Hz, 2H), 7.15 (d, *J* = 8.4 Hz, 2H), 7.10 - 7.06 (m, 2H), 6.64 (app. t, *J* = 7.3 Hz, 1H), 6.51 (d, *J* = 7.6 Hz, 2H), 4.20 (s, 2H), 3.96 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.9, 138.7, 131.8, 129.4, 129.2, 121.0, 117.9, 113.0, 47.8.

***N*-(naphthalen-2-ylmethyl)aniline (2.3h):** [36]



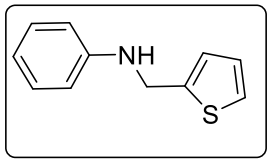
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (198 mg, 85%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86 - 7.81 (m, 4H), 7.52 - 7.46 (m, 3H), 7.20 (t, *J* = 7.6 Hz, 2H), 6.77 - 6.73 (m, 1H), 6.70 (d, *J* = 7.9 Hz, 2H), 4.51 (s, 2H), 4.14 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.3, 137.1, 133.6, 132.9, 129.4, 128.5, 127.9, 127.8, 126.3, 126.0, 125.9, 125.9, 117.8, 113.1, 48.7.

***N*-(pyridin-2-ylmethyl)aniline (2.3i):** [37]



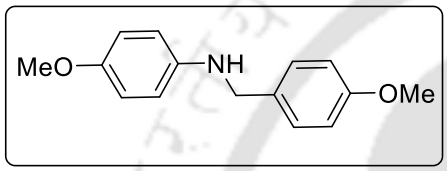
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (149 mg, 81%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.60 - 8.58 (m, 1H), 7.63 (app. t, *J* = 7.7 Hz, 1H), 7.34 (d, *J* = 7.8 Hz, 1H), 7.21 - 7.16 (m, 3H), 6.75 - 6.71 (m, 1H), 6.69 - 6.67 (m, 2H), 4.78 (s, 1H), 4.47 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.7, 149.3, 148.0, 136.7, 129.3, 122.2, 121.7, 117.8, 113.2, 49.4.

_N_-(thiophen-2-ylmethyl)aniline (2.3j): [36]



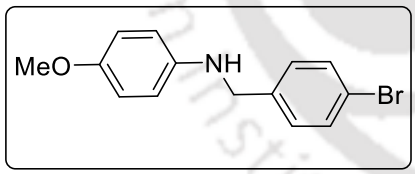
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Brown oil (144 mg, 76%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.24 - 7.19 (m, 3H), 7.04 - 7.03 (m, 1H), 7.00 - 6.97 (m, 1H), 6.77 (app. t, *J* = 7.3 Hz, 1H), 6.71 - 6.68 (m, 2H), 4.53 (s, 2H), 4.05 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.7, 143.1, 129.4, 127.0, 125.2, 124.7, 118.2, 113.3, 43.6.

4-methoxy-_N_-(4-methoxybenzyl)aniline (2.3k): [37]



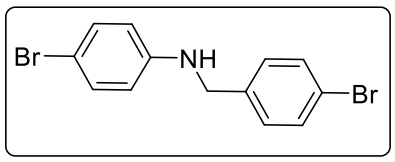
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (192 mg, 79%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 (d, *J* = 8.6 Hz, 2H), 6.90 - 6.87 (m, 2H), 6.80 - 6.77 (m, 2H), 6.63 - 6.59 (m, 2H), 4.22 (s, 2H), 3.81 (s, 3H), 3.75 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.0, 152.3, 142.7, 131.8, 129.0, 115.1, 114.3, 114.1, 56.0, 55.4, 48.9.

_N_-(4-bromobenzyl)-4-methoxyaniline (2.3l):[38]



This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow oil (216 mg, 74%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 (d, *J* = 8.4 Hz, 2H), 7.15 (d, *J* = 8.4 Hz, 2H), 6.69 - 6.67 (m, 2H), 6.49 - 6.46 (m, 2H), 4.15 (s, 2H), 3.64 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.4, 142.2, 138.9, 131.7, 129.2, 120.9, 115.0, 114.3, 55.9, 48.7.

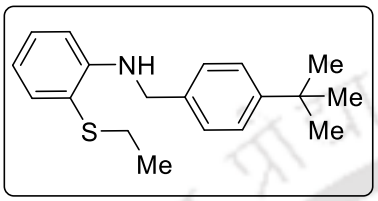
4-bromo-_N_-(4-bromobenzyl)aniline (2.3m):[39]



This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (169 mg, 70%), ^{1}H NMR (400 MHz, $CDCl_3$) δ

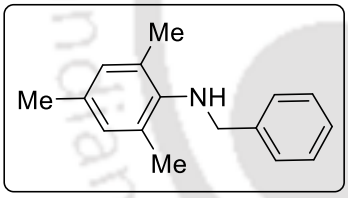
7.47 - 7.44 (m, 2H), 7.23 (t, *J* = 8.4 Hz, 4H), 6.49 - 6.45 (m, 2H), 4.26 (s, 2H), 4.10 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.9, 138.1, 132.1, 131.9, 129.1, 121.3, 114.6, 109.6, 47.7.

***N*-(4-(tert-butyl)benzyl)-2-(ethylthio)aniline (2.3n):**



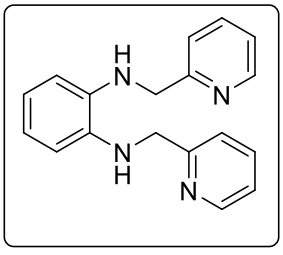
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow solid (242 mg, 81%) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 - 7.38 (m, 3H), 7.31 (d, *J* = 7.9 Hz, 2H), 7.19 (app. t, *J* = 7.5 Hz, 1H), 6.68 - 6.62 (m, 2H), 5.50 (s, 1H), 4.38 (d, *J* = 4.8 Hz, 2H), 2.76 (q, *J* = 7.4 Hz, 2H), 1.35 (s, 9H), 1.24 (t, *J* = 7.4 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 150.2, 149.3, 136.3, 136.3, 130.1, 127.1, 125.7, 117.6, 116.9, 110.5, 47.8, 34.6, 31.5, 29.2, 15.1. HRMS (ESI) calcd. for $C_{19}H_{25}NS$ $(M + H)^+$ 300.1786; found 300.1787.

***N*-benzyl-2,4,6-trimethylaniline (2.3o):**[40]



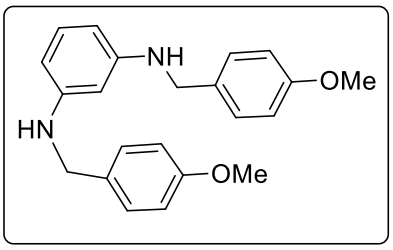
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Orange oil (160 mg, 71%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 - 7.36 (m, 4H), 7.34 - 7.30 (m, 1H), 6.88 (s, 2H), 4.10 (s, 2H), 3.13 (s, 1H), 2.29 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 143.4, 140.7, 131.8, 130.3, 129.6, 128.7, 128.1, 127.4, 53.3, 20.7, 18.4.

***N*^{1},*N*^{2}-bis(pyridin-2-ylmethyl)benzene-1,2-diamine (2.3p):**[41]



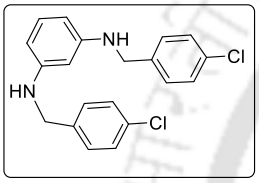
This compound was prepared according to the general procedure **B**. Reaction was completed after 18 h. Brown oil (133 mg, 46%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.59 - 8.58 (m, 2H), 7.64 (app. t, *J* = 7.7 Hz, 2H), 7.36 (d, *J* = 7.8 Hz, 2H), 7.18 (dd, *J* = 7.1, 5.2 Hz, 2H), 6.75 (app. t, *J* = 7.4 Hz, 2H), 6.67 - 6.64 (m, 2H), 4.49 (s, 4H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.0, 149.3, 137.1, 136.8, 122.2, 121.8, 119.49, 112.3, 50.0.

N^1,N^3-bis(4-methoxybenzyl)benzene-1,3-diamine (2.3q):[111]



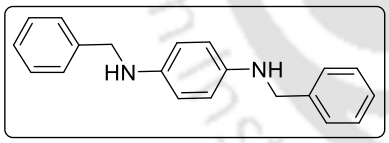
This compound was prepared according to the general procedure **B**. Reaction was completed after 36 h. Pale yellow solid (237 mg, 68%) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17 (d, *J* = 8.5 Hz, 4H), 6.89 (app. t, *J* = 8.0 Hz, 1H), 6.77 (d, *J* = 8.6 Hz, 4H), 5.96 (dd, *J* = 8.0, 2.1 Hz, 2H), 5.82 (app. t, *J* = 2.1 Hz, 1H), 4.11 (s, 4H), 3.70 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.9, 149.5, 131.8, 130.1, 128.9, 114.1, 103.2, 97.4, 55.4, 47.9.

N^1,N^3-bis(4-chlorobenzyl)benzene-1,3-diamine (2.3r):



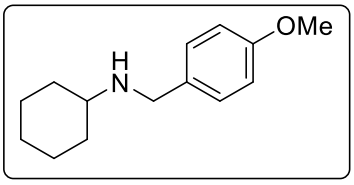
This compound was prepared according to the general procedure **B**. Reaction was completed after 36 h. Pale yellow solid (304 mg, 85%) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.21 - 7.15 (m, 8H), 6.88 (t, *J* = 8.0 Hz, 1H), 5.94 (dd, *J* = 8.0, 2.2 Hz, 2H), 5.74 - 7.73 (m, 1H), 4.15 (s, 4H), 3.88 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 149.2, 138.3, 132.9, 130.2, 128.8, 128.8, 103.4, 97.4, 47.7. HRMS (ESI) calcd. for $C_{20}H_{18}N_2Cl_2$ $(M + H)^+$ 357.0925; found 357.0927.

N^1,N^4-dibenzylbenzene-1,4-diamine (2.3s):[111]



This compound was prepared according to the general procedure **B**. Reaction was completed after 36 h. Pale yellow solid (222 mg, 77%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.28 - 7.21 (m, 8H), 7.18 - 7.13 (m, 2H), 6.48 (s, 4H), 4.16 (s, 4H), 3.45 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 140.9, 140.1, 128.7, 127.8, 127.2, 114.9, 49.7.

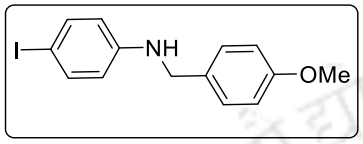
***N*-(4-methoxybenzyl)cyclohexanamine (2.3t):**[42]



This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Colourless liquid (140 mg, 64%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.24 - 7.22 (m, 2H), 6.87 - 6.83 (m, 2H), 3.79 (s,

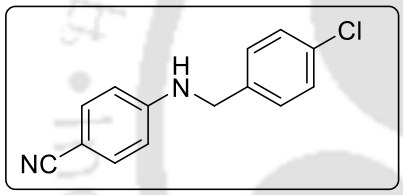
3H), 3.74 (s, 2H), 2.49 - 243 (m, 1H), 2.92 - 1.88 (m, 2H), 1.75 - 170 (m, 2H), 1.63 - 1.58 (m, 1H), 1.43 (s, 1H), 1.29 - 1.07 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.6, 133.2, 129.4, 113.9, 56.2, 55.4, 50.5, 33.7, 26.3, 25.1.

4-iodo-*N*-(4-methoxybenzyl)aniline (2.3u):[43a]



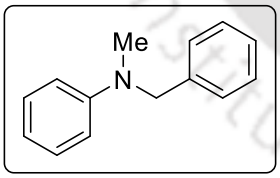
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (210 mg, 62%), ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.41 (d, *J* = 8.8 Hz, 2H), 7.26 (d, *J* = 8.6 Hz, 2H), 6.88 (d, *J* = 8.6 Hz, 2H), 6.41 (d, *J* = 8.8 Hz, 2H), 4.22 (s, 2H), 4.02 (s, 1H), 3.81 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 159.0, 147.8, 137.9, 130.9, 128.8, 115.2, 114.2, 78.1, 55.4, 47.6.

4-((4-chlorobenzyl)amino)benzonitrile (2.3v):[43b]



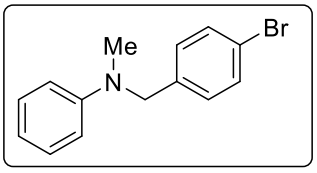
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (126 mg, 52%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.45 - 7.37 (m, 2H), 7.35 - 7.29 (m, 2H), 7.28 - 7.20 (m, 2H), 6.62 - 6.53 (m, 2H), 4.66 (br s, 1H), 4.36 (d, *J* = 5.6 Hz, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 150.9, 136.4, 133.9, 133.5, 129.1, 128.6, 120.4, 112.6, 99.5, 46.9.

***N*-benzyl-*N*-methylaniline (2.13a):**[44]



This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Pale yellow oil (136 mg, 69%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.24 - 7.21 (m, 2H), 7.16 - 7.11 (m, 5H), 6.67 (d, *J* = 8.0 Hz, 2H), 6.63 (app. t, *J* = 7.7 Hz, 1H), 4.45 (s, 2H), 2.93 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 149.9, 139.2, 129.3, 128.7, 127.0, 126.9, 116.7, 112.5, 56.8, 38.6.

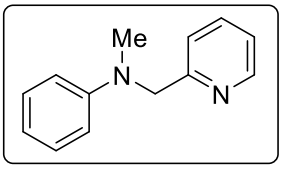
***N*-(4-bromobenzyl)-*N*-methylaniline (2.13b):**[44]



This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Colourless oil (179 mg, 65%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 (dd, *J*

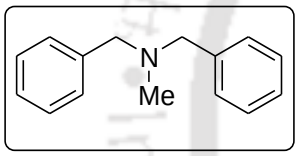
= 8.3, 1.4 Hz, 2H), 7.12 (ddd, *J* = 8.5, 7.5, 1.5 Hz, 2H), 7.00 (d, *J* = 7.6 Hz, 2H), 6.62 (dq, *J* = 9.0, 2.4, 1.9 Hz, 3H), 4.36 (s, 2H), 2.89 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 149.6, 138.2, 131.8, 129.3, 128.6, 120.7, 117.0, 112.6, 56.3, 38.7.

_N_-methyl-_N_-(pyridin-2-ylmethyl)aniline (2.13c):[45]



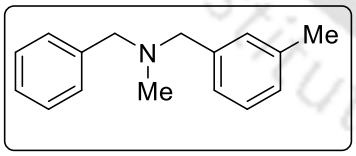
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (133 mg, 67%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.50 - 8.48 (m, 1H), 7.48 (app. t, *J* = 7.7 Hz, 1H), 7.15 - 7.03 (m, 4H), 6.64 - 6.61 (m, 3H), 4.56 (s, 2H), 3.01 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.5, 149.6, 149.3, 136.8, 129.3, 122.0, 120.8, 116.8, 112.3, 58.9, 39.1.

_N_-benzyl-_N_-methyl-1-phenylmethanamine (2.13d):[46]



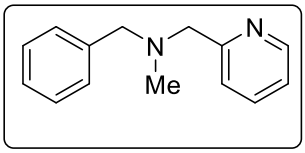
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Colorless oil (139 mg, 66%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.29 - 7.27 (m, 4H), 7.24 (app. t, *J* = 7.5 Hz, 4H), 7.16 (app. t, *J* = 7.1 Hz, 2H), 3.44 (s, 4H), 2.10 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.4, 129.1, 128.3, 127.1, 62.0, 42.4.

_N_-benzyl-_N_-methyl-1-(m-tolyl)methanamine (2.13e):[47]



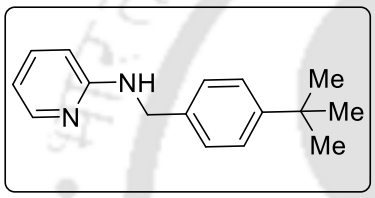
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Colorless oil (153 mg, 68%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.29 - 7.21 (m, 4H), 7.18 - 7.03 (m, 4H), 6.97 (d, *J* = 7.2 Hz, 1H), 3.43 (s, 2H), 3.40 (s, 2H), 2.27 (s, 3H), 2.10 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.5, 139.4, 137.9, 129.8, 129.1, 128.3, 128.2, 127.8, 127.0, 126.1, 62.1, 62.0, 42.4, 21.5.

_N_-benzyl-_N_-methyl-1-(pyridin-2-yl)methanamine (2.13f):[48]



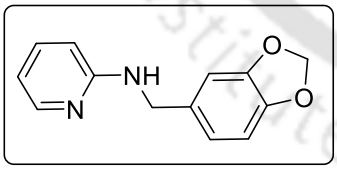
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow oil (129 mg, 61%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.46 - 8.45 (m, 1H), 7.58 (td, *J* = 7.7, 1.8 Hz, 1H), 7.44 (d, *J* = 7.8 Hz, 1H), 7.31 - 7.29 (m, 2H), 7.26 - 7.22 (m, 2H), 7.18 - 7.15 (m, 1H), 7.08 - 7.05 (m, 1H), 3.62 (s, 2H), 3.52 (s, 2H), 2.17 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.8, 149.1, 139.1, 136.5, 129.1, 128.4, 127.1, 123.1, 122.0, 63.5, 62.2, 42.6.

_N_-(4-(tert-butyl)benzyl)pyridin-2-amine (2.15a):



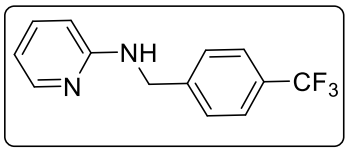
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (205 mg, 80%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 - 8.10 (m, 1H), 7.42 - 7.36 (m, 3H), 7.32 - 7.26 (m, 2H), 6.58 (ddd, *J* = 7.1, 5.1, 0.8 Hz, 1H), 6.38 (d, *J* = 8.4 Hz, 1H), 4.87 (s, 1H), 4.47 (d, *J* = 5.7 Hz, 2H), 1.32 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.8, 150.4, 148.3, 137.6, 136.2, 127.3, 125.7, 113.2, 107.0, 46.2, 34.6, 31.5. HRMS (ESI) calcd. for $C_{16}H_{20}N_2$ (M + H)+ 241.1705; found 241.1705.

_N_-(benzo[d][1,3]dioxol-5-ylmethyl)pyridin-2-amine (2.15b):[49]



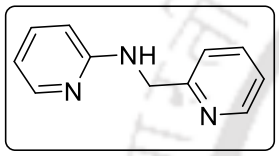
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (178 mg, 78%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 - 8.10 (m, 1H), 7.39 (ddd, *J* = 8.8, 7.2, 1.9 Hz, 1H), 6.85 - 6.75 (m, 3H), 6.61 - 6.56 (m, 1H), 6.36 (d, *J* = 8.4 Hz, 1H), 5.93 (s, 2H), 4.89 (s, 1H), 4.40 (d, *J* = 5.7 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.7, 148.3, 148.0, 146.9, 137.6, 133.2, 120.6, 113.3, 108.4, 108.1, 107.0, 101.1, 46.2.

***N*-(4-(trifluoromethyl)benzyl)pyridin-2-amine (2.15c):**[50]



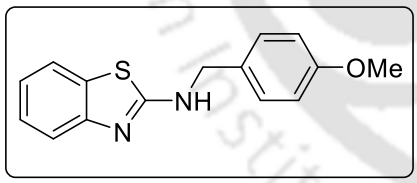
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Pale yellow solid (189 mg, 75%), (^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 - 8.09 (m, 1H), 7.58 (d, *J* = 8.1 Hz, 2H), 7.47 (d, *J* = 8.0 Hz, 2H), 7.41 (t, *J* = 7.2 Hz, 1H), 6.61 (t, *J* = 7.1 Hz, 1H), 6.36 (d, *J* = 8.4 Hz, 1H), 4.99 (s, 1H), 4.59 (d, *J* = 6.0 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.4, 148.4, 143.7, 137.7, 129.6 (d, *J* = 32.5 Hz), 127.6, 127.6, 125.7 (q, *J* = 3.9 Hz), 113.7, 107.1, 45.8.

***N*-(pyridin-2-ylmethyl)pyridin-2-amine (2.15d):**[11p]



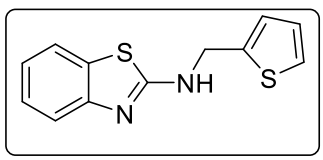
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Brown oil (137 mg, 74%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.47 - 8.46 (m, 1H), 8.09 - 7.97 (m, 1H), 7.61 - 7.48 (m, 1H), 7.35 - 7.17 (m, 2H), 7.14 - 7.01 (m, 1H), 6.52 - 6.45 (m, 1H), 6.37 (d, *J* = 8.4 Hz, 1H), 5.69 (s, 1H), 4.57 (d, *J* = 5.3 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.5, 158.3, 149.1, 148.1, 137.4, 136.7, 122.2, 121.7, 113.2, 107.8, 47.2.

***N*-(4-methoxybenzyl)benzo[d]thiazol-2-amine (2.15e):**[51]



This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (232 mg, 86%), (^{1}H NMR (400 MHz, DMSO-d_6) δ 8.40 (app. t, *J* = 5.6 Hz, 1H), 7.64 (d, *J* = 7.8 Hz, 1H), 7.38 (d, *J* = 8.0 Hz, 1H), 7.29 (d, *J* = 8.7 Hz, 2H), 7.21 (app. t, *J* = 7.8 Hz, 1H), 7.01 (app. t, *J* = 7.8 Hz, 1H), 6.89 (d, *J* = 6.7 Hz, 2H), 4.49 (d, *J* = 5.6 Hz, 2H), 3.71 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 166.3, 158.4, 152.3, 130.7, 130.2, 128.8, 125.6, 121.0, 120.9, 118.0, 113.8, 55.1, 46.7.

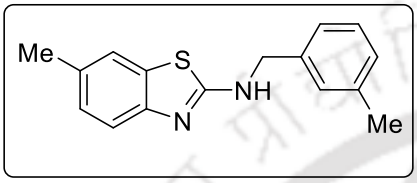
***N*-(thiophen-2-ylmethyl)benzo[d]thiazol-2-amine (2.15f):**[51]



This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid

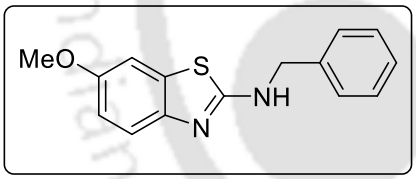
(197 mg, 80%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (d, *J* = 7.8 Hz, 1H), 7.38 (d, *J* = 7.7 Hz, 1H), 7.20 - 7.14 (m, 2H), 7.00 (app. t, *J* = 7.9 Hz, 1H), 6.91 - 6.84 (m, 2H), 4.71 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.8, 151.7, 144.4, 131.2, 126.8, 126.0, 125.4, 125.3, 122.2, 120.9, 118.9, 59.6.

6-methyl-*N*-(3-methylbenzyl)benzo[d]thiazol-2-amine (2.15g):



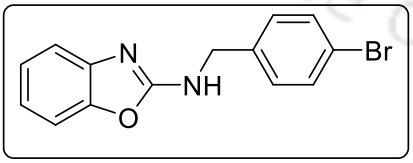
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (225 mg, 84%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 (d, *J* = 8.2 Hz, 1H), 7.39 (s, 1H), 7.24 (d, *J* = 7.4 Hz, 1H), 7.20-7.17 (m, 2H), 7.13 - 7.09 (m, 2H), 5.50 (s, 1H), 4.59 (s, 2H), 2.39 (s, 3H), 2.35 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.7, 150.4, 138.7, 137.6, 131.6, 130.8, 128.9, 128.8, 128.6, 127.3, 124.9, 121.0, 118.8, 49.5, 21.5, 21.4. HRMS (ESI) calcd. for $C_{16}H_{16}N_2S$ (M + H)+ 269.1112; found 269.1111.

***N*-benzyl-6-methoxybenzo[d]thiazol-2-amine (2.15h):**[51]



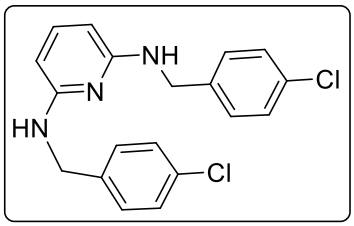
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (216 mg 82%), (^{1}H NMR (400 MHz, $CDCl_3$) δ 7.22 (d, *J* = 6.8 Hz, 5H), 6.80-6.78 (m, 1H), 6.59 - 6.55 (m, 2H), 5.06 (s, 2H), 3.66 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.4, 155.3, 136.1, 134.7, 128.8, 127.5, 126.9, 123.6, 112.2, 110.3, 107.9, 56.0, 46.3.

***N*-(4-bromobenzyl)benzo[d]oxazol-2-amine (2.15i):**



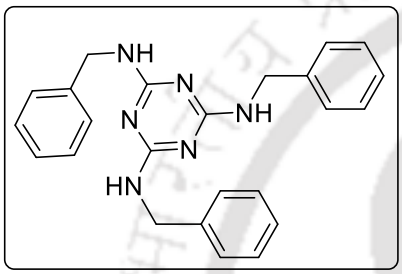
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. White solid (230 mg 76%),^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 - 7.38 (m, 2H), 7.26 - 7.12 (m, 3H), 7.05 - 7.00 (m, 2H), 6.74 (dd, *J* = 5.8, 3.2 Hz, 1H), 4.88 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.8, 142.8, 133.8, 132.3, 130.7, 129.5, 124.0, 122.9, 122.5, 110.3, 108.9, 45.6. HRMS (ESI) calcd. for $C_{14}H_{11}N_2BrO$(M + H)+ 303.0133; found 303.0133.

N^2,N^6-bis(4-chlorobenzyl)pyridine-2,6-diamine (2.15j):[52]



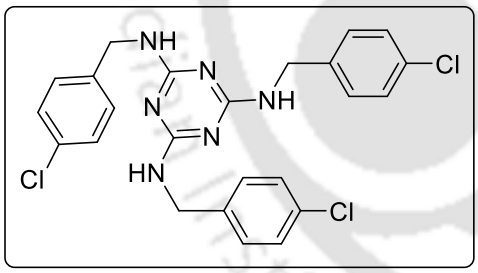
This compound was prepared according to the general procedure **B**. Reaction was completed after 36 h. Colourless solid (268 mg 75%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.21 - 7.16 (m, 8H), 7.12 (s, 1H), 5.64 (d, *J* = 7.9 Hz, 2H), 4.56 (s, 2H), 4.34 (d, *J* = 5.9 Hz, 4H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.9, 139.3, 138.5, 132.8, 128.8, 128.7, 95.6, 45.7.

N^2,N^4,N^6-tribenzyl-1,3,5-triazine-2,4,6-triamine (2.15k):[29]



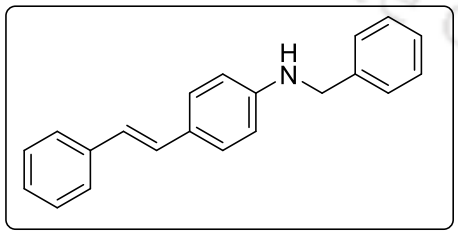
This compound was prepared according to the general procedure **B**. Reaction was completed after 52 h. White solid (157 mg 79%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17-7.15 (m, 15H), 5.38 (s, 3H), 4.44 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.4, 139.6, 128.6, 127.6, 127.2, 44.7.

N^2,N^4,N^6-tris(4-chlorobenzyl)-1,3,5-triazine-2,4,6-triamine (2.15l):[29]



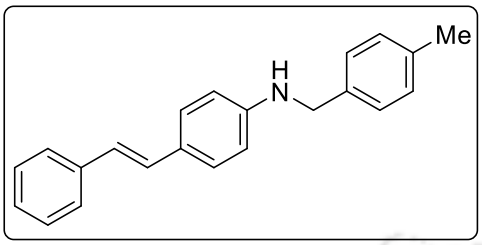
This compound was prepared according to the general procedure **B**. Reaction was completed after 52 h. White solid (237 mg 95%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.79-6.71 (m, 12H), 5.10 (s, 3H), 4.03 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.2, 137.9, 132.8, 128.7, 128.6, 43.9.

(E)-*N*-benzyl-4-styrylaniline (2.17a):[23a]



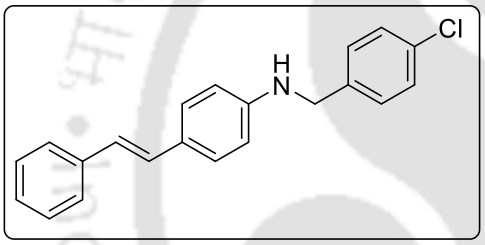
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow solid (219 mg, 77%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 -7.37 (m, 2H), 7.31 - 7.18 (m, 9H), 7.14 - 7.10 (m, 1H), 6.97 - 6.80 (m, 2H), 6.57 - 6.53 (m, 2H), 4.29 (s, 2H), 4.09 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.0, 139.3, 138.2, 128.9, 128.8, 128.7, 127.9, 127.6, 127.5, 127.2, 126.9, 126.2, 124.8, 113.1, 48.3.

(E)-*N*-(4-methylbenzyl)-4-styrylaniline (2.17b):



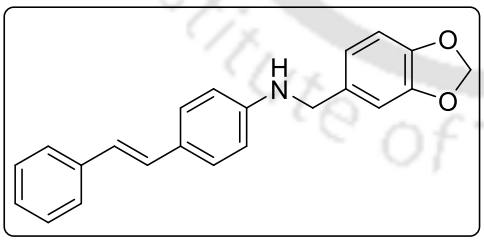
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow solid (227 mg, 76%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 - 7.35 (m, 2H), 7.26 - 7.20 (m, 4H), 7.16 - 7.14 (m, 2H), 7.11 - 7.09 (m, 1H), 7.07 - 7.04 (m, 2H), 6.92 (d, *J* = 16.3 Hz, 1H), 6.79 (d, *J* = 16.3 Hz, 1H), 6.54 - 6.49 (m, 2H), 4.19 (s, 2H), 3.98 (s, 1H), 2.25 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.0, 138.2, 137.1, 136.2, 129.5, 129.0, 128.7, 127.9, 127.6, 127.0, 126.8, 126.2, 124.6, 113.0, 48.1, 21.2. HRMS (ESI) calcd. for $C_{22}H_{21}N$ (M + H)+ 300.1752; found 300.1752.

(E)-*N*-(4-chlorobenzyl)-4-styrylaniline (2.17c):[23a]



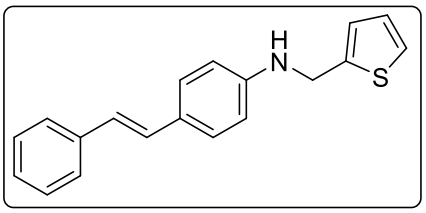
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow solid (236 mg, 74%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 - 7.38 (m, 2H), 7.28 - 7.18 (m, 8H), 7.15 - 7.10 (m, 1H), 6.94 (d, *J* = 16.3 Hz, 1H), 6.82 (d, *J* = 16.3 Hz, 1H), 6.53 - 6.51 (m, 2H), 4.27 (s, 2H), 4.11 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.5, 138.2, 137.8, 133.1, 129.0, 128.8, 128.7, 127.9, 127.5, 127.0, 126.2, 125.0, 113.2, 47.7.

(E)-*N*-(benzo[d][1,3]dioxol-5-ylmethyl)-4-styrylaniline (2.17d): [23a]



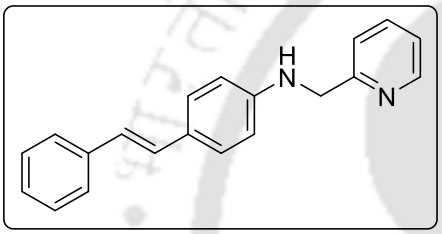
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow solid (237 mg, 72%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 - 7.37 (m, 2H), 7.28 - 7.22 (m, 4H), 7.16 - 7.11 (m, 1H), 6.94 (d, *J* = 16.3 Hz, 1H), 6.81 (d, *J* = 16.3 Hz, 1H), 6.80 - 6.68 (m, 3H), 6.53 - 6.51 (m, 2H), 5.86 (s, 2H), 4.17 (s, 2H), 4.00 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.1, 147.8, 146.9, 138.2, 133.2, 128.9, 128.7, 127.9, 127.2, 126.9, 126.2, 124.8, 120.7, 113.1, 108.5, 108.1, 101.1, 48.1.

(E)-4-styryl-*N*-(thiophen-2-ylmethyl)aniline (2.17e): [23a]



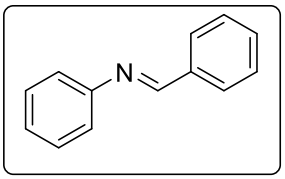
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow solid (203 mg, 70%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 - 7.37 (m, 2H), 7.29 - 7.22 (m, 4H), 7.15 - 7.10 (m, 2H), 6.96 - 6.80 (m, 4H), 6.59 - 6.50 (m, 2H), 4.44 (s, 2H), 4.07 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.4, 142.8, 138.1, 128.8, 128.7, 127.9, 127.6, 127.0, 126.9, 126.2, 125.3, 125.0, 124.8, 113.4, 43.5.

(E)-*N*-(pyridin-2-ylmethyl)-4-styrylaniline (2.17f):



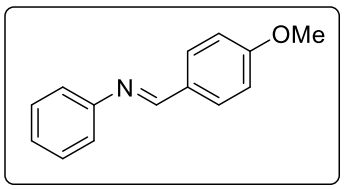
This compound was prepared according to the general procedure **B**. Reaction was completed after 24 h. Yellow solid (191 mg, 67%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.59 (d, *J* = 4.4 Hz, 1H), 7.66 (td, *J* = 7.7, 1.7 Hz, 1H), 7.47 (d, *J* = 7.5 Hz, 2H), 7.48 – 7.31 (m, 5H), 7.20 (t, *J* = 6.7 Hz, 2H), 7.03 (d, *J* = 16.3 Hz, 1H), 6.90 (d, *J* = 16.3 Hz, 1H), 6.67 (d, *J* = 8.6 Hz, 2H), 4.94 (s, 1H), 4.50 (s, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 158.3, 149.4, 147.7, 138.2, 136.8, 128.9, 128.7, 127.9, 127.1, 126.9, 126.2, 124.7, 122.3, 121.7, 113.2, 49.2. HRMS (ESI) calcd. for $C_{20}H_{18}N_2$ (M + H)+ 287.1548; found 287.1545.

(E)-*N*,1-diphenylmethanimine (2.7a):[53]



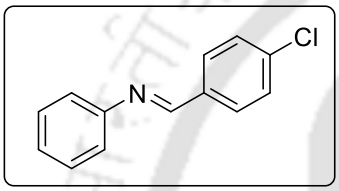
This compound was prepared according to the general procedure **C**. Reaction was completed after 24 h. White solid (74%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.38 (s, 1H), 7.83 (app. t, *J* = 7.1 Hz, 2H), 7.40 - 7.38 (m, 3H), 7.32 (app. t, *J* = 7.5 Hz, 2H), 7.17 - 7.13 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.6, 152.2, 136.3, 131.5, 129.3, 128.9, 128.9, 126.1, 121.0.

(E)-1-(4-methoxyphenyl)-*N*-phenylmethanimine (2.7b):[53]



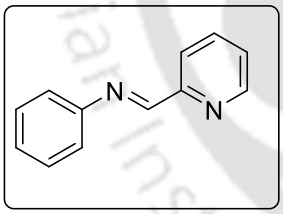
This compound was prepared according to the general procedure **C**. Reaction was completed after 24 h. White solid (81%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.41 (s, 1H), 7.90 - 7.88 (m, 2H), 7.44 - 7.25 (m, 2H), 7.25-7.23 (m, 3H), 7.01 (d, *J* = 8.8 Hz, 2H), 3.88 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.3, 159.8, 152.4, 130.6, 129.2, 125.6, 121.0, 114.2, 55.4.

(E)-1-(4-chlorophenyl)-*N*-phenylmethanimine (2.7d):[53]



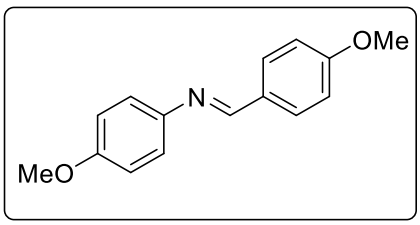
This compound was prepared according to the general procedure **C**. Reaction was completed after 24 h. White solid (84%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.34 (s, 1H), 7.81 - 7.73 (m, 2H), 7.39 - 7.35 (m, 1H), 7.34 - 7.29 (m, 2H), 7.19 - 7.16 (m, 1H), 7.15 - 7.11 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.0, 151.8, 137.5, 134.8, 130.1, 129.3, 129.2, 126.3, 121.0.

(E)-*N*-phenyl-1-(pyridin-2-yl)methanimine (2.7f):[54]



This compound was prepared according to the general procedure **C**. Reaction was completed after 24 h. Light Yellow oil (75%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.64 (d, *J* = 4.4 Hz, 1H), 8.53 (s, 1H), 8.13 (d, *J* = 7.9 Hz, 1H), 7.74 (t, *J* = 7.7 Hz, 1H), 7.36 - 7.28 (m, 3H), 7.22 - 7.18 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.8, 154.7, 151.1, 149.8, 136.8, 129.4, 126.8, 125.3, 122.0, 121.2.

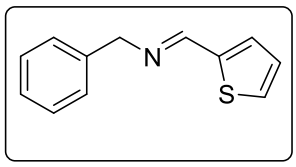
(*E*)-*N*,1-bis(4-methoxyphenyl)methanimine (2.7h):[55]



This compound was prepared according to the general procedure **C**. Reaction was completed after 24 h. White solid (83%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.32 (s, 1H), 7.75 (d, *J* = 8.7 Hz, 2H), 7.13 (d, *J* = 8.8 Hz, 2H), 6.89 (d, *J* = 8.7 Hz, 2H), 6.84 (d, *J* = 8.8

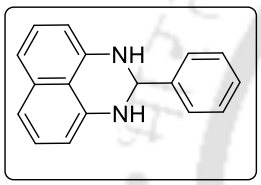
Hz, 2H), 3.79 (s, 3H), 3.75 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.1, 158.1, 158.0, 145.3, 130.4, 129.5, 122.2, 114.4, 114.3, 55.6, 55.5.

(*E*)-*N*-benzyl-1-(thiophen-2-yl)methanimine (2.7j):[56]



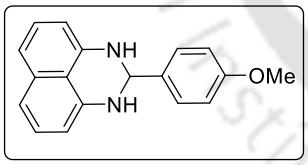
This compound was prepared according to the general procedure **C**. Reaction was completed after 24 h. Pale yellow oil (70%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.47 (s, 1H), 7.42 - 7.35 (m, 6H), 7.32 - 7.30 (m, 1H), 7.11 - 7.09 (m, 1H), 4.83 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.2, 142.4, 139.1, 139.0, 130.7, 130.7, 129.0, 128.5, 128.0, 127.4, 127.0, 64.4.

2-phenyl-2,3-dihydro-1*H*-perimidine (2.19a):[57]



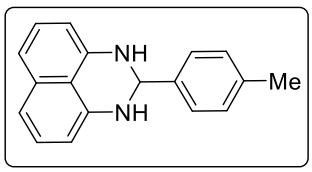
This compound was prepared according to the general procedure **D**. Reaction was completed after 24 h. White Solid (190 mg, 77%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.57 - 7.54 (m, 2H), 7.37 - 7.35 (m, 3H), 7.20 - 7.13 (m, 4H), 6.44 (dd, *J* = 6.9, 1.4 Hz, 2H), 5.39 (s, 1H), 4.44 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.2, 140.3, 135.1, 129.7, 129.0, 128.0, 127.0, 118.0, 113.6, 106.0 68.5.

2-(4-methoxyphenyl)-2,3-dihydro-1*H*-perimidine (2.19b):[58]



This compound was prepared according to the general procedure **D**. Reaction was completed after 24 h. White solid (232 mg, 84%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47 - 7.45 (m, 2H), 7.18 - 7.11 (m, 4H), 6.88 - 6.85 (m, 2H), 6.41 (dd, *J* = 6.9, 1.4 Hz, 2H), 5.31 (s, 1H), 4.39 (s, 2H), 3.75 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.7, 142.4, 135.0, 132.4, 129.3, 127.0, 117.9, 114.2, 113.6, 105.8, 68.0, 55.5.

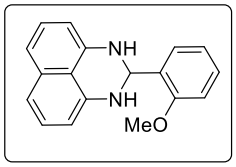
2-(p-tolyl)-2,3-dihydro-1*H*-perimidine (2.19c):[57]



This compound was prepared according to the general procedure **D**. Reaction was completed after 24 h. White solid (213mg, 81%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 (d, *J* = 7.0 Hz, 2H), 7.17 - 7.12 (m, 6H), 6.42 (d, *J* = 6.9 Hz, 2H), 5.34 (s,

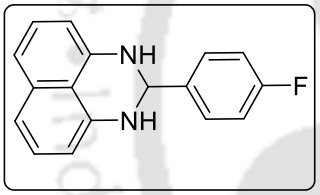
1H), 4.41 (s, 2H), 2.32 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.2, 139.5, 137.2, 134.9, 129.5, 127.8, 126.9, 117.8, 113.5, 105.8, 68.2, 21.3.

2-(2-methoxyphenyl)-2,3-dihydro-1*H*-perimidine (2.19d):[58]



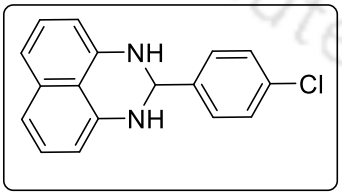
This compound was prepared according to the general procedure **D**. Reaction was completed after 24 h. White solid (199 mg, 72%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56 (dd, *J* = 7.6, 1.4 Hz, 1H), 7.22 (td, *J* = 7.3, 6.5, 1.0 Hz, 1H), 7.16 - 7.08 (m, 4H), 6.89 (t, *J* = 7.5 Hz, 1H), 6.82 (d, *J* = 8.2 Hz, 1H), 6.42 (dd, *J* = 7.1, 0.9 Hz, 2H), 5.80 (s, 1H), 4.55 (s, 2H), 3.75 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.1, 142.2, 135.0, 129.8, 128.7, 127.5, 126.9, 121.2, 117.7, 113.6, 110.7, 106.0, 61.5, 55.6.

2-(4-fluorophenyl)-2,3-dihydro-1*H*-perimidine (2.19e):[59]



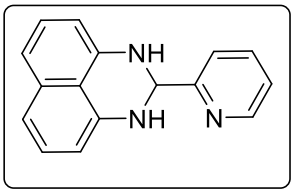
This compound was prepared according to the general procedure **D**. Reaction was completed after 24 h. White Solid (172 mg, 65%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 (dd, *J* = 8.6, 5.5 Hz, 2H), 7.20 - 7.13 (m, 4H), 7.04 (t, *J* = 8.6 Hz, 2H), 6.44 (dd, *J* = 6.7, 1.6 Hz, 2H), 5.36 (s, 1H), 4.39 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.6 (d, *J* = 248.3 Hz), 142.1, 136.1 (d, *J* = 3.1 Hz), 135.0, 129.9 (d, *J* = 8.3 Hz), 127.0, 118.2, 115.9 (d, *J* = 21.5 Hz), 113.5, 106.0, 67.8.

2-(4-chlorophenyl)-2,3-dihydro-1*H*-perimidine (2.19f):[59]



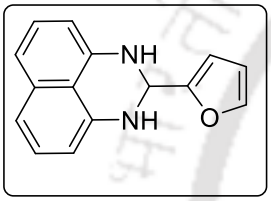
This compound was prepared according to the general procedure **D**. Reaction was completed after 24 h. White Solid (199 mg, 71%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 (d, *J* = 8.4 Hz, 2H), 7.33 - 7.30 (m, 2H), 7.19 - 7.13 (m, 4H), 6.43 (dd, *J* = 6.7, 1.7 Hz, 2H), 5.33 (s, 1H), 4.37 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 141.9, 138.8, 135.5, 135.0, 129.4, 129.2, 127.0, 118.2, 113.5, 106.1, 67.8.

2-(pyridin-2-yl)-2,3-dihydro-1*H*-perimidine (2.19g):[60]



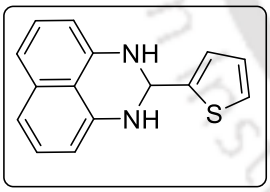
This compound was prepared according to the general procedure **D**. Reaction was completed after 24 h. Pale yellow Solid (183 mg, 74%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.5-8.51 (m, 1H), 7.62 (d, *J* = 7.7 Hz, 1H), 7.52 (d, *J* = 7.2 Hz, 1H), 7.19 - 7.12 (m, 5H), 6.51 (app. t, *J* = 7.0 Hz, 2H), 5.50 (s, 1H), 4.82 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.4, 149.4, 141.1, 137.4, 134.9, 127.0, 123.7, 120.9, 118.2, 114.2, 106.8, 67.8.

2-(furan-2-yl)-2,3-dihydro-1*H*-perimidine (2.19h):[61]



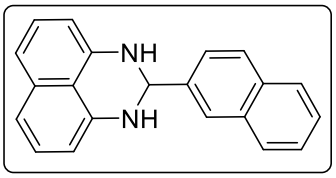
This compound was prepared according to the general procedure **D**. Reaction was completed after 24 h. White Solid (158 mg, 67%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30-7.29 (m, 1H), 7.219 - 7.13 (m, 5H), 6.95-6.93 (m, 1H), 6.44 (dd, *J* = 6.6, 1.7 Hz, 2H), 5.70 (s, 1H), 4.56 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.2, 141.4, 134.9, 127.0, 126.9, 126.5, 126.3, 118.2, 113.8, 106.2, 63.8.

2-(thiophen-2-yl)-2,3-dihydro-1*H*-perimidine (2.19i):[62]



This compound was prepared according to the general procedure **D**. Reaction was completed after 24 h. White olid (177 mg, 70%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.24 - 7.23 (m, 1H), 7.12 - 7.07 (m, 4H), 6.40 - 6.34 (m, 2H), 6.18 - 6.16 (m, 2H), 5.39 (s, 1H), 4.53 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.5, 142.5, 140.7, 134.7, 126.9, 118.2, 113.8, 110.5, 107.6, 106.6, 61.4.

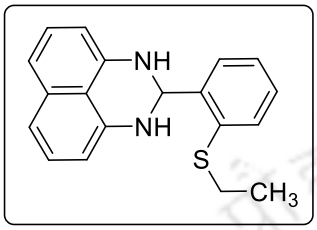
2-(naphthalen-2-yl)-2,3-dihydro-1*H*-perimidine (2.19j):[63]



This compound was prepared according to the general procedure **D**. Reaction was completed after 24 h. White Solid (246 mg, 83%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (s, 1H), 7.83 - 7.75 (m, 3H), 7.67 (app. t, *J* = 8.5 Hz, 1H), 7.46 - 7.40 (m, 2H), 7.19 - 7.12 (m, 4H), 6.42 (app. t, *J* = 6.7 Hz, 2H), 5.49 (s, 1H), 4.46 (s,

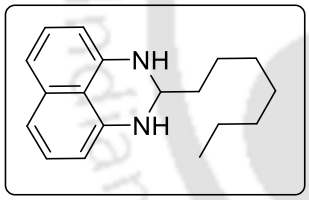
2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.2, 137.6, 135.0, 134.2, 133.2, 128.9, 128.3, 128.0, 127.5, 127.0, 126.8, 126.6, 125.3, 118.0, 113.6, 106.0, 68.6.

2-(2-(ethylthio)phenyl)-2,3-dihydro-1*H*-perimidine (2.19k):



This compound was prepared according to the general procedure **D**. Reaction was completed after 24 h. Pale yellow Solid (217 mg, 71%), ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74 (dd, *J* = 7.7, 1.6 Hz, 1H), 7.32 - 7.30 (m, 1H), 7.26 (td, *J* = 7.5, 1.6 Hz, 1H), 7.21 - 7.12 (m, 5H), 6.47 (dd, *J* = 6.9, 1.3 Hz, 2H), 5.96 (s, 1H), 4.50 (s, 2H), 2.89 (q, *J* = 7.3 Hz, 2H), 1.25 (t, *J* = 7.3 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.2, 139.5, 135.8, 135.0, 129.5, 129.0, 128.1, 127.0, 126.8, 118.0, 113.6, 106.2, 64.3, 28.2, 14.3. HRMS (ESI) calcd. for $C_{19}H_{18}N_2S$ (M + H)+ 307.1269; found 307.1266.

2-heptyl-2,3-dihydro-1H-perimidine (2.19l):[63]



This compound was prepared according to the general procedure **D**. Reaction was completed after 72 h. White Solid (80 mg, 30%) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17 - 7.08 (m, 4H), 6.43 (dd, *J* = 7.2, 1.0 Hz, 2H), 4.40 (t, *J* = 5.7 Hz, 1H), 4.26 (s, 2H), 1.69 - 1.64 (m, 2H), 1.46 - 1.39 (m, 2H), 1.32 - 1.19 (m, 8H), 0.83 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.1, 135.1, 126.9, 117.7, 114.2, 106.0, 65.0, 36.1, 31.9, 29.7, 29.3, 24.6, 22.8, 14.2.

Theoretical Calculations:

Effect of various DFT methods and basis sets on the energy profile of the reaction:

Molecules	A	B	C	D	E	F	G	H
II + $PhCH_2OH$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
III + $PhCH_2OH$	6.51	6.22	6.80	5.95	7.71	11.65	8.06	5.05
TS(III-IV) +	18.83	18.49	17.50	18.86	24.43	19.07	13.10	18.93

$PhCH_2OH$								
IV + $PhCH_2OH$	-2.62	-2.23	-2.26	-3.22	-4.84	-0.34	-0.99	-2.50
V + PhCHO	-5.90	-4.52	-4.44	-4.40	-4.60	-5.09	-4.94	-4.80
TS(V-VI) + PhCHO	13.96	14.26	14.38	14.26	14.09	11.57	12.78	14.90
VI + PhCHO	-2.80	-3.22	-.317	-3.65	-4.78	-2.94	-3.09	-3.53
TS(VI-III) + PhCHO	2.00	1.23	1.18	1.00	1.22	3.07	1.13	1.11
III + $PhCH_2OH$	-23.47	-24.01	-23.19	-22.53	-25.53	-25.34	-17.97	-24.11

A = B3PW91/6-31G(d,p){C,N,H,O,S}-SDD{Mn}

B=B3PW91/6-311++G(d,p){C,N,H,O,S}-SDD{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-SDD{Mn}

C=B3PW91/6-311++G(d,p){C,N,H,O,S}-LANL2DZ{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-

SDD{Mn}

D=B3LYP/6-311++G(d,p){C,N,H,O,S}-SDD{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-SDD{Mn}

E=B2PLYP/6-311++G(d,p){C,N,H,O,S}-SDD{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-SDD{Mn}

F=wB97/6-311++G(d,p){C,N,H,O,S}-SDD{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-SDD{Mn}

G=TPSSTPSS/6-311++G(d,p){C,N,H,O,S}-SDD{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-

SDD{Mn}

H=B3PW91/cc-PVTZ{C,N,H,O,S}-SDD{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-SDD{Mn}

All values are in kcal/mol. Effect of the toluene solvent was included in all the calculations using IEFPCM method. Energy values obtained from method B are presented in **Scheme 2.12**.

Effect of dispersion correction on the energy profile of the reaction:

Molecules	A	GD3	GD3BJ	GD2	PFD
II + $PhCH_2OH$	0.00	0.00	0.00	0.00	0.00
III + $PhCH_2OH$	6.22	6.80	5.00	7.89	14.72
TS(III-IV) + $PhCH_2OH$	18.49	15.07	16.38	10.29	12.89
IV + $PhCH_2OH$	-2.23	5.19	5.82	4.91	5.81
V + PhCHO	-4.52	-6.88	-6.30	-6.58	-7.74
TS(V-VI) + PhCHO	14.26	9.98	9.64	10.50	11.02
VI + PhCHO	-3.22	-1.90	-1.75	-1.16	-0.91
TS(VI-III) + PhCHO	1.23	3.97	3.87	3.10	3.50
III + $PhCH_2OH$	-24.01	-25.42	-27.67	-21.07	-24.58

A=B3PW91/6-311++G(d,p){C,N,H,O,S}-SDD{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-SDD{Mn}

GD3[64a]=B3PW91/6-311++G(d,p){C,N,H,O,S}-SDD{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-

SDD{Mn} with EmpiricalDispersion=GD3

GD3BJ[64b]=B3PW91/6-311++G(d,p){C,N,H,O,S}-SDD{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-

SDD{Mn} with EmpiricalDispersion=GD3BJ

GD2[64c]=PBEPBE/6-311++G(d,p){C,N,H,O,S}-SDD{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-

SDD{Mn} with EmpiricalDispersion=GD2

PFD[64d]=B3LYP/6-311++G(d,p){C,N,H,O,S}-SDD{Mn}//B3PW91/6-31G(d,p){C,N,H,O,S}-

SDD{Mn} with Empirical Dispersion=PFD

All values are in kcal/mol. Effect of the toluene solvent was included in all the calculations using IEFPCM method.

Effect of zero point, enthalpy and Gibbs free energy corrections on the relative energies:

Molecules	**TE**	**ZPE**	**Enthalpy**		**Gibbs**	
			T = 298.15#	**T = 413.15$**	**T = 298.15#**	**= 413.15$**
II + $PhCH_2OH$	0.00	0.00	0.00	0.00	0.00	0.00
III + $PhCH_2OH$	6.51	5.74	6.25	6.34	3.36	2.22
TS(III-IV) + $PhCH_2OH$	25.34	22.23	22.00	21.94	22.82	23.15
IV + $PhCH_2OH$	22.72	19.95	20.49	2065	17.88	16.85
V + PhCHO	16.82	14.47	13.98	13.75	14.94	15.35
TS(V-VI) + PhCHO	30.78	24.03	23.73	23.74	24.54	24.86
VI + PhCHO	27.98	22.83	23.05	23.30	22.17	21.79

TE = Energetics obtained from total energies; ZPE = energetics obtained from 'sum of electronic and zero-point energies'; Enthalpy = energetics obtained from 'sum of electronic and thermal enthalpies'; Gibbs = energetics obtained from 'sum of electronic and thermal free energies'. Enthalpy and Gibbs values were obtained by performing

frequency calculations at two different temperatures. Temperature (T) is given in Kelvin. # Default temperature of Gaussian program. $ Experiments were performed on this temperature. All relative energy values are in kcal/mol.

Changes in the geometry along the path of the reaction:

Molecule	Geometry
II	Octahedral
III	Square Pyramidal
TS(III-IV)	Octahedral
IV	Octahedral
V	Octahedral
TS(V-VI)	Octahedral
VI	Octahedral- η 2-dihydrogen
TS(VI-III)	Octahedral- η 2-dihydrogen
III	Square Pyramidal

2.7. References:

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2.8. Selected spectra of products:

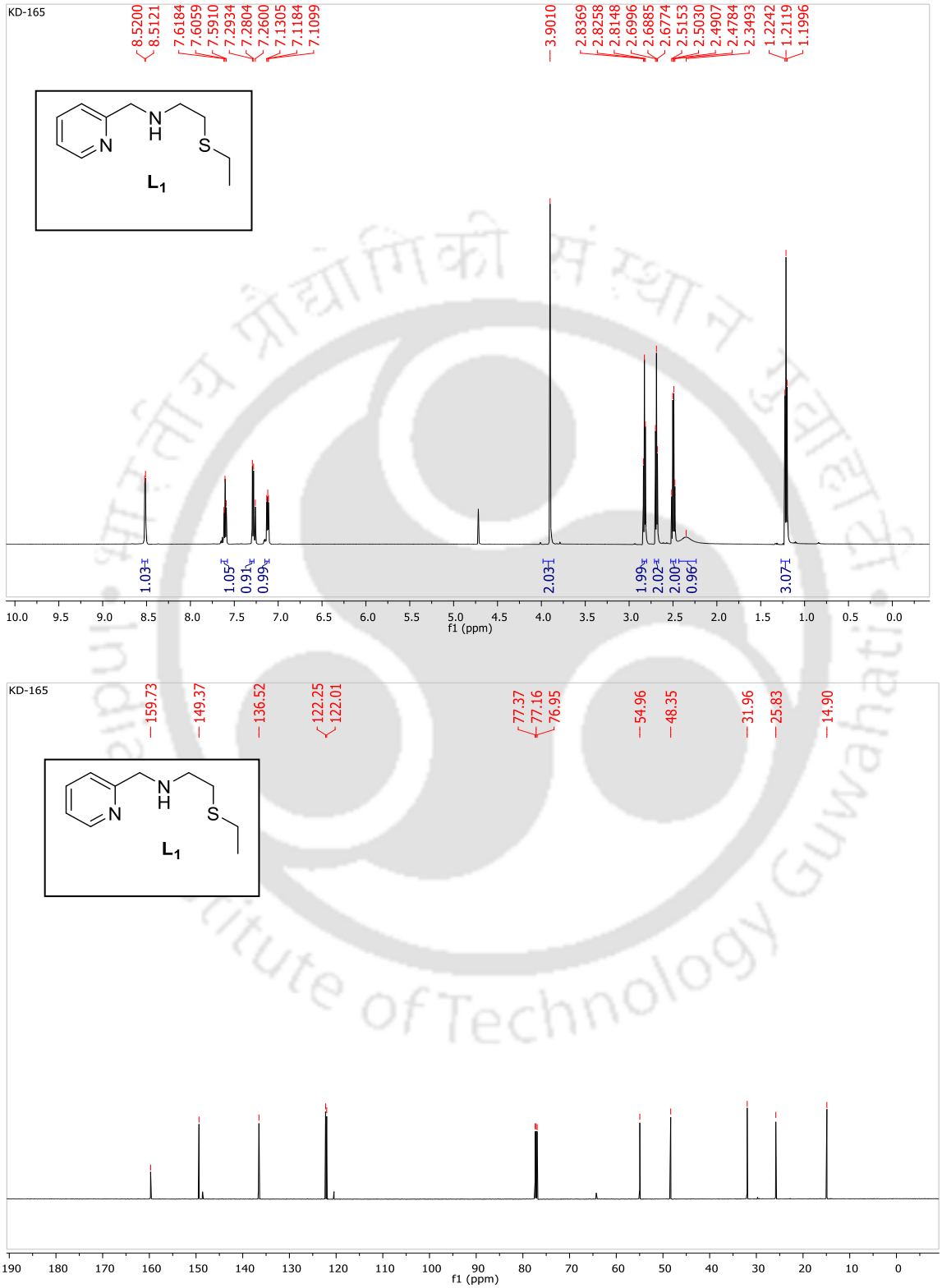


Figure 2.2: ^{1}H and ^{13}C NMR of ligand **L_1**.

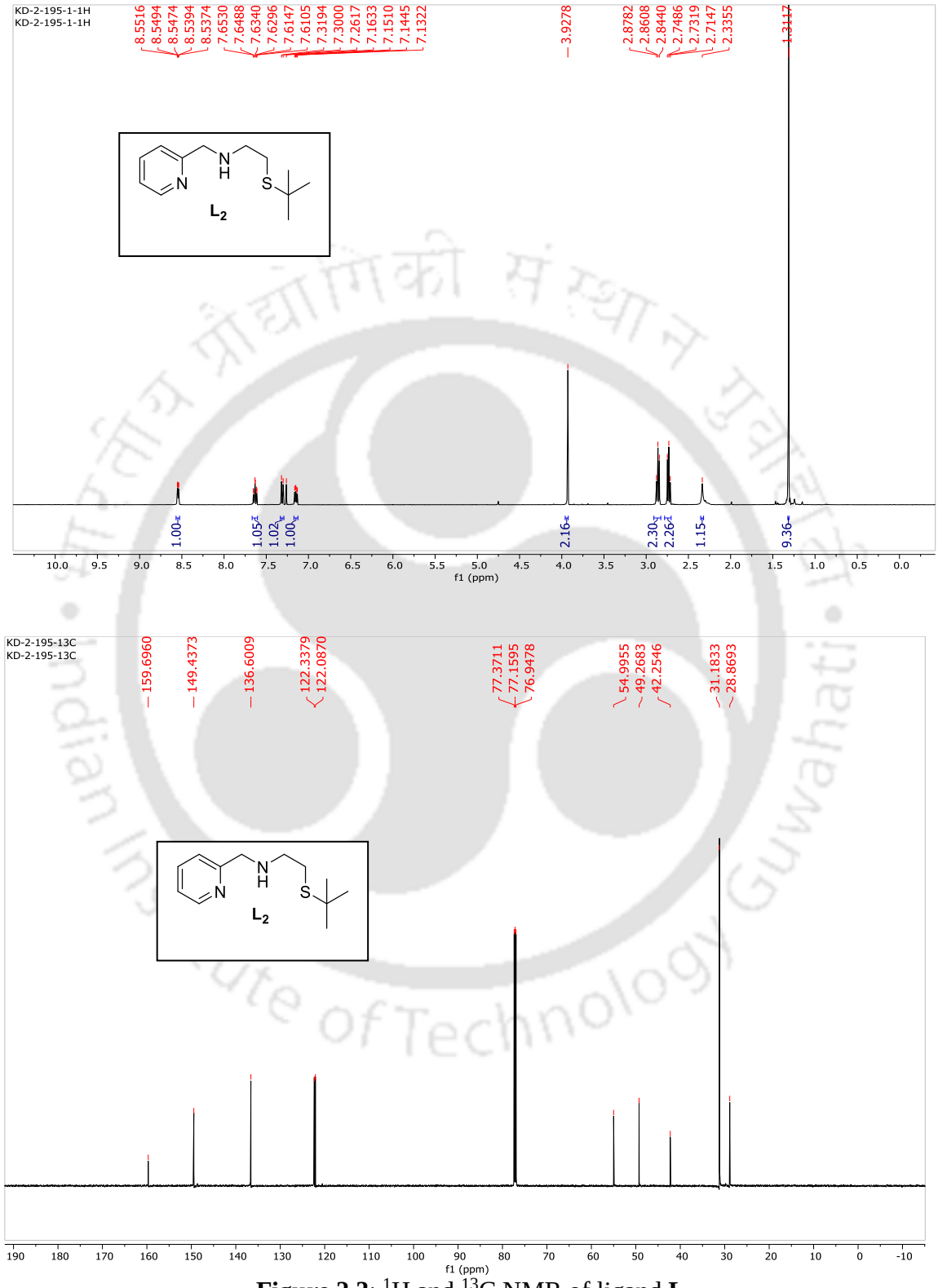


Figure 2.3: ^{1}H and ^{13}C NMR of ligand $\mathbf{L_2}$

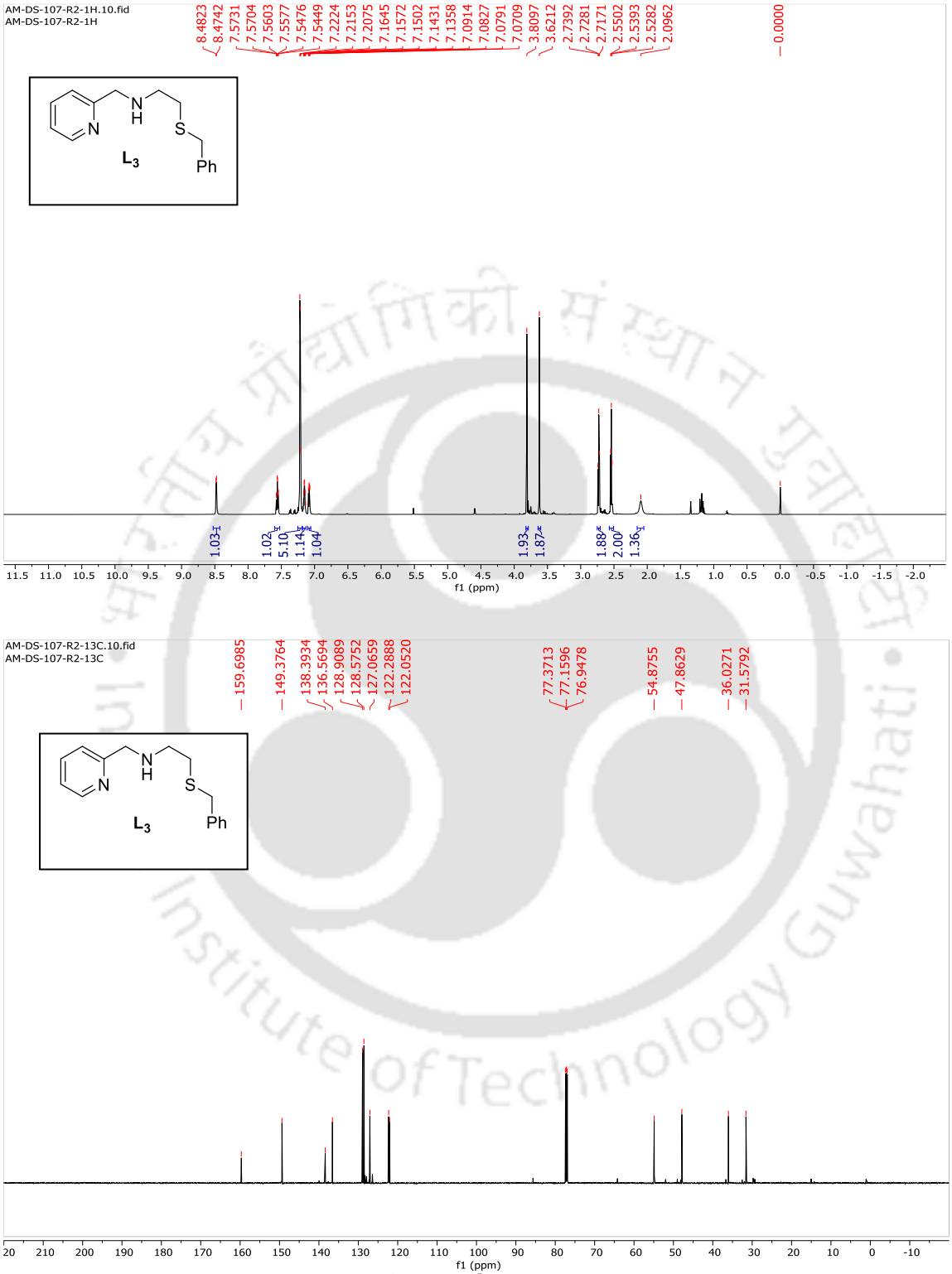


Figure 2.4: ^{1}H and ^{13}C NMR of ligand **L_3**

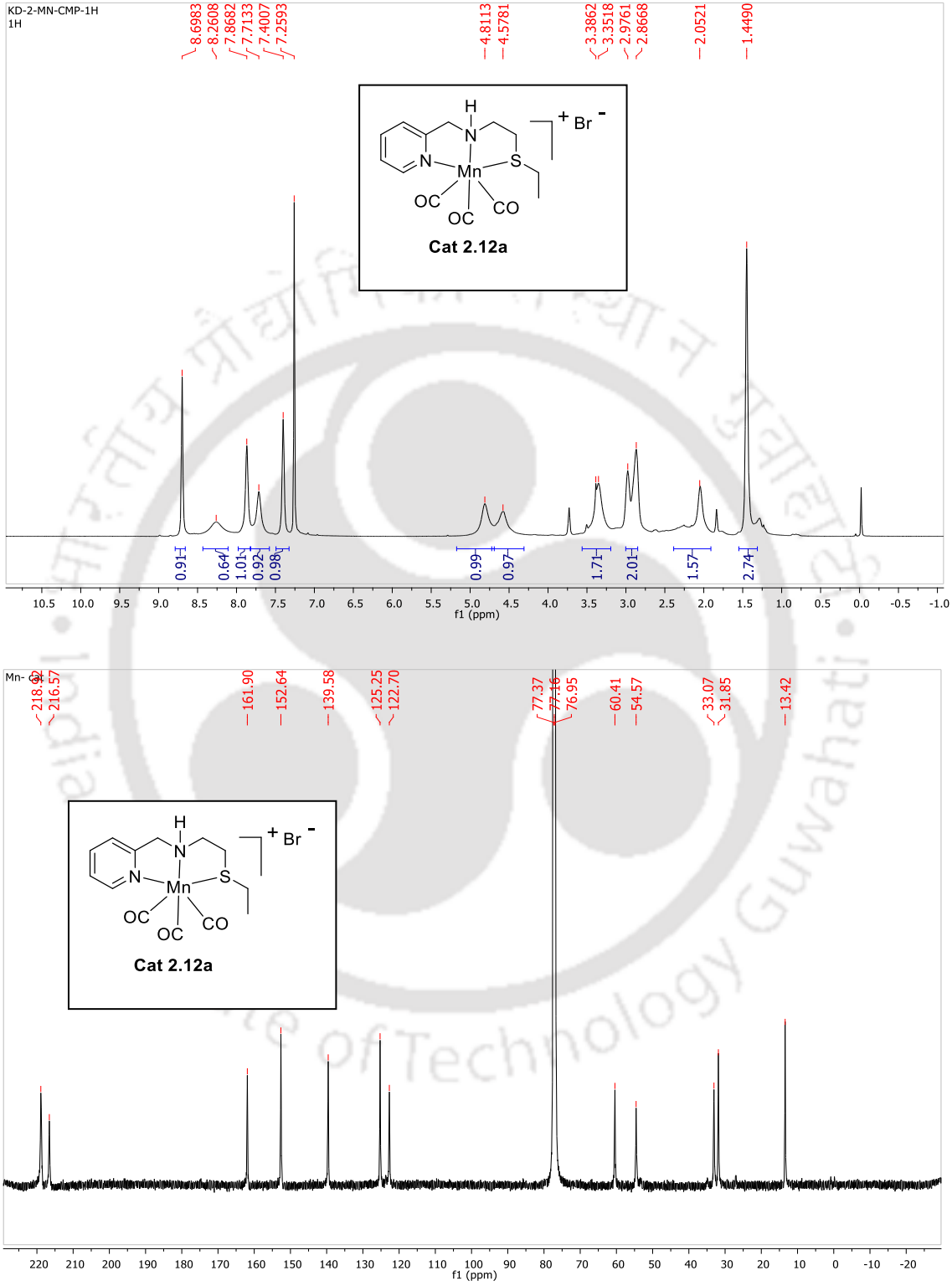


Figure 2.5: ^{1}H and ^{13}C NMR of Cat **2.12a.**

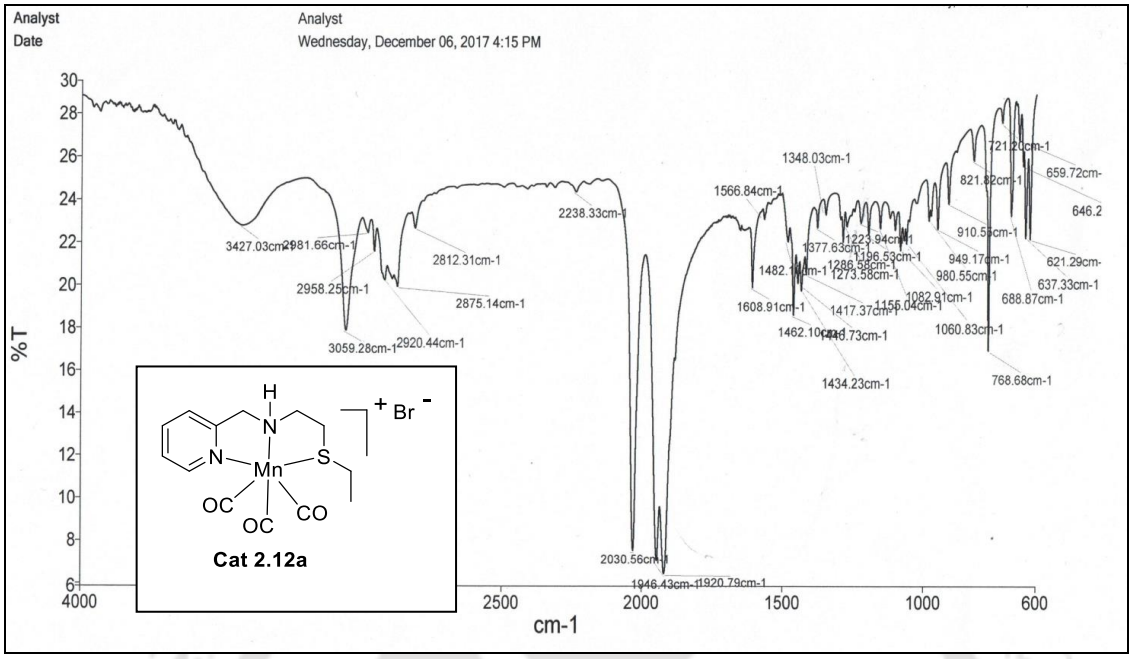


Figure 2.6: IR Spectrum of Cat **2.12a.**

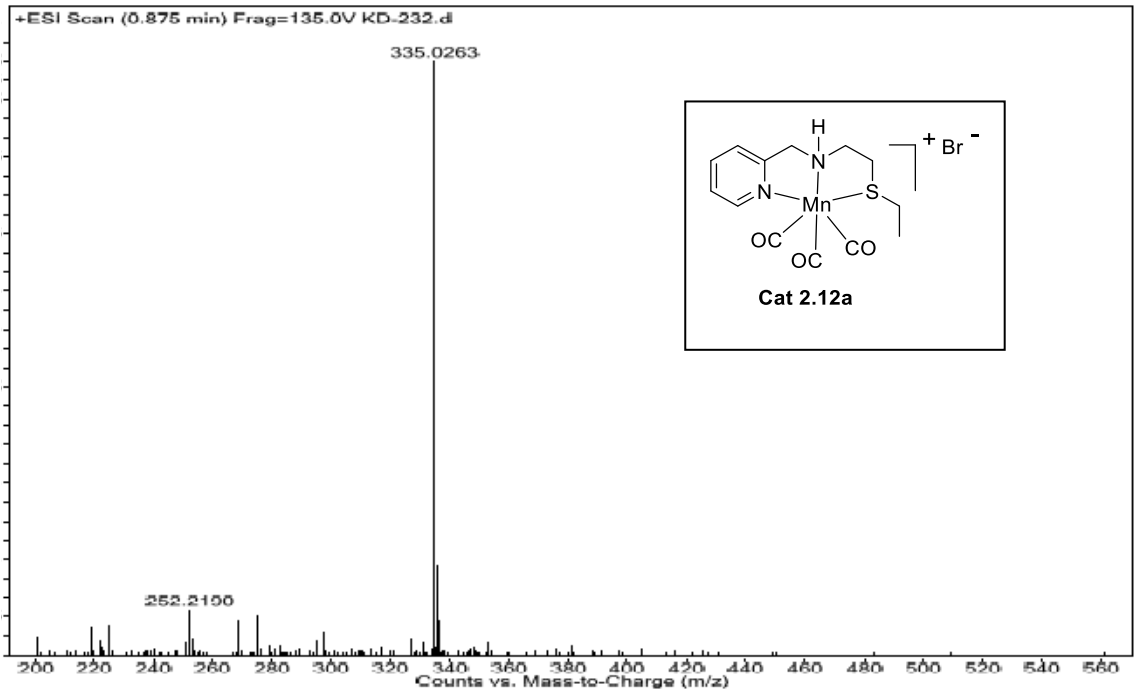


Figure 2.7: Mass Spectrum of Cat **2.12a.**

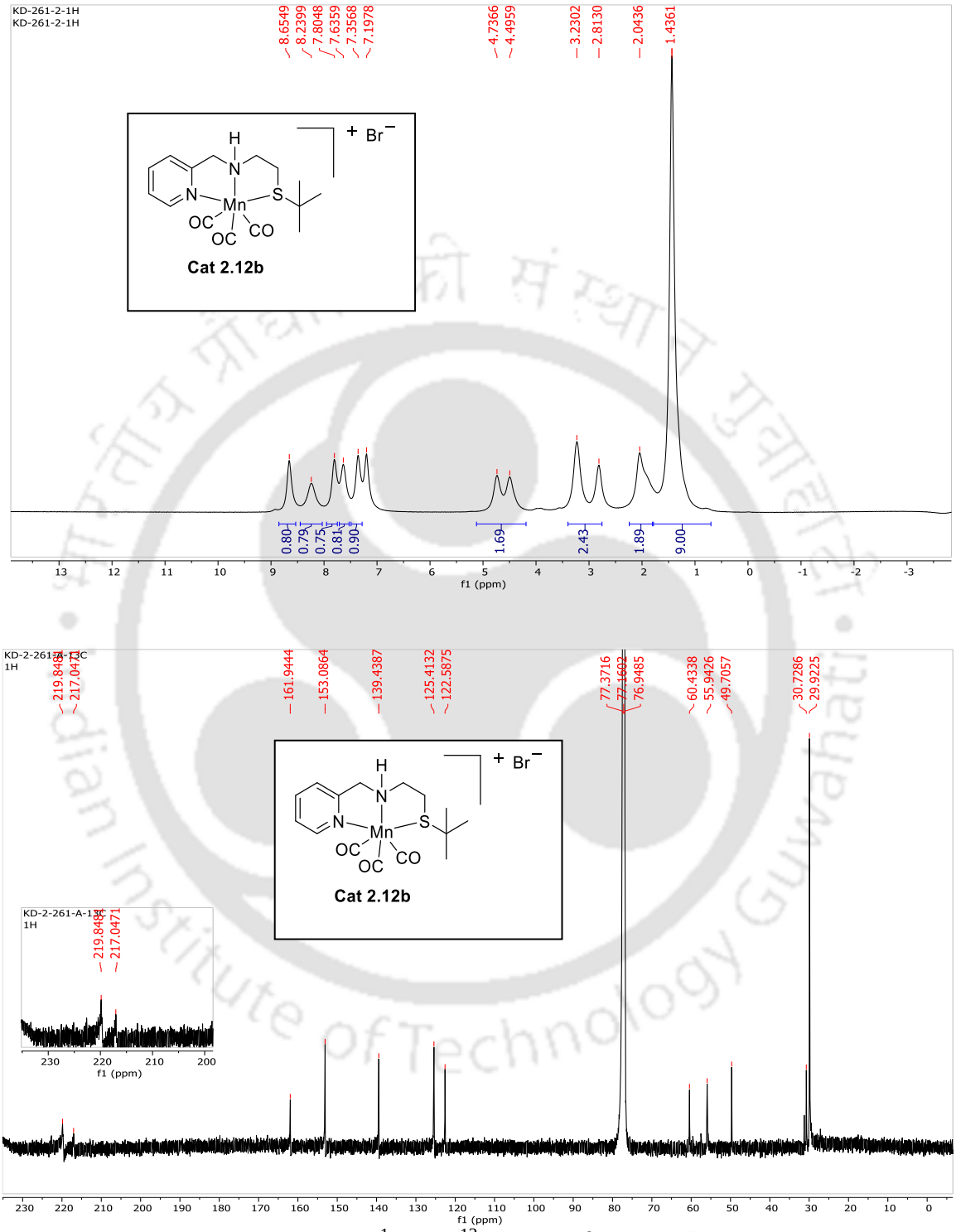


Figure 2.8: ^{1}H and ^{13}C NMR of Cat **2.12b.**

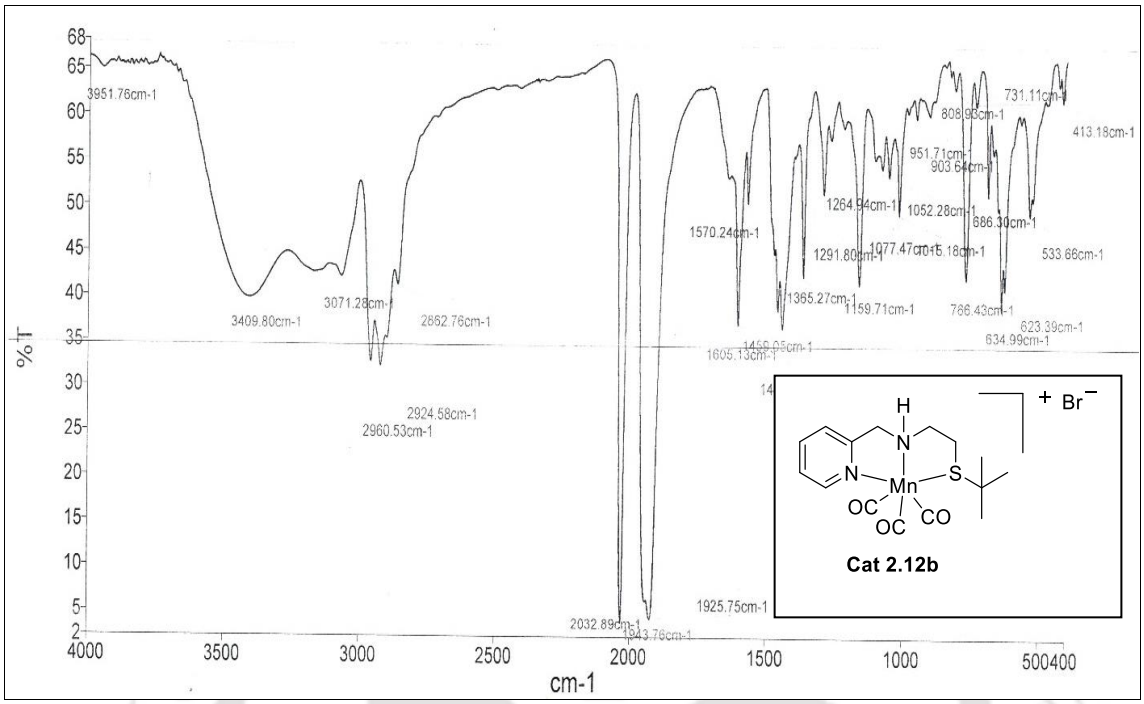


Figure 2.9: IR Spectrum of Cat **2.12b.**

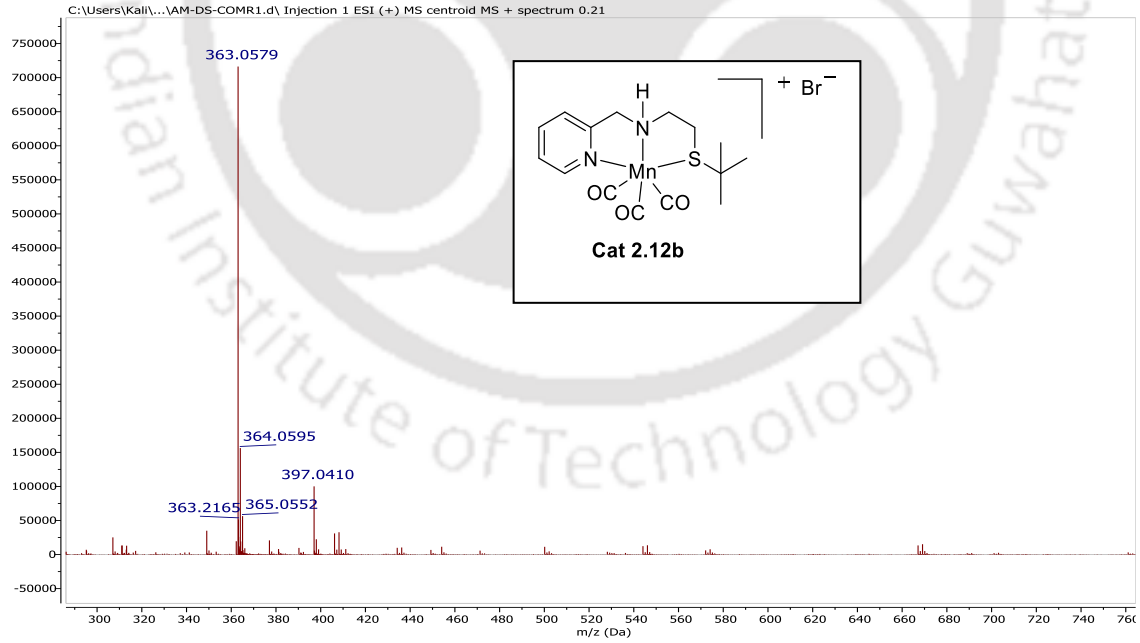


Figure 2.10: Mass Spectrum of Cat **2.12a.**

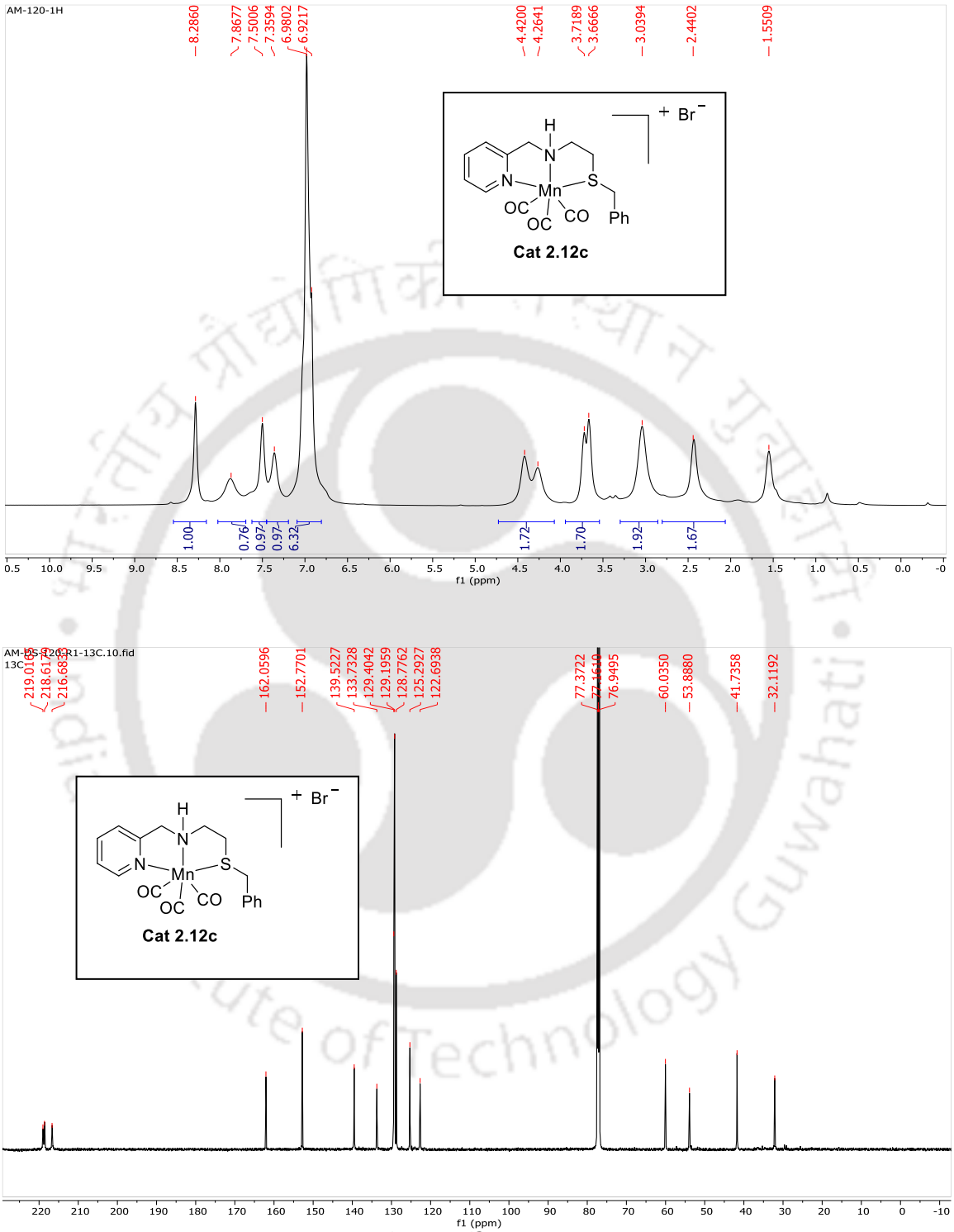


Figure 2.11: ^{1}H and ^{13}C NMR of Cat **2.12c.**

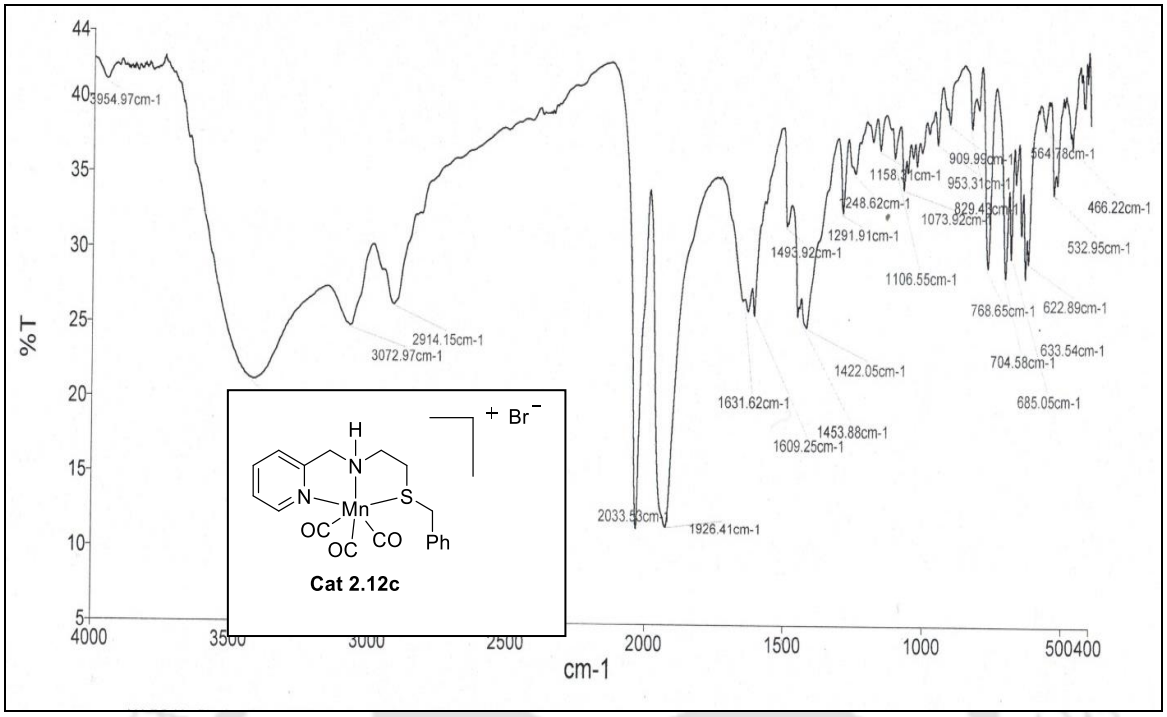


Figure 2.12: IR Spectrum of Cat **2.12c.**

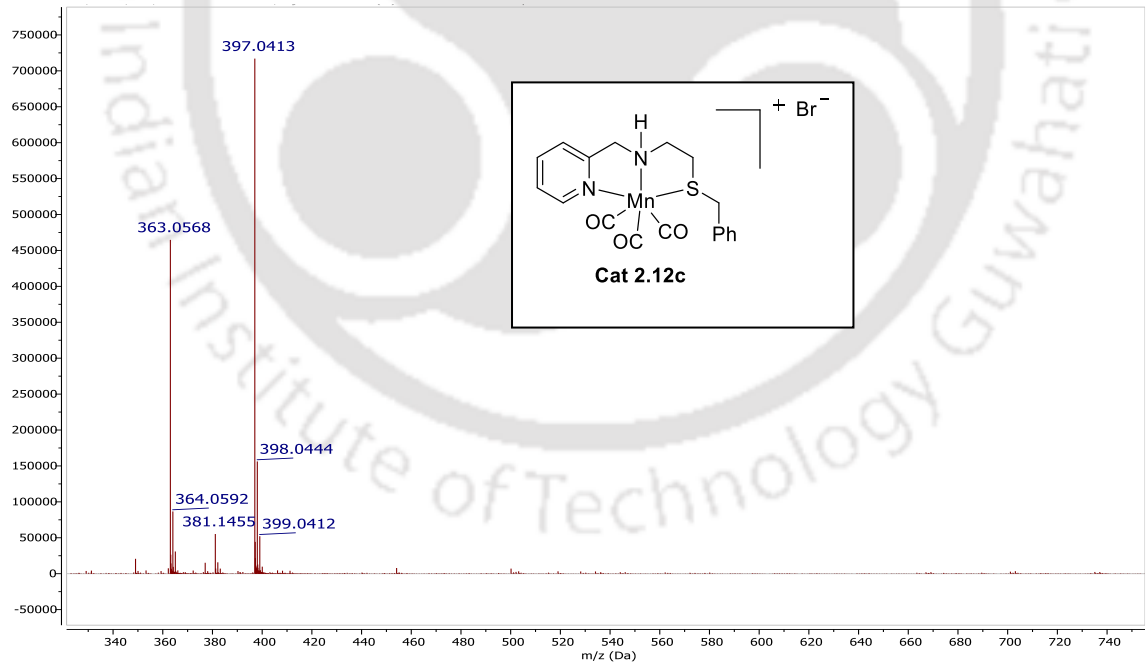


Figure 2.13: Mass Spectrum of Cat **2.12c.**

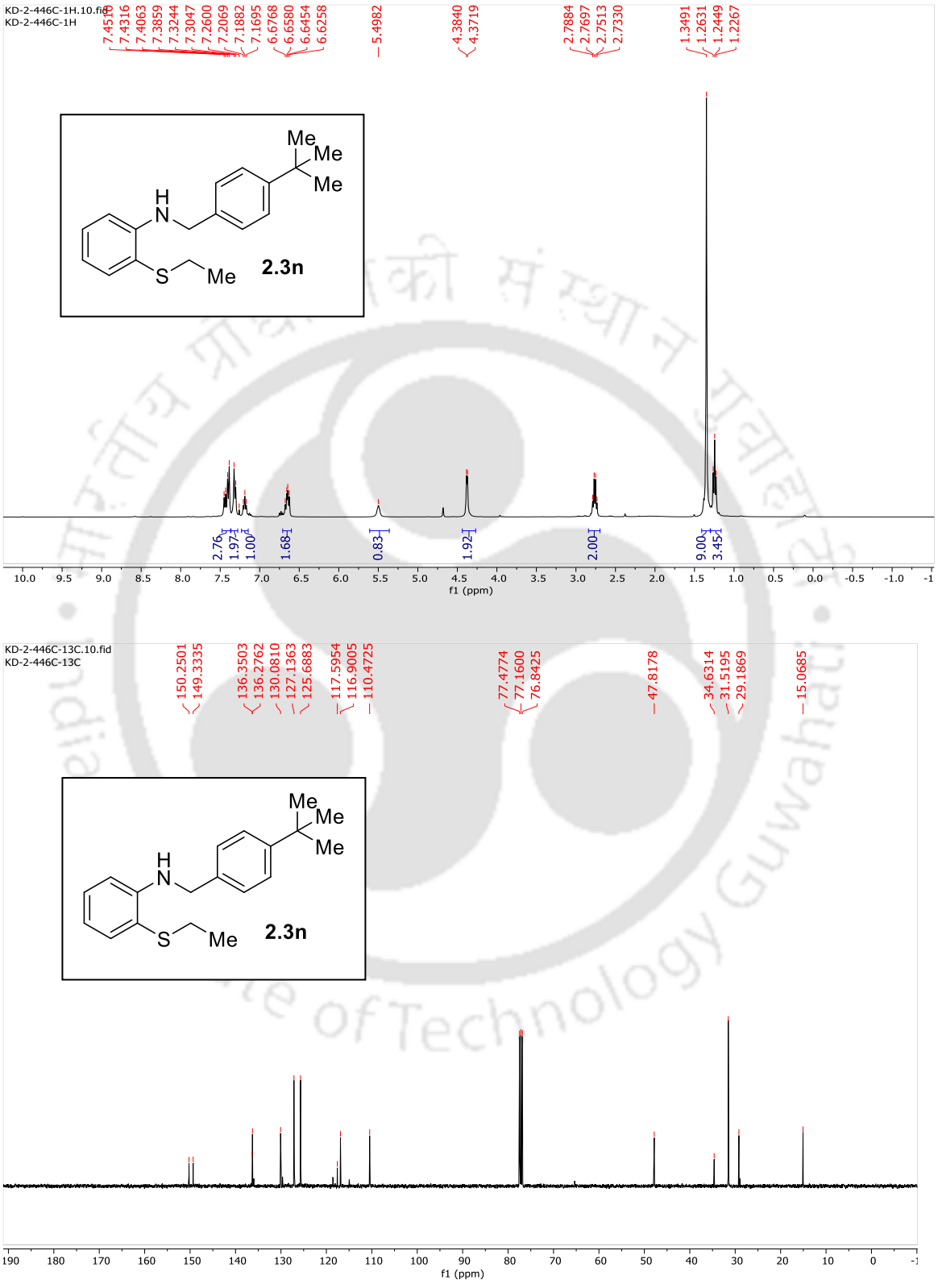


Figure 2.14: ^{1}H and ^{13}C NMR of compound **2.3n**.

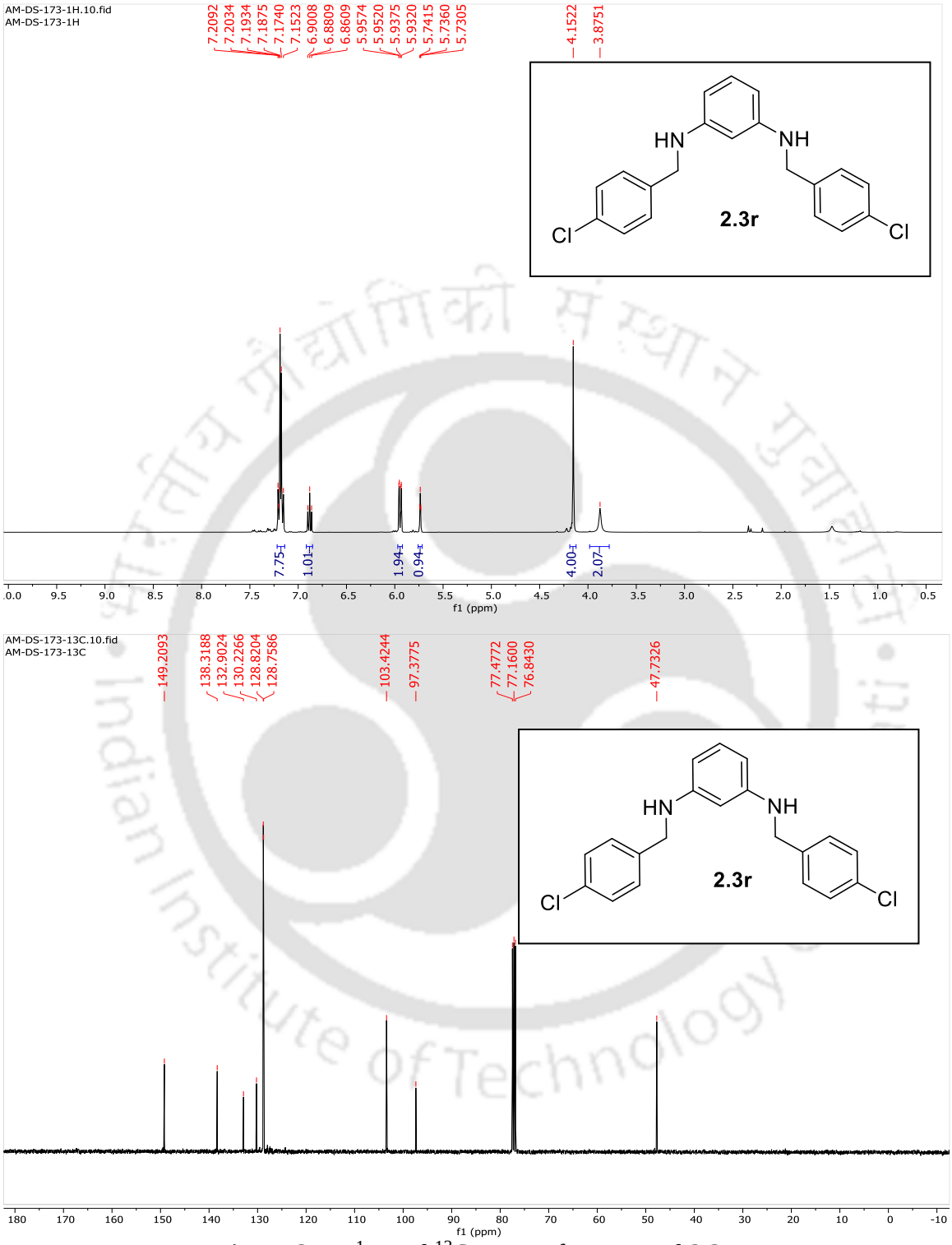


Figure 2.15: ^{1}H and ^{13}C NMR of compound **2.3r**.

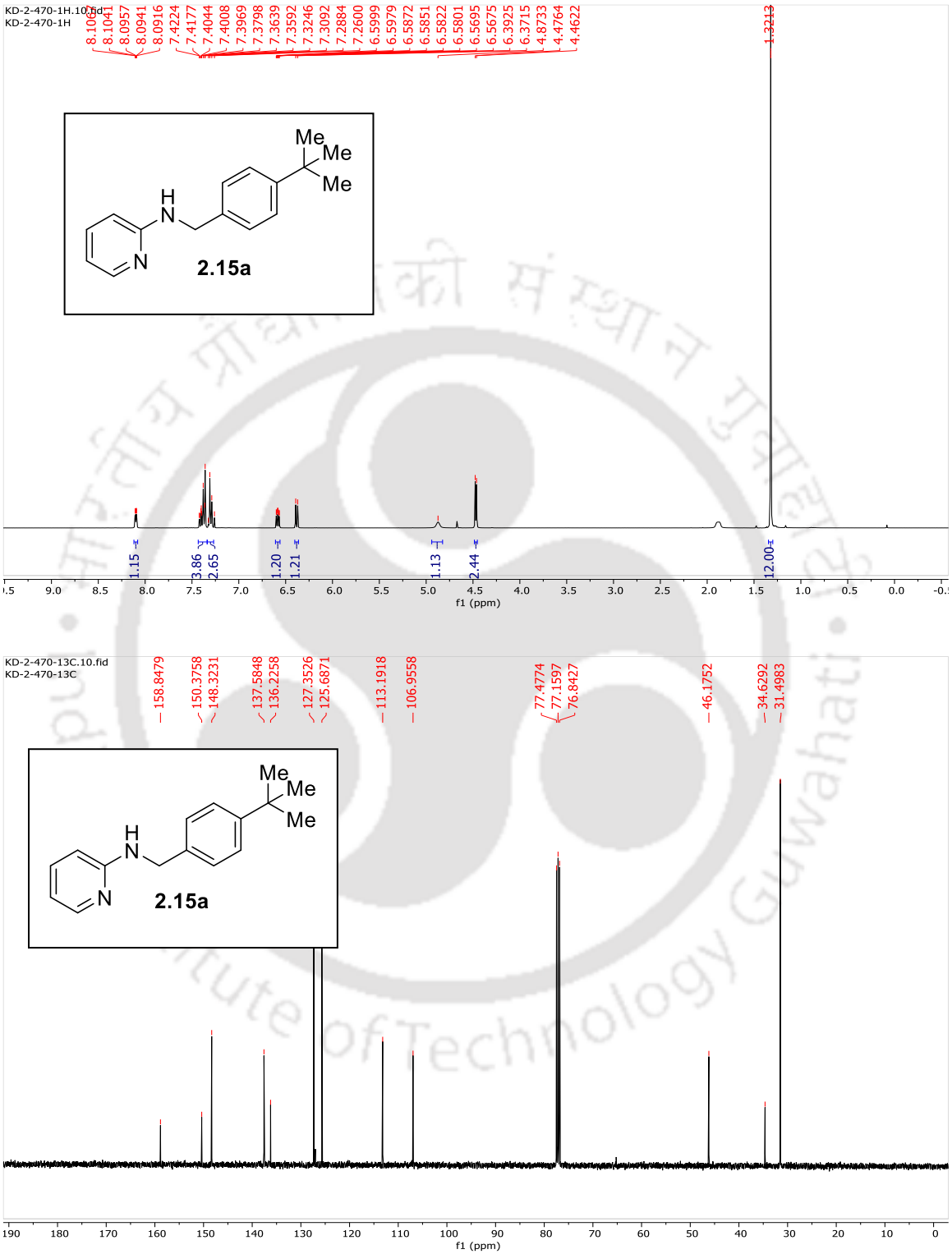


Figure 2.16: ^{1}H and ^{13}C NMR of compound **2.15a**.

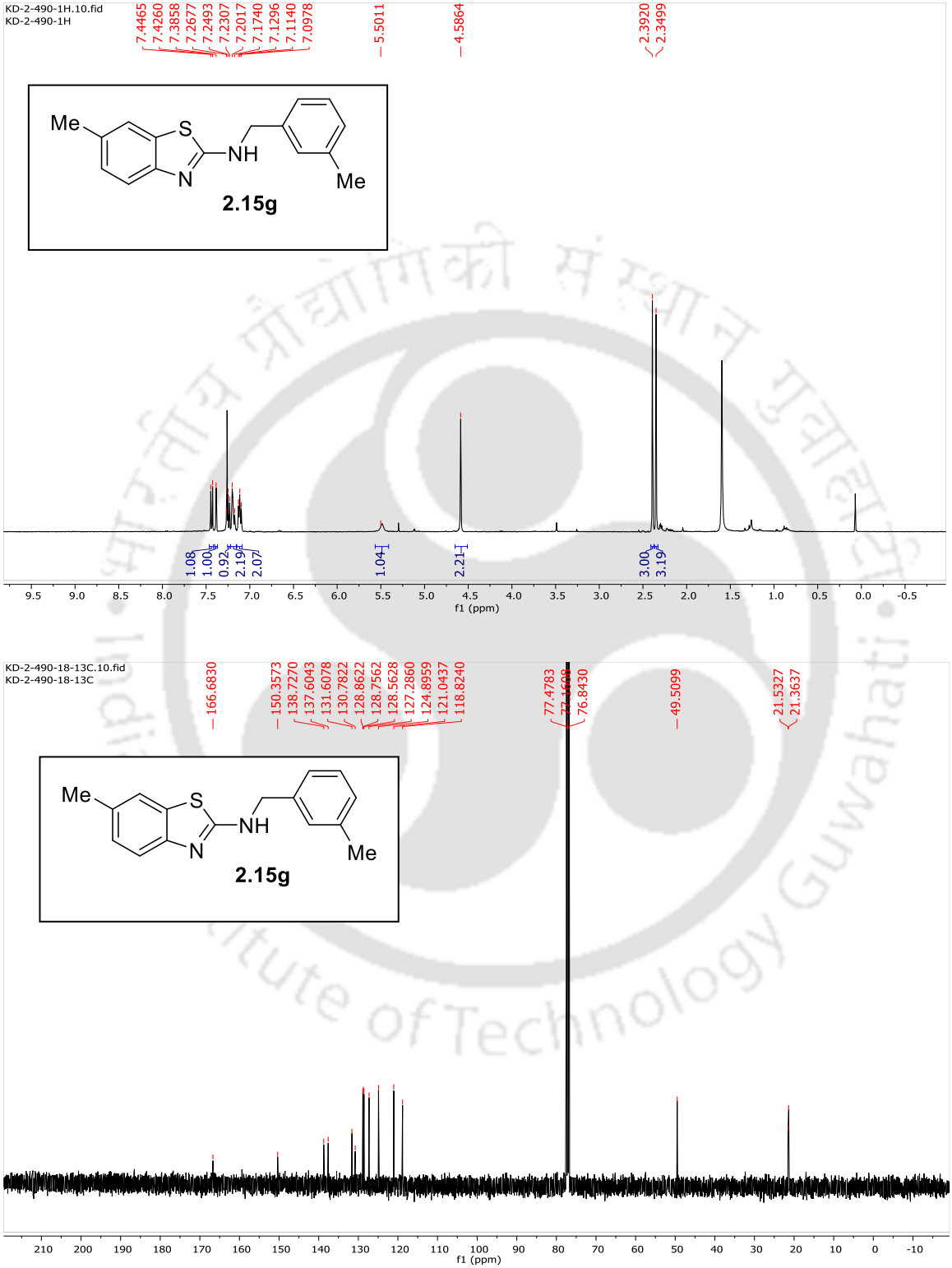


Figure 2.17: ^{1}H and ^{13}C NMR of compound **2.15g**.

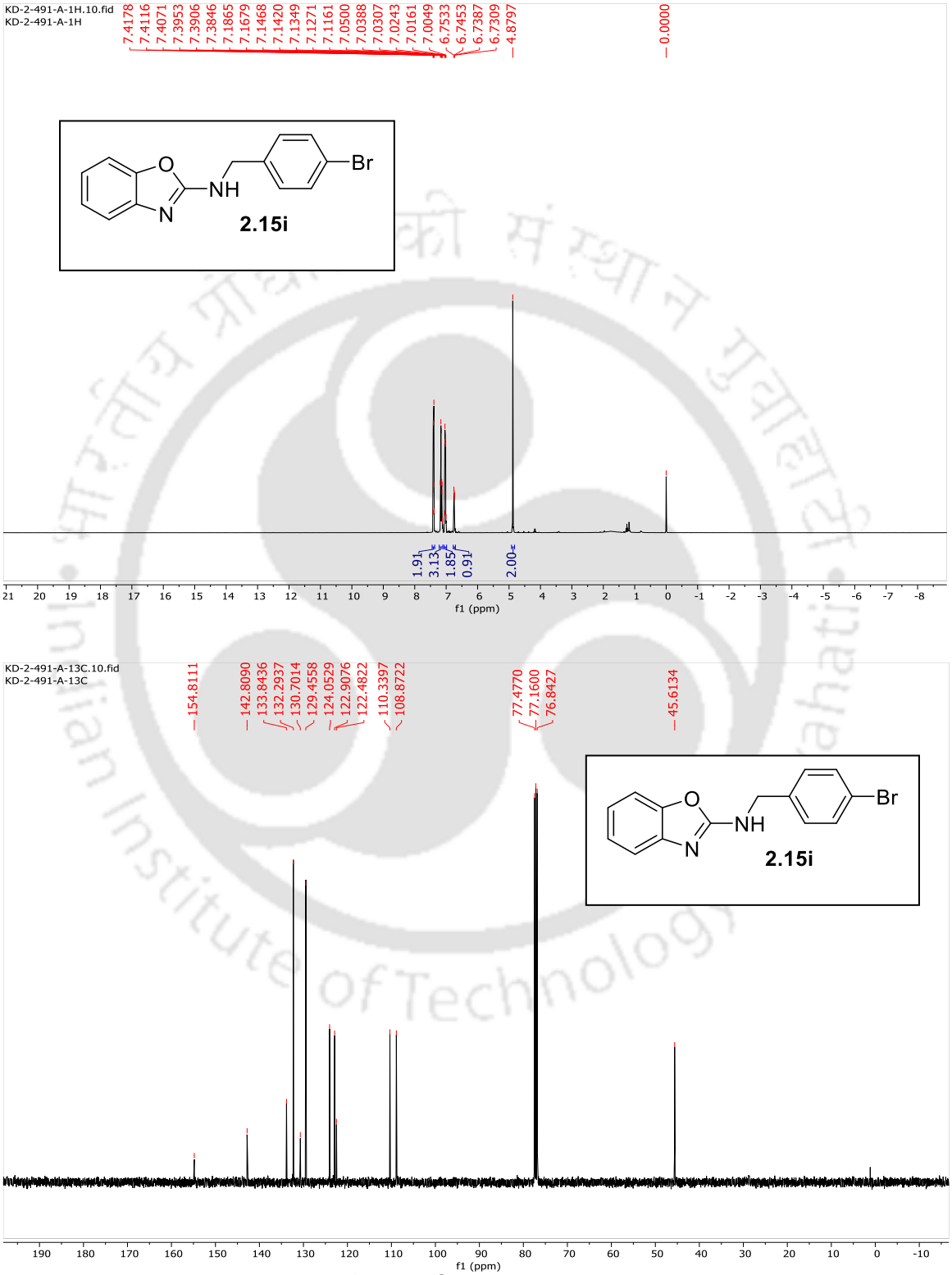


Figure 2.18: ^{1}H and ^{13}C NMR of compound **2.15i**.

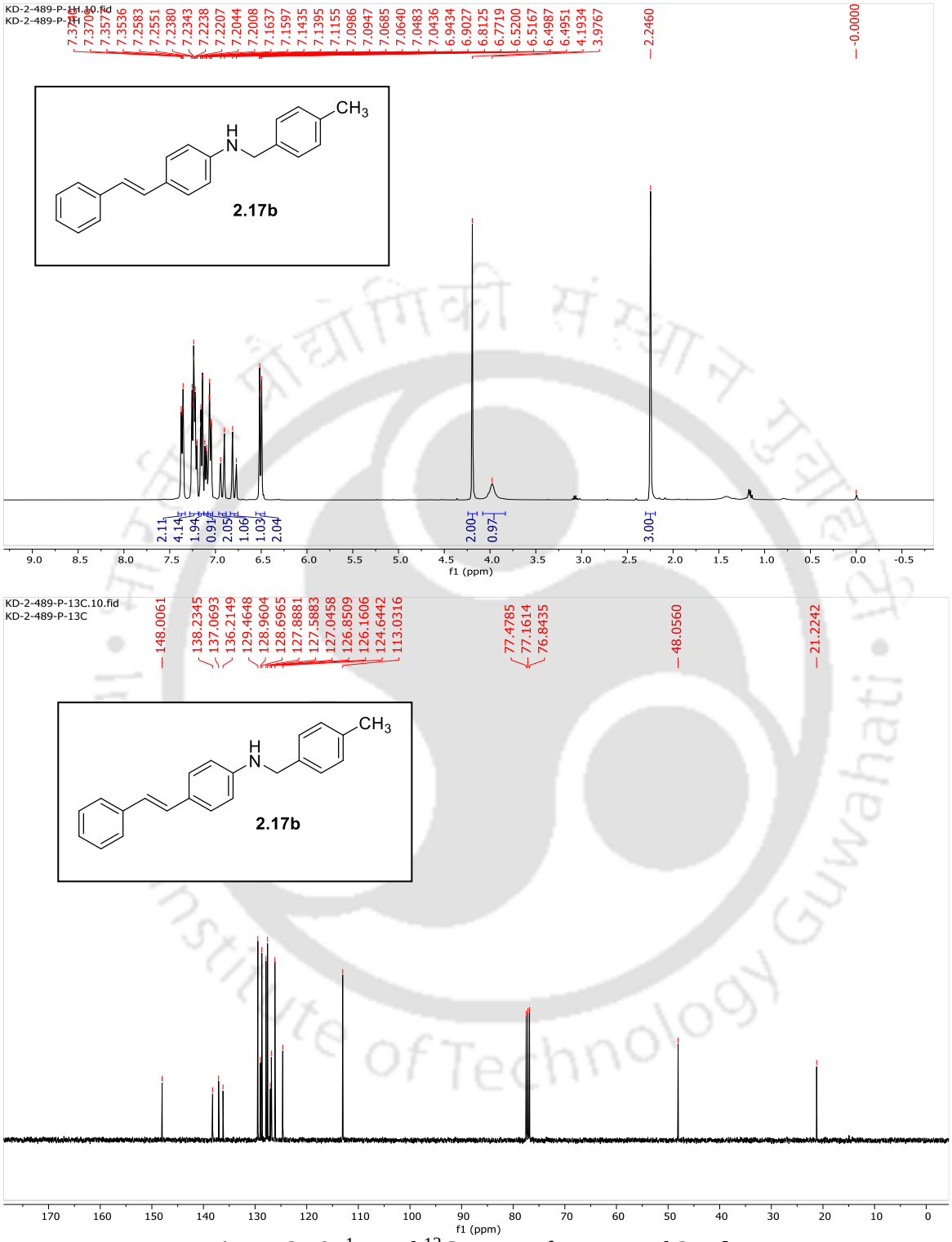


Figure 2.19: ^{1}H and ^{13}C NMR of compound **2.17b**.

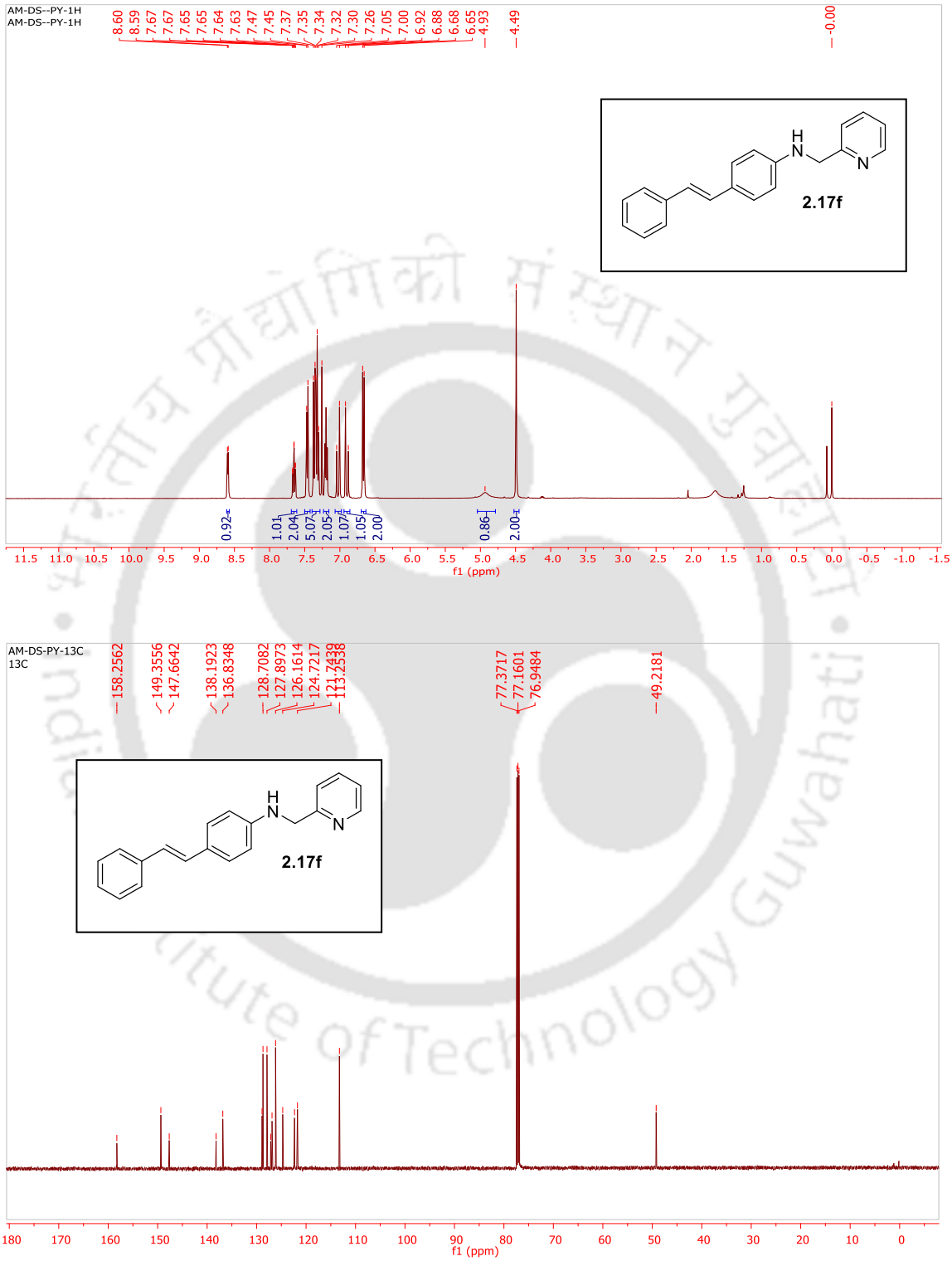


Figure 2.20: ^{1}H and ^{13}C NMR of compound **2.17f**.

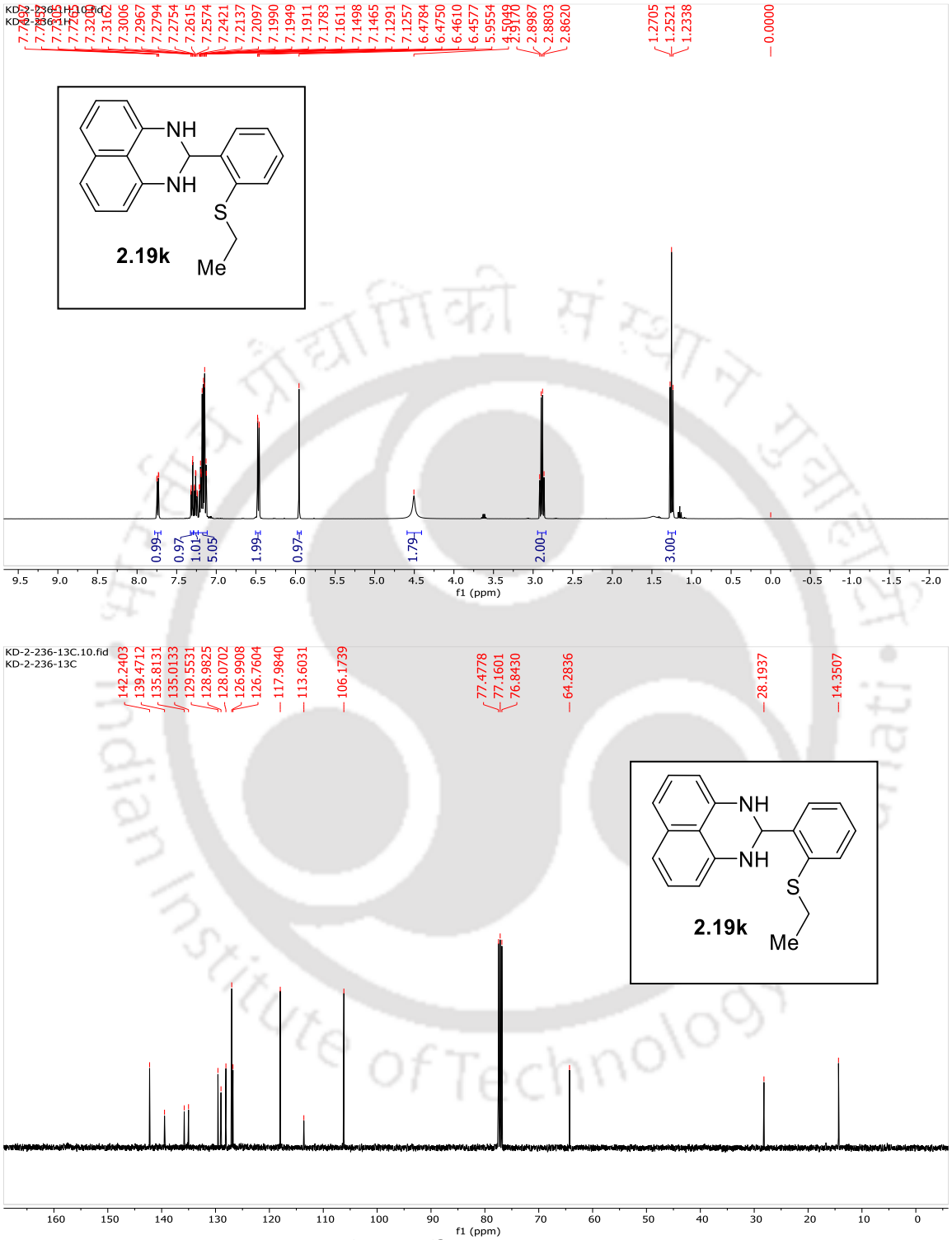


Figure 2.21: ^{1}H and ^{13}C NMR of compound **2.19k**.

Chapter 3

Synthesis of Substituted Benzimidazoles and Benzothiazoles Derivatives Catalyzed by Non-phosphine Manganese(I) Complexes

3.1. Introduction:

In recent times, benzimidazoles and benzothiazole derivatives have attracted considerable attention due to their important biological and pharmacological properties.[1] Many pharmaceutically important molecules having these heterocyclic scaffolds as core units are known for their application as anticancer,[2] antimicrobial,[3] antimalarial,[4] anti-inflammatory,[5] antitubercular,[6] anthelmintic,[7] anticonvulsant,[8] antioxidant,[9] anti-ulcer,[10] and anti-HBV[11] agents. Furthermore, benzimidazole derivatives are also effective against HIV[12] and human cytomegalovirus (HCMV).[13] Recently, antidiabetic property of different benzimidazole derivatives has also been disclosed.[14] Several benzothiazole derivatives are used as amyloid imaging[15] agents in Alzheimers disease and organic functional materials such as fluorescent dyes and liquid crystals.[16] Thus, the development of new strategies to synthesize these heterocycles become an important topic in organic chemistry.

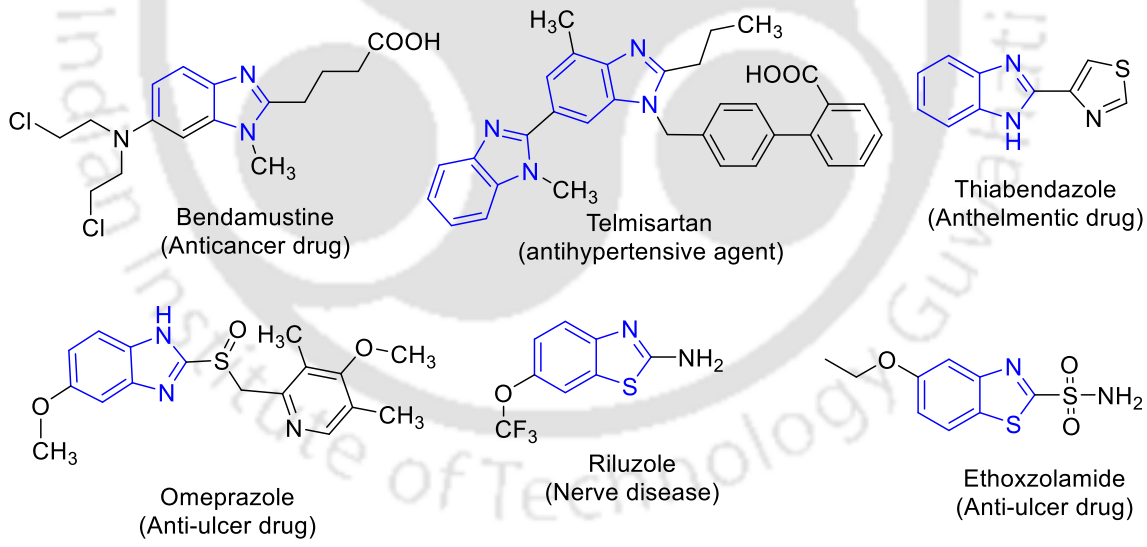


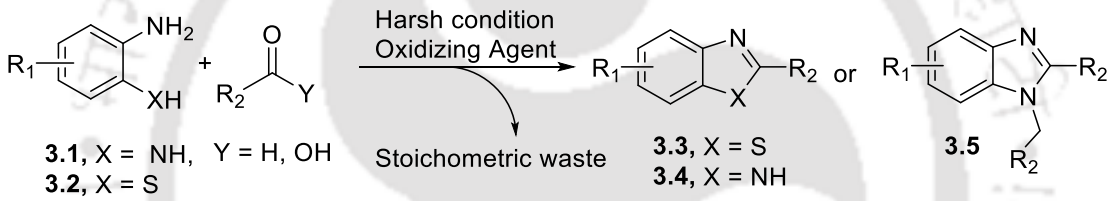
Figure 3.1: Some selected examples of benzimidazole/benzothiazole containing drug molecules.

3.2. Strategies for benzimidazole and benzothiazole synthesis:

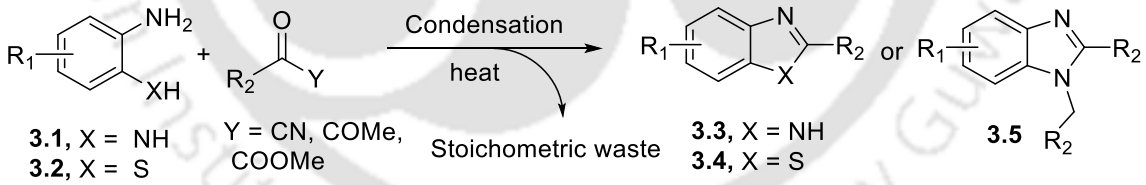
3.2.1. Classical Method:

Three main approaches have been established for the synthesis of benzimidazoles/benzothiazoles over the past few decades. Traditionally, the synthesis of these scaffolds were achieved *via* condensation of *o*-phenylenediamine/2-amino thiophenols with aldehyde[17] or carboxylic acids[18] under oxidative conditions (**Scheme 3.1,** A). Another widely used strategy involves the condensation reactions of *o*-phenylenediamine/2-aminothiophenols with *β*-ketonitriles,[19] *β*-ketoesters,[20] or *β*-diketones[21] (**Scheme 3.1**, B) at elevated temperature. The last strategy includes the

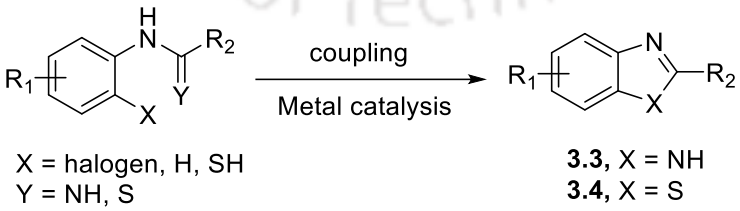
A) Condensation with Aldehyde/Carboxylic Acids:



B) Condensation with Carboxylic Acids Derivative:



C) Intramolecular Coupling Method:

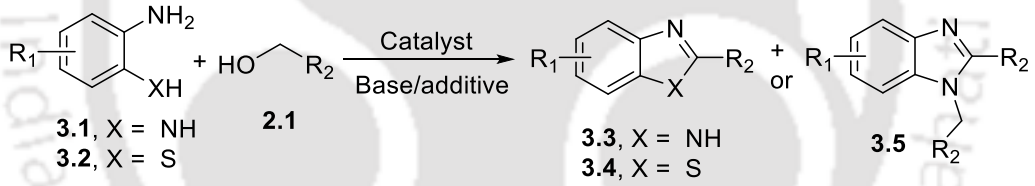


Scheme 3.1: The general method for the synthesis of benzimidazole derivatives.

transition metal catalysed intramolecular coupling reactions of 2-haloanilides and its analogue (**Scheme 3.1, C**).[22] However, these methods suffer either from the generation of stoichiometric amount of waste, involvement of toxic solvent and harsh reaction condition. Another major problem is the selectivity during the synthesis of 2-substituted and 1,2-disubstituted benzimidazoles. To overcome these drawbacks, acceptorless dehydrogenative approaches to synthesize such compounds have been exploited.

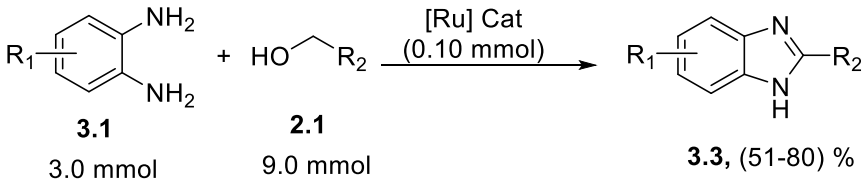
3.2.2 Acceptorless dehydrogenative method:

In this approach, the synthesis of benzimidazoles[23] (**3.3, 3.5**) or benzothiazoles[24] (**3.4**) directly from primary alcohol and *o*-phenylenediamine/2-amino thiophenol has been achieved. This strategy attracted much attention due to its atom-economical and environmental benign nature as hydrogen and water are the only byproducts. Another major advantage is the direct use of inexpensive and readily available alcohols that can be obtained renewably from biomass resources *via* fermentation or catalytic conversion.



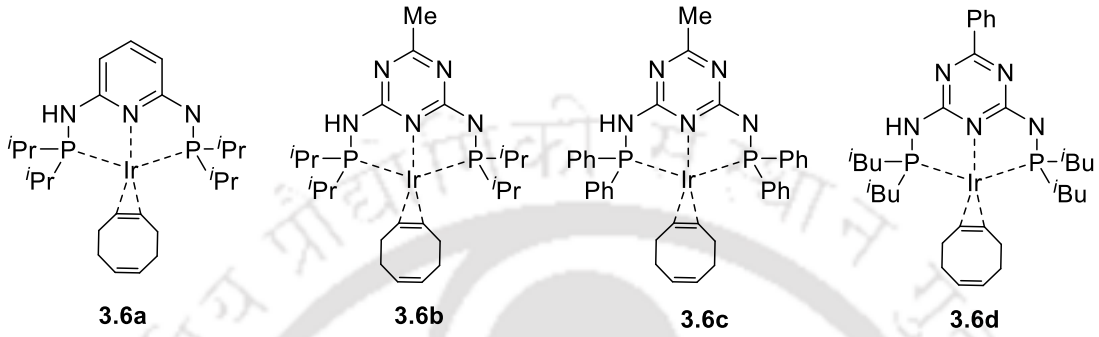
Scheme 3.2: The general catalytic method for the synthesis benzimidazoles.

One of the earliest example of the synthesis of 2-substituted benzimidazoles *via* acceptorless dehydrogenation was developed by *Watanabe and co-workers*.[25] The reaction is catalyzed by $RuCl_2(PPh_3)_3$ complex at elevated temperature (215 °C).



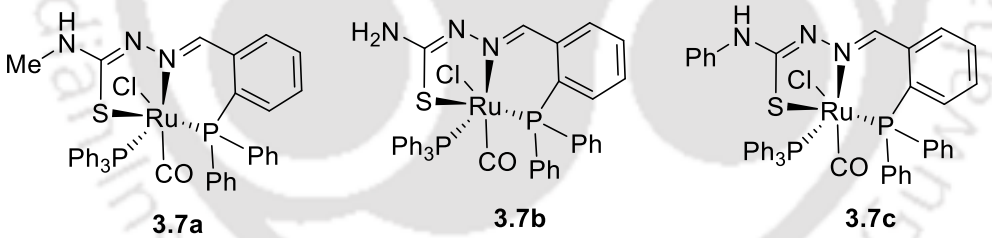
Scheme 3.3: Synthetic procedure of 2-substituted benzimidazoles by Ru-complex.

In 2014, *Kempe and co-workers* developed an elegant method to synthesize selectively 2-substituted benzimidazoles (**3.3**) under relatively milder condition (110 °C).[26] The reaction is catalyzed by phosphine based iridium pincer complex (1.4 mol%, **Scheme 3.4**) with traditional solvent medium.



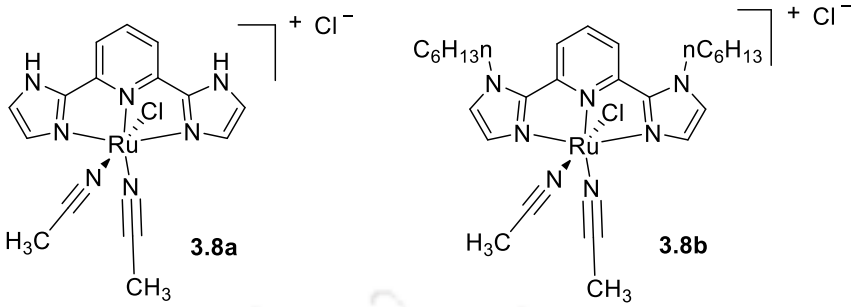
Scheme 3.4: Some Ir-complexes that have been used by *Kempe* in benzimidazole synthesis.

In the same year, *Viswanathamurthi and co-workers* were able to prepare selectively 2-substituted benzimidazoles (**3.3**) using phosphine based Ru-complex under mild condition (100 °C).[27] Good yield of the desired benzimidazoles were obtained in presence of 0.5 mol % catalyst and 2 equivalents of KOH (relative to the substrate).



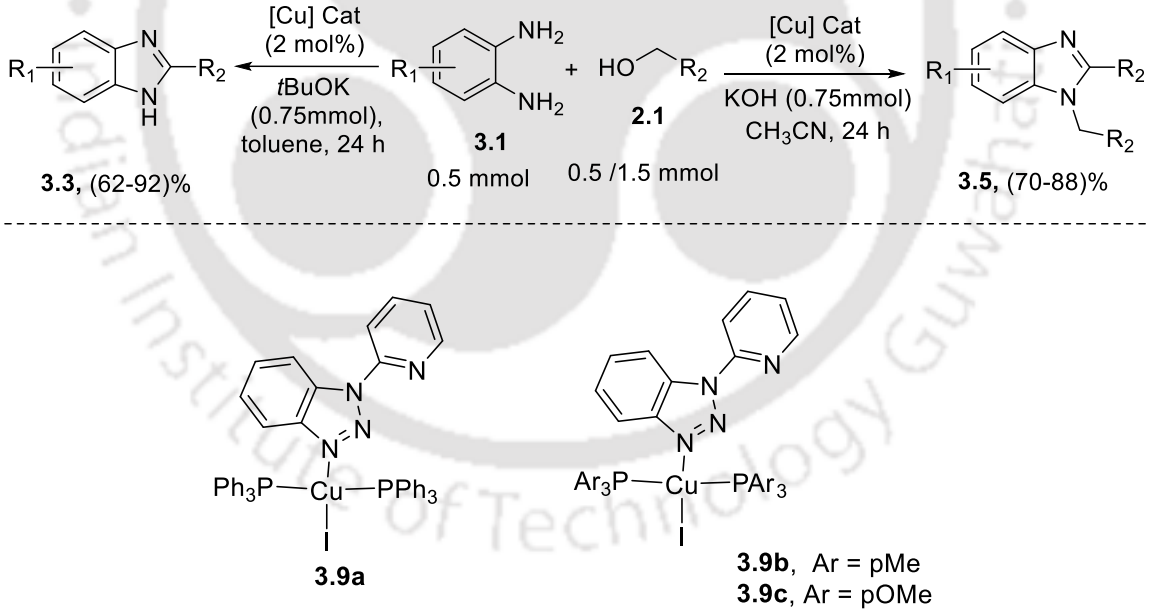
Scheme 3.5: Some Ru-complexes that have been used by *Viswanathamurthi* in benzimidazole synthesis.

Very recently, *Zhang and Peng* illustrated air stable Ru-*NNN* [*NNN*=2,6-bis(1*H*-imidazol-2-yl)pyridine] complexes[28] catalysed condensation of various primary alcohols and benzene-1,2-diamine to form 2-substituted 1*H*-benzo[d]imidazole derivatives. The reaction worked efficiently in the presence of 0.25 mol% of Ru(II) and catalytic amount of base using dppe ligand [1,2-bis(diphenylphosphino)ethane] (0.25 mol%) as additive.



Scheme 3.6: Some Ru-complexes that have been used by *Zhang* in benzimidazole synthesis.

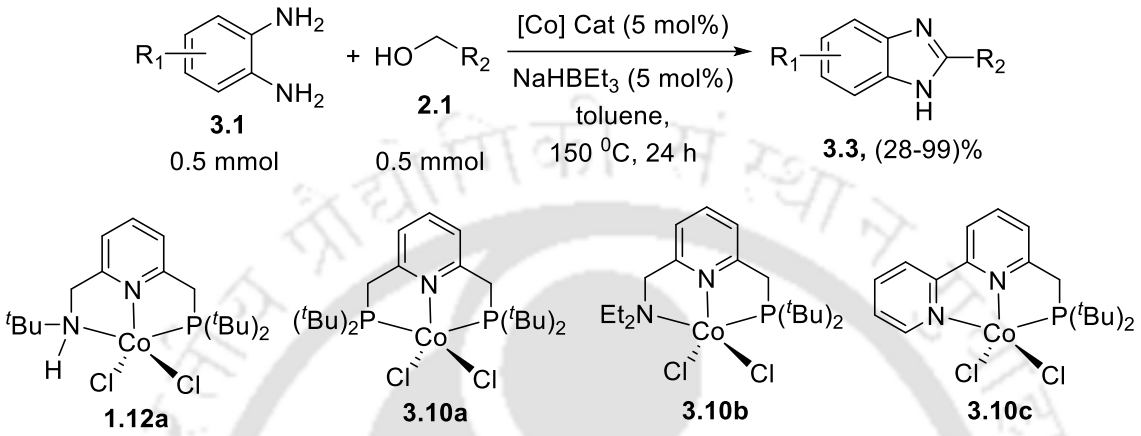
The replacement of costly noble-metal catalyst by inexpensive earth-abundant metal is an important goal in homogenous catalysis. In recent year, the scope and limitation of this reaction using 3d-transition metals were investigated. In 2017, *Wang and his group* reported the selective synthesis of 2-substituted (**3.3**) and 1,2-disubstituted benzimidazoles (**3.5**) using Cu-triazole-phosphine complexes.[29]



Scheme 3.7: Synthetic procedure of 2-substituted and 1,2-disubstituted benzimidazole by Cu(I) -complex.

In the same year, *Milstein and co-workers* first reported cobalt[30] catalysed dehydrogenative coupling of primary alcohols and aromatic diamines to form

selectively 2-substituted benzimidazoles without using any traditional base at very high temperature (150 °C). They have used catalytic amount sodium triethylborohydride ($NaHBEt_3$) together with phosphine based Co-complexes.



Scheme 3.8: Synthetic procedure of 2-substituted benzimidazoles by Co(II)–complex.

A number of catalysts performing such type of reaction have been reported. However, most of them contain either costly noble-metal catalyst or earth-abundant catalysts having sophisticated phosphine derived ligands. Thus, selective synthesis of both 2-substituted and 1,2-disubstituted benzimidazoles from 1,2-diamino benzene and alcohol using earth-abundant,[31] nontoxic Mn-metal catalyst is highly desirable.

3.3. Present Work:

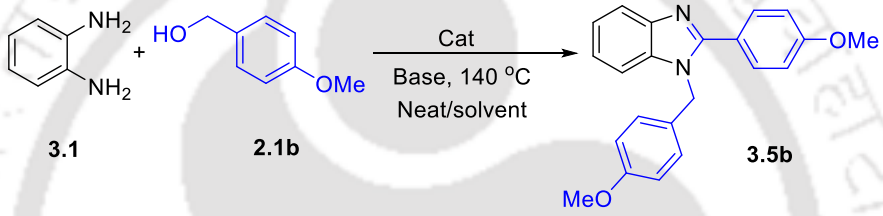
Herein, the scope of the NNS-Mn complexes towards the selective synthesis 2-substituted and 1,2-disubstituted benzimidazole *via* acceptorless dehydrogenation is investigated. The applicability of these complexes toward the synthesis of benzothiazole from primary alcohol and 2-aminothiophenol has also been studied.

3.3.1 Optimization of reaction conditions:

Initially, I attempted to find out the optimum reaction conditions for the selective synthesis of 1,2-disubtituted benzimidazole. Thus, 1,2-diaminobenzene and 4-methoxybenzyl alcohol were taken as model substrates. At the outset, I examined the

reaction of 1,2-diaminobenzene (0.5 mmol) with 4-methoxy benzyl alcohol (1.5 mmol) in presence of *t*BuOK (1.2 mmol) and Cat **2.12a** (5 mol %) at 140 °C under argon condition in toluene (3 mL) medium (**Table 3.1**, entry 1). After 20 hours, only 12% of the desired product was identified as 1-(4-methoxybenzyl)-2-(4-methoxyphenyl)-*1H*-benzo[*d*]imidazole (**3.5b**) by ^{1}H NMR analysis and NMR yield of the product was calculated using CH_3CN as internal standard. When, xylene was used as solvent keeping other conditions unchanged, the yield of the desired product was not improved effectively (**Table 3.1**, entry 2).

Table 3.1: Screening Table:[a,b]



3.1 2.1b 3.5b

Exp. No.	Catalyst (mmol)	Base (mmol)	Solvent (3 mL)	Time (hours)	Diamine : Alcohol (mmol)	% of yield[b]
1	Cat **2.12a**	*t*BuOK-1.2	toluene	20	0.5 : 1.5	12
2	Cat **2.12a**	*t*BuOK-1.2	xylene	20	0.5 : 1.5	15
3	Cat **2.12a**	*t*BuOK-1.2	neat	20	0.5 : 1.5	63
4	Cat **2.12a**	*t*BuOK-1.2	neat	20	0.5 : 1.7	71
5	Cat **2.12a**	*t*BuOK-1.2	neat	20	0.5 : 2.0	71
6	Cat **2.12a**	*t*BuOK-1.4	neat	20	0.5 : 1.7	56
7	Cat **2.12a**	*t*BuOK -2.0	neat	24	0.5 : 1.7	56
8	Cat **2.12a**	*t*BuOK -0.75	neat	20	0.5 : 1.7	42
9	**Cat 2.12a**	***t*BuOK-1.0**	**neat**	**20**	**0.5 : 1.7**	**83**
10[c]	Cat **2.12a**	*t*BuOK-1.0	neat	20	0.5 : 1.7	39
11	Cat **2.12b**	*t*BuOK-1.0	neat	20	0.5 : 1.7	74

12	Cat **2.12c**	*t*BuOK-1.0	neat	20	0.5 : 1.7	62
13[d]	Cat **2.12a**	*t*BuOK-1.0	neat	20	0.5 : 1.7	55
14	Cat **2.12a**	KOH-1.0	neat	20	0.5 : 1.7	61
15	Cat **2.12a**	K_2CO_3-1.0	neat	20	0.5 : 1.7	0
16[e]	Cat **2.12a**	*t*BuOK-1.0	neat	10	0.5 : 1.7	48
17[f]	Cat **2.12a**	*t*BuOK-1.0	neat	20	0.5 : 1.7	0
18	Cat **2.12a**	…..	neat	20	0.5 : 1.7	0
19	…..	*t*BuOK-1.0	neat	20	0.5 : 1.7	0
20	$Mn(CO)_5Br$	*t*BuOK-1.0	neat	20	0.5 : 1.7	trace

[a] Reaction conditions: 1,2-aminobenzene (0.5 mmol), alcohol (1.5-2.0 mmol), *t*BuOK (0.75-2.0 mmol), cat (0.05 mmol), under argon. [b] NMR yield using CH_3CN as internal standard, [c] under air, [d] Cat **2.12a** (0.025 mmol), [e]10 h, [f]80 °C.

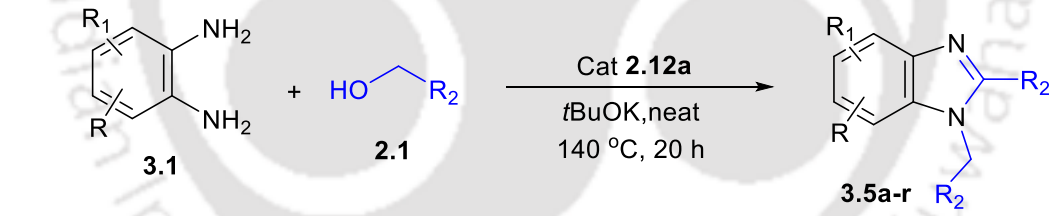
Interestingly, when the reaction carried out under neat condition the yield of the desired product improved (63%) (**Table 3.1**, entry 3). The yield was further enhanced from 63% to 71% when alcohol amount was increased from 1.5 mmol to 1.7 mmol without changing other parameters. Increasing the ratio of 1,2-aminobenzene and the 4-methoxy benzyl alcohol further (1:4), did not improve the yield even after 24 h (**Table 3.1**, entry 5). Next, the effect of the amount and the nature of the base in the reaction were examined. Thus, keeping the other condition unaltered, the amount of the base was changed. 1.0 mmol of *t*BuOK was found to be optimum to get the best yield (83%) (**Table 3.1**, entry 9). Increasing or decreasing the amount of *t*BuOK led to the formation of the lower amount of the desired product (**Table 3.1**, entries 6, 7 and 8). Under the similar reaction conditions, cat **2.12b** and cat **2.12c** gave, 74% and 62% yield respectively (**Table 3.1**, entries 11, 12). Other weak bases (such as KOH, K_2CO_3) were also screened but only moderate to poor results were obtained (**Table 3.1**, entries 14, 15). Changing the catalyst loading from 5 mol % to 2.5 mol% lowered the yield (55%)

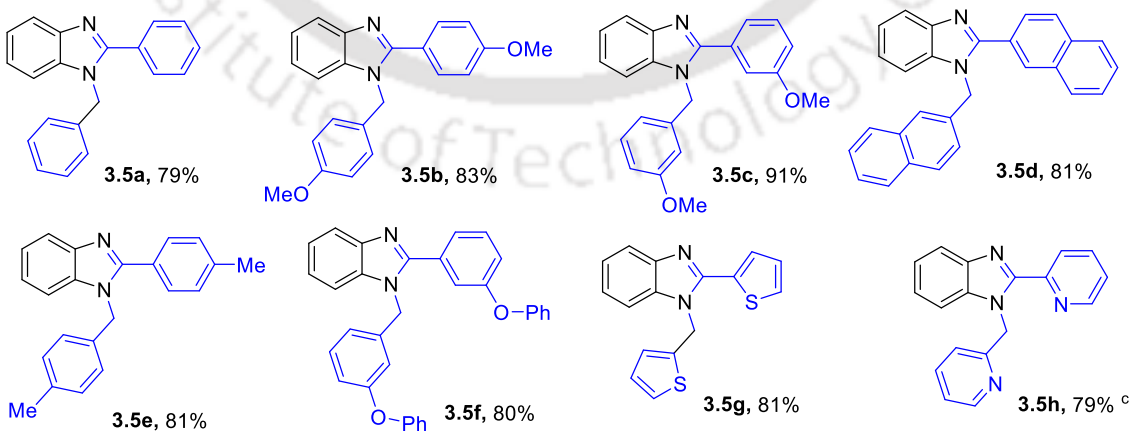
(**Table 3.1**, entry 13). Lower reaction time was found to have detrimental effect on the yield of the product (**Table 3.1**, entry 16**)** and in case of lower temperature (80 °C) no product formation was observed (**Table 3.1**, entry 17). The control experiments were also performed, and it was observed that in the absence of catalyst, no desired product (**Table 3.1**, entry 19) was obtained, and similarly, without the presence of base, complex **2.12a** failed to give any desired product (**Table 3.1**, entry 18). Yield of the desired product was drastically decreases (39%) when this reaction was performed under open air without changing any other parameters (**Table 3.1**, entry 10). $MnBr(CO)_5$ gave only trace amount of the product under the optimized reaction condition.

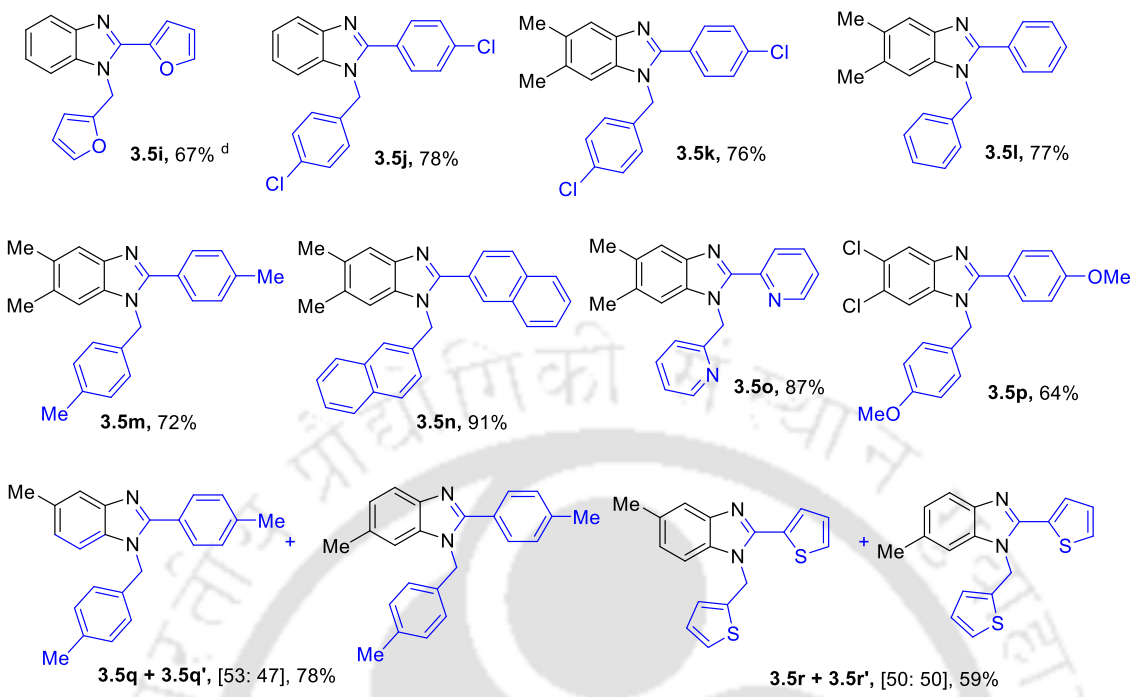
3.3.2. Substrate scope:

After achieving the optimized reaction conditions, the generality and scope of the reaction were investigated. A wide range of 1-benzyl-2-aryl-*1H*-benzo[*d*]imidazole derivatives **3.5a-r** were synthesized from 1,2-diaminobeznene and primary alcohols.

Table 3.2: Scope of the reaction to synthesize 1,2-disubstituted benzimidazole[a,b]





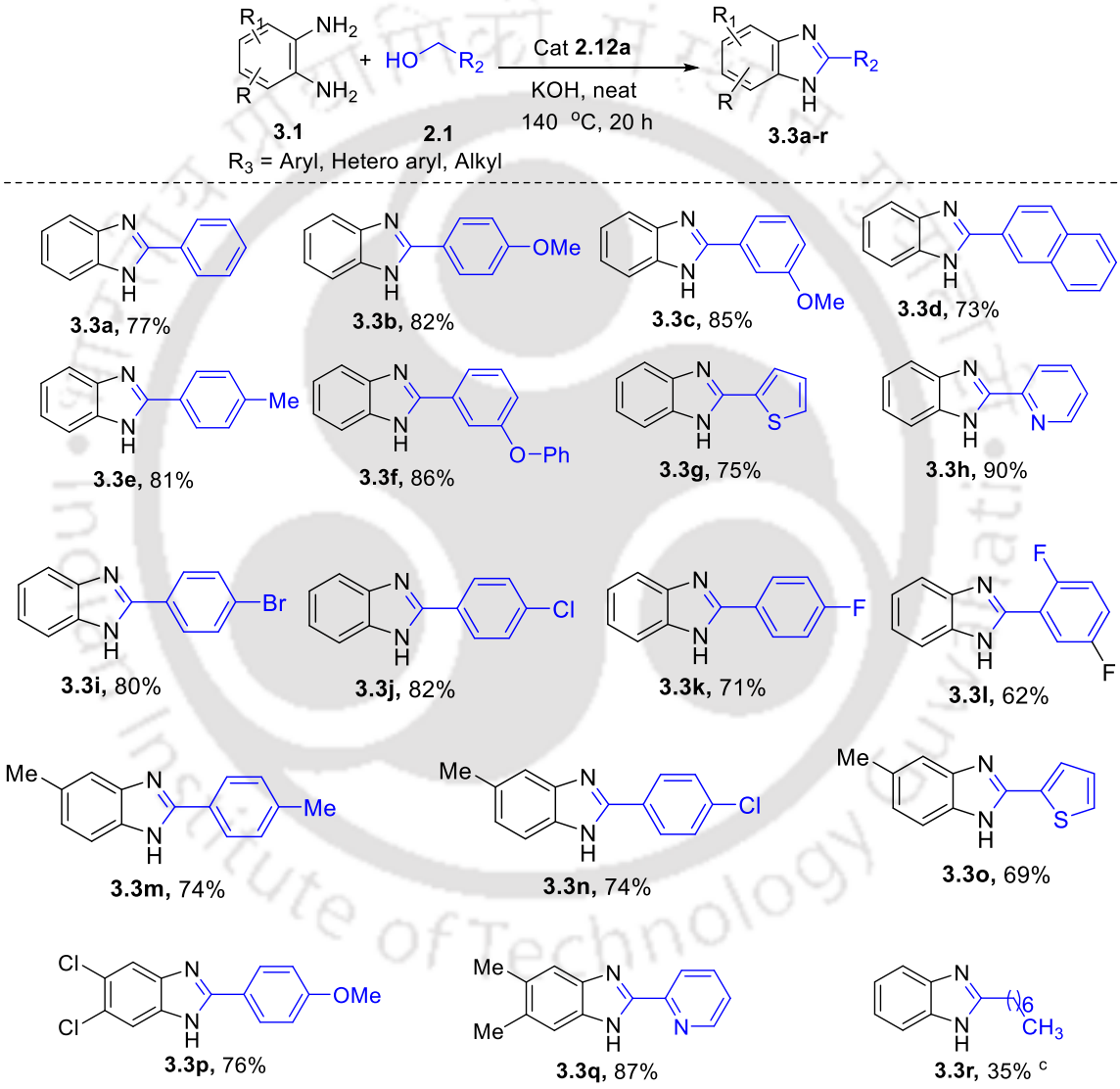


[a] Reaction conditions: Diamine (0.5 mmol), alcohol (1.7 mmol), *t*BuOK (1 mmol), cat **2.12a** (0.05 mmol), 20 h, under argon, [b] isolated yield, [c] 44 h, [d] 26 h.

Various substituted benzyl alcohols as well as 2-naphthalenemethanol reacted smoothly with 1,2-diaminobenzene to give good yield of the desired 1,2-disubstituted benzimidazoles (**Table 3.2**). When heterocyclic alcohols such as 2-pyridinemethanol and furfural have been employed as substrates longer reaction time were required to obtain good yields whereas 2-thiophenemethanol gave good yield after 20 h. A small amount of *bis N*-alkylated product of the *o*-phenylenediamine was also observed in some cases, which might be due to the hydrogenation of *bis*-imines formed in situ during the reaction. I have also used the diamine derivatives such as 4,5-Dimethyl-1,2-phenylenediamine, 4,5-Dichloro-*o*-phenylenediamine and 3,4-diaminotoluene which were reacted well under the optimized condition. In case of 3,4-diaminotoluene, a mixture of two isomeric 1-benzyl-2-aryl-*1H*-benzo[*d*]imidazole products were formed almost in equal amount.

Next, the scope of the selective synthesis of 2-substituted benzimidazole from 1,2-diaminobenzene and 4-methoxybenzyl alcohol were investigated. The reaction was carried out in presence of cat **2.12a** and KOH at 140 °C under air. Interestingly, 2-aryl-*1H*-benzo[*d*]imidazole derivatives (**Table 3.3, 3.3a-r)** were achieved just by tuning

Table 3.3: Scope of the reaction to synthesize 2-substituted benzimidazole[a,b]



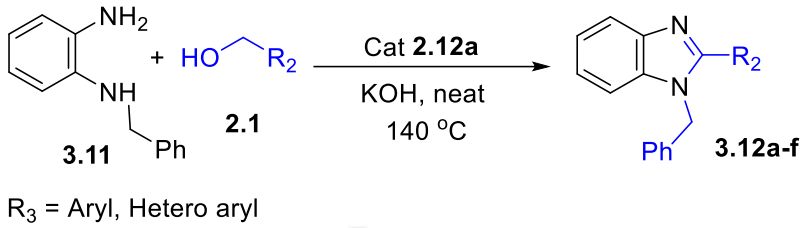
[a] Reaction conditions: Diamine (1.0 mmol), alcohol (1.3 mmol), KOH (0.27 mmol), cat **2.12a** (0.05 mmol), 20 h, under air, [b] isolated yield, [c] 72 h.

the reaction conditions. It was noticed that lowering the amount of weaker base such as KOH is effective to get the highest yield the targeted product. The best result (84%) was gained when I have used 0.27 mmol of KOH, amine-alcohol ratio 1.0 : 1.3 in the presence of 5 mol% of cat **2.12a** under air. When this reaction was carried out under argon atmosphere I have got only 47% yield of the desired product. Furthermore, when the reaction was performed in the presence of 1.06 mmol or 0.14 mmol KOH, a lower yield of the product (68% and 73% respectively) was obtained.

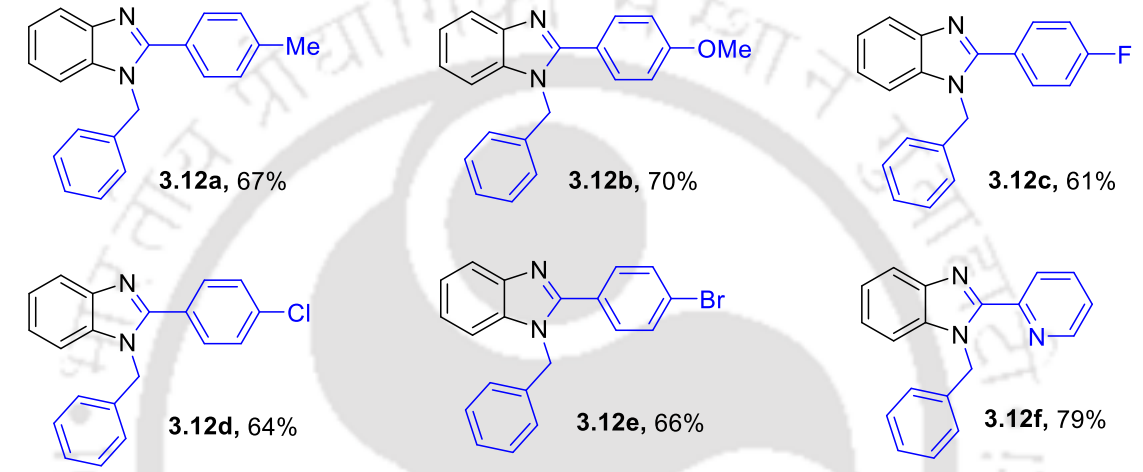
To further evaluate the efficiency of this methodology, benzyl alcohol with various substituents were examined (**Table 3.3**). Benzyl alcohol bearing electron-withdrawing such as -F, -Br, -Cl groups and electron-donating groups such as -Me, -OMe participated well in the reaction to afford corresponding products in excellent yields. Differently substituted benzylic alcohols as well as 2-naphthalenemethanol reacted well with *o*-phenylenediamine to give good yield of the desired products. Moderate to good yield of the desired 1,2-disubstituted benzimidazoles were achieved when heterocyclic alcohols such as 2-pyridinemethanol, furfural or 2-thiophenemethanol have been employed as substrates. Furthermore, 4,5-Dimethyl-1,2-phenylenediamine, 4,5-Dichloro-*o*-phenylenediamine and 3,4-diaminotoluene reacted smoothly under the optimized reaction condition. However, the reaction produced lower yields with aliphatic alcohols. Thus, when octanol was used as substrate, 35% of the 2-ethyl-*1H*-benzo[*d*]imidazole was obtained after 72 hours.

Next I am interested to synthesize 1,2-disubstituted benzimidazoles having different aryl groups at 2-position and 1-benzyl position of the products. Thus, the dehydrogenative coupling of *N*-benzyl-1,2-diaminobenzene with different electron donating and electron withdrawing benzyl alcohols were investigated to afford 1-benzyl-2-aryl-*1H*-benzo[*d*]imidazole derivatives (**Table 3.4**). It was observed that the benzyl alcohol having electron withdrawing group gave slightly lower yield compared to its electron donating analogue. Heterocyclic alcohol such as 2-pyridinemethanol gave 79% yields the desired product under the similar reaction condition (**Table 3.4**, **3.12f**).

Table 3.4: Synthesis of 1-benzyl-2-aryl-*1H*-benzo[*d*]imidazoles[a,b]



R_3 = Aryl, Hetero aryl



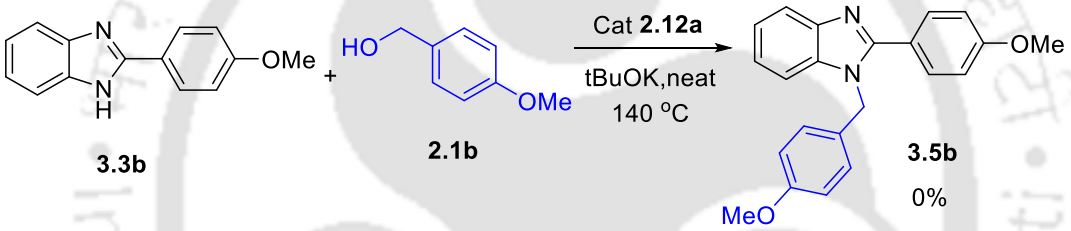
[a] Reaction conditions: *N*-benzyl-1,2-diaminobenzene (1.0 mmol), alcohol (1.3 mmol), KOH (0.27 mmol), cat **2.12a** (0.05 mmol), 20 h, under air, [b] isolated yield.

Interestingly, using this protocol, a wide range of 1-benzyl-2-aryl-*1H*-benzo[*d*]imidazole derivatives (**Table 3.4**, **3.12a-f**) were synthesized from N^1-benzylbenzene-1,2-diamine and primary alcohol. Various substituted benzylic alcohols such as electron withdrawing, electron donating and 2-pyridinemethanol reacted well with N^1-benzylbenzene-1,2-diamine to give good yield of the desired products.

3.3.3. Plausible reaction mechanism:

In addition, three possible mechanistic pathways are proposed which are depicted in the (**Scheme 3.10**). At first, the aldehyde was formed by the assistance of Mn-Pincer complex **2.12a** through dehydrogenative process. The diamine can react with the

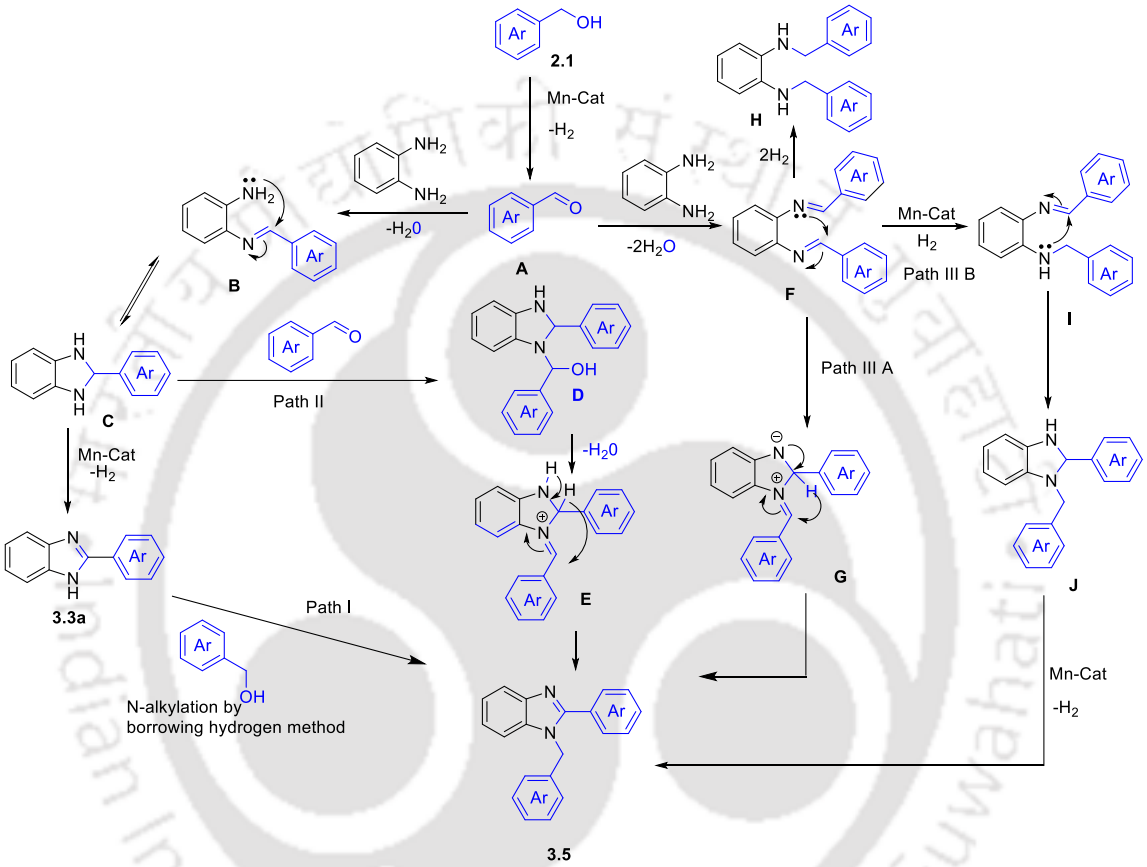
aldehyde **A** to form monoamine **B** which can further undergo nucleophilic addition to the imine carbon to form benzimidazoline intermediate **C**. This intermediate benzimidazoline **C** either undergoes oxidation leading to the formation of 2-substituted benzimidazole **3.3a** or reacts further with the aldehyde **A** to generate intermediate **D** which will finally transform to 1,2-disubstituted imidazole **3.5a** (Path II). There is also a possibility of *N*-alkylation of 2-substituted benzimidazole[32] by primary alcohol through borrowing hydrogen strategy, which will eventually transform **3.3a**, to **3.5a** (Path I). Furthermore, diamine also can lead to the formation of *bis*-imine **F** which undergoes rearrangement to afford 1,2-disubstituted benzimidazole or *via* the partial hydrogenation reaction (Path IIIA and IIIB).[23i] I tried to shed light on the mechanism by performing control experiment.



Scheme 3.9: Study of *N*-alkylation of 2-substituted benzimidazole by cat **2.12a.**

First of all, when 2-(4-methoxyphenyl)-*1H*-benzo[*d*]imidazole **3.3b** was treated with 4-methoxybenzyl alcohol **2.1** in presence of Cat **2.12a** and *t*BuOK, no *N*-alkylated product, 1-(4-methoxybenzyl)-2-(4-methoxyphenyl)-*1H*-benzo[*d*]imidazole **3.5b** was observed (**Scheme 3.9**). Thus, it is clear that the reaction is not following Path I. Mass spectral analysis of the crude reaction mixture of *o*-phenylenediamine and 4-methoxybenzyl alcohol after 2 h, showed peak which corresponds either to *bis*-imine (**F**, Ar= *p*-C_6H_4OMe) or 1,2-disubstituted benzimidazole **3.5** (as the molecular weight of both the compound are same) while the ion peak corresponds to intermediate (**D**, Ar = *p*-C_6H_4OMe) was not observed. The small amount of *bis*-amine **H** was isolated during the synthesis of 1-benzyl-2-aryl-*1H*-benzo[*d*]imidazole derivatives. Thus, there is also a possibility of partial reduction of *bis*-imine **F** to **I** which after cyclisation and dehydrogenation can lead to the formation of 1,2-disubstituted benzimidazole **3.5b**.

Thus, the mass spectral analysis and isolation *bis*-amine **H** indicate the involvement of *bis*-imine intermediate **F** in the formation of 1,2-disubstituted imidazole derivatives *via* Path IIIA or IIIB.

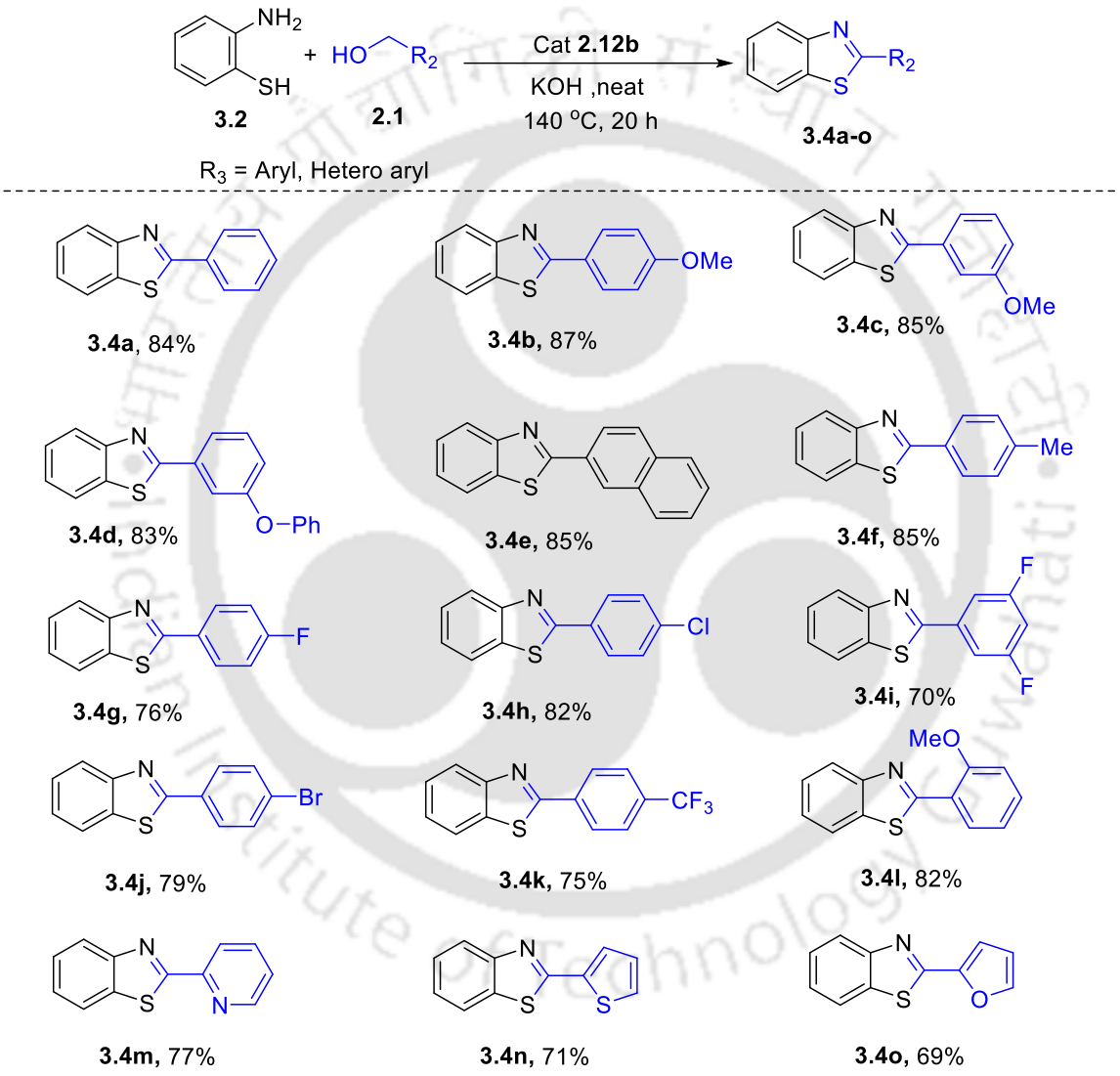


Scheme 3.10: Plausible mechanistic pathway.

Encouraged by this result, I wanted to apply this methodology to synthesize 2-substituted benzothiazole *via* dehydrogenative coupling of alcohols **2.1** and 2-aminothiophenol **3.2**. Cat **2.12b** gave slightly better yield (87%) of 2-(4-methoxyphenyl)benzo[*d*]thiazole compared to cat **2.12a** (80%). Thus, the scope of the reaction was further studied with cat **2.12b**. The substrate scope for the synthesis of benzothiazole is summarised in **Table 3.5**. Not only *m*- and *p*-substituted benzyl alcohols, but also *o*-substituted benzyl alcohol gave excellent yield of **3.4o**. It is interesting to note that halo substituted benzyl alcohol were well tolerated and the desired halo-substituted benzothiazoles **3.4g**-**3.4i** were

obtained in excellent yield, which could be further used for functionalization. Heteroaryl alcohols such as 2-thiophenemethanol, furfuryl alcohol and 2-pyridinemethanol worked succesfully under the optimized reaction condition and afforded good yield of expected products.

Table 3.5: Scope of the reaction to synthesize 2-substituted benzothiadazole[a,b]



[a] Reaction conditions: 2-aminothiphenol (1.0 mmol), alcohol (1.3 mmol), KOH (0.27 mmol), cat **2.12b** (0.05 mmol), 20 h, under air, [b] isolated yield.

3.4. Conclusion:

Herein, a facile synthesis of 1,2-disubstitituted benzimidazole, 2-substituted benzimidazole and benzothiazole derivatives *via* acceptorless dehydrogenation strategy is demonstrated. This method is operationally simple, convenient and the reaction conditions are amenable to scale-up. This method may be very useful in the synthesis of various natural products and may have application in drug discovery.

3.5. Experimental section:

General information:

All the chemicals were purchased from common commercial sources and used as received. All solvents were dried by using standard procedure. The preparation of catalyst was carried out under argon atmosphere with freshly distilled dry THF. All catalytic reactions were carried out with air and/or under argon atmosphere using dried glassware and standard syringe/septa techniques. DRX-400 Varian spectrometer and Bruker Avance III 600 and 400 spectrometers were used to record ^{1}H and ^{13}C NMR spectra using $CDCl_3$ and DMSO-d_6 as solvent and TMS as an internal standard. Chemical shifts (δ) are reported in ppm; spin-spin coupling constant (J) are expressed in Hz, and other data are reported as follows: s = singlet, d = doublet, t = triplet, m = multiplet, q = quartet, and br s = broad singlet. FTIR were collected on PerkinElmer IR spectrometer. Q-Tof ESI-MS instrument (model HAB 273) was used for recording mass spectra. SRL silica gel (100-200 mesh) was used for column chromatography.

A. General Experimental Procedure for the Synthesis of 1,2-Disubstituted Benzimidazoles:

A mixture of *o*-phenylenediamine (0.5 mmol), primary alcohol (1.7 mmol), *t*BuOK (1.0 mmol), and complex **2.12a** (0.05 mmol) was stirred at 140 °C for the specified time (20 - 44 h) under solvent-free conditions in an open system under argon. Then, the reaction mixture was cooled to room temperature and diluted with chloroform. Then, it was filtered through celite and the filtrate was concentrated under vacuum. The

residue obtained was further purified by column chromatography on silica gel using 10−30% ethyl acetate in hexane as an eluent.

B. General Experimental Procedure for the Synthesis of 2-Substituted Benzimidazoles:

A mixture of 1,2-diaminobenzene (1.0 mmol), primary alcohol (1.3 mmol), KOH (0.27 mmol), and catalyst **2.12a** (0.05 mmol) was stirred under neat condition at 140 °C for 20 h in open air. After cooling, MeOH was added to dilute the mixture and filtered through Celite. The filtrate was concentrated under reduced pressure, and the residue was purified by silica gel column chromatography using 10-30% ethyl acetate in hexane as an eluent to get pure compound.

C. General Experimental Procedure for the Synthesis of 1-Benzyl-2-aryl-*1H*-benzo[*d*]imidazoles:

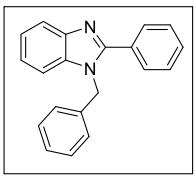
A mixture of *N*-benzyl-1,2- diaminobenzene (1.0 mmol), primary alcohol (1.3 mmol), KOH (0.27 mmol), and catalyst **2.12a** (0.05 mmol) was stirred under neat condition at 140 °C for 20 h in open air. After cooling, $CHCl_3$ was added to dilute the mixture and was then filtered through Celite. The filtrate was concentrated under vacuum, and the residue was purified by silica gel column chromatography using 10 - 30% ethyl acetate in hexane as an eluent to get pure compound.

D. General experimental procedure for the synthesis of benzothiazoles:

A mixture of 2-aminothiophenol (1.0 mmol), primary alcohol (1.27 mmol), KOH (0.27 mmol) and complex **2.12b** (0.04 mmol) was stirred at 140 °C for the specified time under solvent free condition under argon. Then the reaction mixture was cooled to room temperature and was diluted with chloroform. Then it was filtered through celite and the filtrate was concentrated under vacuum. The residue obtained was further purified by column chromatography on silica gel using 2%-5 % ethyl acetate in hexane as an eluent.

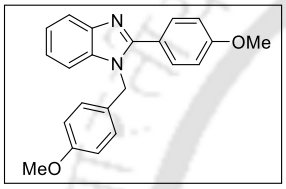
3.6. Characterization data of products:

1-Benzyl-2-phenyl-*1H*-benzo[*d*]imidazole (3.5a).[23a]



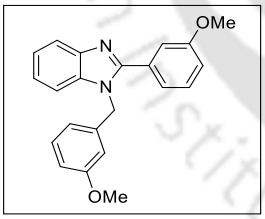
This compound was prepared according to the general procedure **A**. Reaction was completed after 20 h. White solid, (113 mg, 79% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.80 (d, *J* = 8.0 Hz, 1H), 7.62-7.60 (m, 2H), 7.40- 7.36 (m, 3H), 7.27-7.21 (m, 4H), 7.18-7.13 (m, 2H), 7.03 (d, *J* = 7.0 Hz, 2H), 5.39 (s, 2H); **^{13}C NMR** (150 MHz, $CDCl_3$) δ 154.3, 143.3, 136.5, 136.2, 130.2, 130.0, 129.4, 129.2, 128.9, 127.9, 126.1, 123.2, 122.8, 120.1, 110.7, 48.5.

1-(4-methoxybenzyl)-2-(4-methoxyphenyl)-*1H*-benzo[*d*]imidazole (3.5b).[23a]



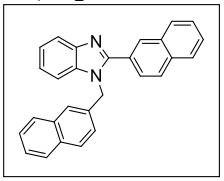
This compound was prepared according to the general procedure A. Reaction was completed after 20 h. White solid, (0.129mg, 83% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) *δ* 7.75 (d, *J* = 8.0 Hz, 1H), 7.55 (d, *J* = 8.7 Hz, 2H), 7.22-7.18 (m, 1H), 7.15-7.12 (m, 2H), 6.94 (d, *J* = 8.5 Hz, 2H), 6.88 (d, *J* = 8.7 Hz, 2H), 6.76 (d, *J* = 8.7 Hz, 2H), 5.29 (s, 2H), 3.75 (s, 3H), 3.69 (s, 3H); **^{13}C NMR** (150 MHz, $CDCl_3$) *δ* 161.0, 159.2, 154.2, 143.2, 136.2, 130.8, 128.6, 127.3, 122.8, 122.6, 122.5, 119.8, 114.5, 114.3, 110.5, 55.5, 55.4, 48.0.

1-(3-methoxybenzyl)-2-(3-methoxyphenyl)-*1H*-benzo[*d*]imidazole (3.5c).[33]



This compound was prepared according to the general procedure A. Reaction was completed after 20 h. White solid, (0.156mg, 91% yield). ^{1}H NMR (400 MHz, $CDCl_3$) *δ* 7.79 (d, *J* = 5.3 Hz, 1H), 7.29-7.23 (m, 2H), 7.19-7.16 (m, 5H), 6.95-6.96 (m, 1H), 6.75 (dd, *J* = 7.2 Hz, 1.14 Hz, 1H), 6.62 (d, *J* = 5.1 Hz, 1H), 6.58 (s,1H), 5.36 (s, 2H), 3.66 (s, 3H), 3.65 (s, 3H);^{13}C NMR (100 MHz, $CDCl_3$); *δ* 160.3, 159.8, 154.1, 143.1, 138.3, 136.3, 131.3, 130.3, 129.9, 123.2, 122.8, 121.5, 120.1, 118.3, 116.7, 114.1, 113.0, 111.9, 110.6, 55.4, 55.3, 48.4.

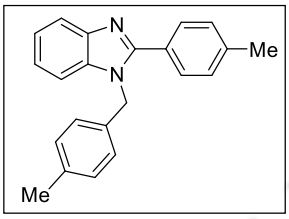
2-(naphthalen-2-yl)-1-(naphthalen-2-ylmethyl)-*1H*-benzo[*d*]imidazole (3.5d).[23a]



This compound was prepared according to the general procedure A. Reaction was completed after 20 h. White solid, (0.155mg, 81%

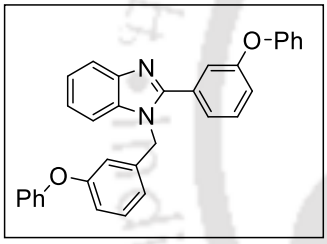
yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 (s, 1H), 7.88-7.75 (m, 6H), 7.67-7.63 (m, 2H), 7.49-7.39 (m, 5H), 7.30-7.16 (m, 4H), 5.59 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.4, 143.4, 136.5, 134.1, 133.8, 133.5, 133.0, 133.0, 129.4, 129.2, 128.7, 128.7, 128.0, 127.9, 127.4, 126.8, 126.8, 126.4, 126.2, 124.9, 124.0, 123.4, 123.0, 120.2, 110.7, 48.9.

1-(4-methylbenzyl)-2-(p-tolyl)-*1H*-benzo[*d*]imidazole (3.5e).[23a]



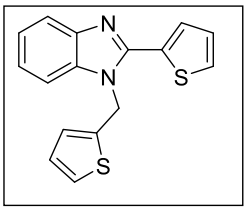
This compound was prepared according to the general procedure A. Reaction was completed after 20 h. White solid, (0.126mg, 81% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.78 (d, J = 8.0 Hz, 1H), 7.51 (d, J = 8.0 Hz, 2H), 7.23-7.11 (m, 5H), 7.06 (d, J = 7.9 Hz, 2H), 6.92 (d, J = 7.9 Hz, 2H), 5.33 (s, 2H), 2.33 (s, 3H), 2.26 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 154.5, 143.3, 140.1, 137.5, 136.2, 133.6, 129.8, 129.6, 129.3, 127.3, 126.0, 122.9, 122.7, 119.9, 110.6, 48.3, 21.6, 21.2.

1-(3-phenoxybenzyl)-2-(3-phenoxybenzyl)-*1H*-benzo[*d*]imidazole (3.5f).[34]



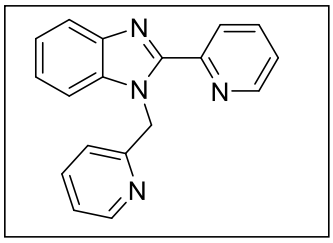
This compound was prepared according to the general procedure A. Reaction was completed after 20 h. Brown liquid, (0.186mg, 80% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.75-7.29 (m, 3H), 7.24-7.21 (m, 6H), 7.19-7.16 (m, 1H), 7.14-7.12 (m, 2H), 7.05-7.0 (m, 3H), 6.92 (dd, J = 8.6 Hz, 1.0 Hz, 2H), 6.86 (dd, J =8.6 Hz, 1.0 Hz, 2H), 6.80 (d, J = 6.7 Hz, 1H), 6.64 (d, J = 6.7 Hz, 2H); 5.31 (s, 2H); ^{13}C NMR (150 MHz, $CDCl_3$); δ 158.1, 157.9, 156.6, 153.5, 143.1, 138.3, 136.0, 131.7, 130.5, 130.3, 130.0, 129.9, 129.8, 123.9, 123.9, 123.8, 123.4, 122.9, 120.6, 120.2, 120.2, 119.4, 119.3, 119.2, 117.9, 116.3,110.6, 48.2.

2-(thiophen-2-yl)-1-(thiophen-2-ylmethyl)-*1H*-benzo[*d*]imidazole (3.5g).[23a]



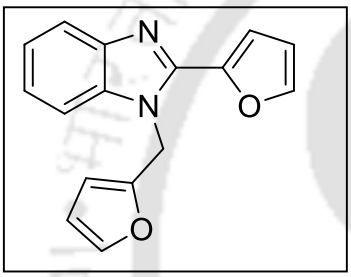
White solid, (0.121mg, 81% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.77-7.75 (m, 1H), 7.45 (dd, J = 5.4 Hz, 1.0 Hz, 1H), 7.40 (dd, J = 3.7 Hz, 1.0 Hz, 1H), 7.31-7.29 (m, 1H), 7.25-7.19 (m, 2H), 7.17 (dd, J = 5.1 Hz, 1.1 Hz, 1H), 7.08-7.06 (m, 1H), 6.88-6.87 (m, 1H), 6.80-6.79 (m, 1H), 5.63 (s, 2H); ^{13}C NMR (150 MHz, $CDCl_3$); δ 147.7, 143.1, 138.9, 136.0, 132.0, 129.1, 128.1, 128.1, 127.4, 125.6, 125.5, 123.4, 123.1, 120.1, 110.0, 44.2.

2-(pyridin-2-yl)-1-(pyridin-2-ylmethyl)-*1H*-benzo[*d*]imidazole (3.5h).[23a]



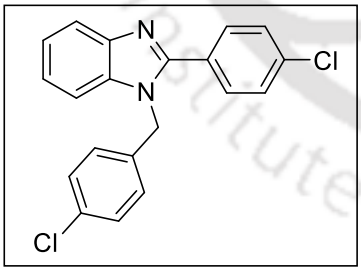
This compound was prepared according to the general procedure A. Reaction was completed after 44 h. White solid, (0.113mg, 79% yield). ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.50 (t, J = 5.0 Hz, 2H), 8.39 (d, J = 8.0 Hz, 1H), 7.80-7.74 (m, 2 H), 7.42-7.38 (dt, J = 7.7 Hz, 1.7 Hz, 1H), 7.29 (d, J = 7.9 Hz, 1H), 7.25-7.16 (m, 3H), 7.07-7.04 (m, 1H), 6.82 (d, J = 7.9 Hz, 1H), 6.22 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.6, 150.5, 150.0, 149.3, 148.8, 142.8, 137.0, 137.0, 136.9, 124.7, 124.0, 123.8, 123.1, 122.4, 121.1, 120.2, 110.9, 51.2.

2-(furan-2-yl)-1-(furan-2-ylmethyl)-*1H*-benzo[*d*]imidazole (3.5i).[23a]



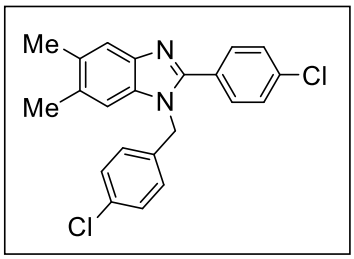
This compound was prepared according to the general procedure A. Reaction was completed after 26 h. White solid, (0.089mg, 67% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.72-7.69 (m, 1H), 7.57 (d, J =1.0 Hz, 1H), 7.44-7.40 (m, 1H), 7.25-7.18 (m, 3H), 7.14 (d, J = 3.4 Hz, 1H), 6.54-6.53 (m, 1H), 6.21-6.16 (m, 2H), 5.57 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$); δ 149.7, 145.5, 144.1, 144.0, 143.1, 142.8, 135.6, 123.4, 123.1, 119.9, 113.1, 112.2, 110.7, 110.1, 108.5, 41.8.

1-(4-chlorobenzyl)-2-(4-chlorobenzyl)-*1H*-benzo[*d*]imidazole (3.5j).[23a]



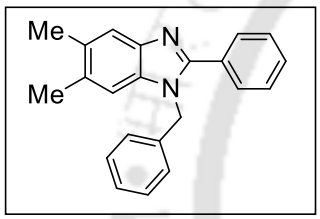
This compound was prepared according to the general procedure A. Reaction was completed after 20 h. White solid, (0.137mg, 78% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.79 (d, J =7.9 Hz, 1H), 7.51 (d, J = 8.5 Hz, 2H), 7.37 (d, J = 8.5 Hz, 2H), 7.30 - 7.22 (m, 3H), 7.20-7.12 (m, 2H), 6.95 (d, J = 8.4 Hz, 2H), 5.33 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.0, 143.2, 136.5, 136.1, 134.8, 134.0, 130.6, 129.5, 129.3, 128.5, 127.4, 123.6, 123.2, 120.3, 110.4, 47.9.

1-(4-chlorobenzyl)-2-(4-chlorophenyl)-5,6-dimethyl-*1H*-benzo[*d*]imidazole (3.5k).[35]



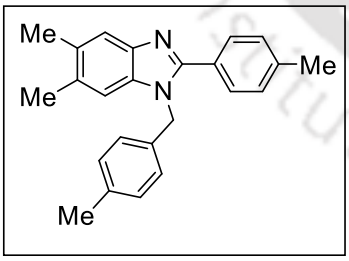
This compound was prepared according to the general procedure A. Reaction was completed after 20 h. White solid, (0.145mg, 76% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61 (s, 1H), 7.56 (d, J = 8.5 Hz, 2H), 7.41 (d, J = 8.5 Hz, 2H), 7.31 (d, J = 8.4 Hz, 2H), 7.01 (d, J = 8.2 Hz, 2H), 6.95 (s, 1H), 5.34 (s, 2H), 2.39 (s, 3H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.2, 141.9, 136.2, 135.1, 134.7, 133.9, 132.9, 132.2, 130.5, 129.5, 129.2, 128.8, 127.3, 120.3, 110.5, 47.8, 20.8, 20.5.

1-benzyl-5,6-dimethyl-2-phenyl-1H-benzo[d]imidazole (3.5l).[36]

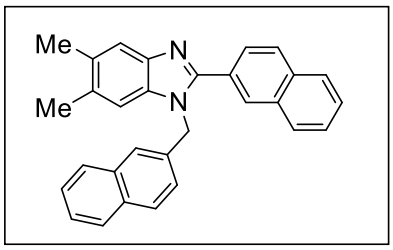


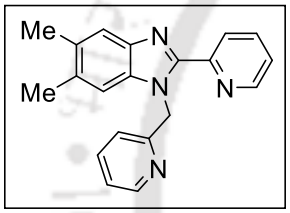
This compound was prepared according to the general procedure A. Reaction was completed after 20 h. White solid, (0.121mg, 77% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.67-7.65 (m, 2H), 7.63 (s, 1H), 7.45-7.40 (m, 3H), 7.35-7.28 (m, 3H), 7.10 (d, J = 7.1 Hz, 2H), 6.97 (s, 1H), 5.41 (s, 2H), 2.39 (s, 3H), 2.32 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 153.5, 141.9, 136.8, 134.8, 132.4, 131.7, 130.4, 129.8, 129.3, 129.2, 128.8, 127.8, 126.0, 120.1, 110.7, 48.4, 20.7, 20.5.

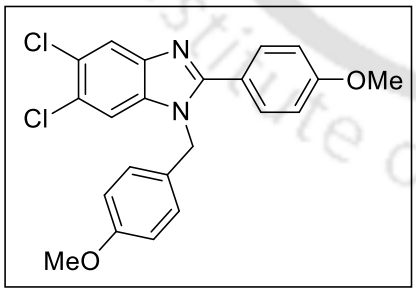
5,6-Dimethyl-1-(4-methylbenzyl)-2-(4-methylphenyl)-*1H*-benzimidazole (3.5m).[36]



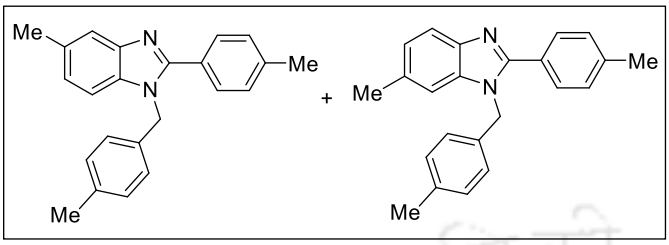
This compound was prepared according to the general procedure A. Reaction was completed after 20 h. White solid, (0.122mg, 72% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.61 (s, 1H), 7.55 (d, J = 8.0 Hz, 2H), 7.22 (d, J = 7.9 Hz, 2H), 7.13 (d, J = 7.9 Hz, 2H), 6.99 (d, J = 7.9 Hz, 2H), 6.96 (s, 1H), 5.36 (s, 2H), 2.39 (s, 3H), 2.38 (s, 3H), 2.34 (s, 3H), 2.32 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 153.6, 141.8, 139.8, 137.4, 134.8, 133.9, 132.1, 131.5, 129.8, 129.5, 129.2, 127.5, 125.9, 120.0, 110.7, 48.2, 21.5, 21.2, 20.7, 20.5.

5,6-dimethyl-2-(naphthalen-2-yl)-1-(naphthalen-2-ylmethyl)-*1H*-benzo[*d*]imidazole (3.5n).[36]  This compound was prepared according to the general procedure A. Reaction was completed after 20 h. White solid, (0.187mg, 91% yield). ^{1}H NMR ($CDCl_3$, 600 MHz) δ 8.18 (s, 1H), 7.90-7.82 (m, 5H), 7.74-7.70 (m, 3H), 7.57 (s, 1H), 7.53-7.46 (m, 4H), 7.33 (d, *J* = 8.5 Hz, 1H), 7.05 (s, 1H), 5.63(s, 2H), 2.42 (s, 3H), 2.33(s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 153.6, 142.1, 135.1, 134.4, 133.7, 133.6, 133.0, 132.9, 132.6, 131.9, 129.2, 129.1, 128.7, 128.6, 128.1, 127.9, 127.9, 127.7, 127.2, 126.7, 126.7, 126.3, 126.3, 124.7, 124.0, 120.2, 110.7, 48.8, 20.8, 20.5.

5,6-dimethyl-2-(pyridin-2-yl)-1-(pyridin-2-ylmethyl)-*1H*-benzo[*d*]imidazole (3.5o).[37]  This compound was prepared according to the general procedure A. Reaction was completed after 20 h. Orange solid, (0.137mg, 87% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.59 (m, 1H), 8.53 (m, 1H), 8.44 (d, *J* = 8.0 Hz, 1H), 7.81 (dt, *J* =7.7 Hz, 1.6 Hz, 1H), 7.62 (s, 1H), 7.47 (dt, *J* = 7.7 Hz, 1.7 Hz, 1H), 7.27-7.25 (m, 1H), 7.15-7.13 (m, 1H), 7.11 (s, 1H), 6.83 (d, *J* = 8.0 Hz, 1H), 6.25 (s, 2H), 2.38 (s, 3H), 2.33 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 157.8, 150.6, 149.2, 149.2, 148.7, 141.4, 137.0, 136.9, 135.5, 133.3, 132.1, 124.4, 123.7, 122.3, 120.9, 120.1, 110.8, 51.2, 20.8, 20.5.

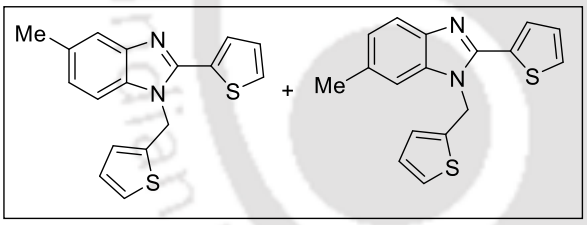
5,6-dichloro-1-(4-methoxybenzyl)-2-(4-methoxyphenyl)-*1H*-benzo[*d*]imidazole (3.5p).[23h]  This compound was prepared according to the general procedure A. Reaction was completed after 20 h. White solid, (0.122mg, 64% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 (s, 1H), 7.62 (d, *J* = 8.6 Hz, 2H), 7.28 (s, 1H), 6.99 (t, *J* = 8.2 Hz, 4H), 6.88 (d, *J* =8.6 Hz, 2H), 5.34 (s, 2H), 3.86 (s, 3H), 3.80 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 161.4, 159.5, 156.2 142.7, 135.5, 130.8, 127.6, 127.2, 126.7, 126.7, 121.7, 121.0, 114.8, 114.5, 111.9, 55.6, 55.5, 48.2.

5-methyl-1-(4-methylbenzyl)-2-(p-tolyl)-*1H*-benzo[*d*]imidazole & 6-methyl-1-(4-methylbenzyl)-2-(p-tolyl)-*1H*-benzo[*d*]imidazole (1:1) (3.5q & 3.5q′).[29]

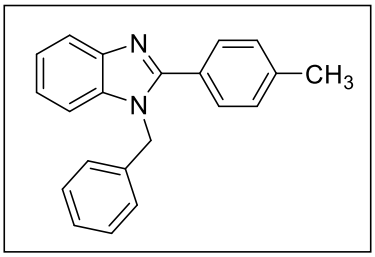


This compound was prepared according to the general procedure A. Reaction was completed after 20 h. White solid, (0.127mg, 78% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.72 (d, J = 8.2 Hz, 1H), 7.63 (s, 1H), 7.58-7.55 (m, 4H), 7.25-7.22 (m, 4H), 7.15-7.11 (m, 5H), 7.07-7.02 (m, 2H), 7.00-6.98 (m, 5H), 5.36 (s, 4H), 2.48 (s, 3H), 2.42 (s, 3H), 2.39 (s, 3H), 2.39 (s, 3H), 2.34 (s, 3H), 2.33 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 154.3, 154.0, 143.5, 141.3, 140.0, 139.9, 137.5, 137.4, 136.5, 134.3, 133.7, 133.7, 133.0, 132.3, 129.8, 129.8, 129.5, 129.5, 129.2, 129.2, 127.4, 126.0, 125.9, 124.4, 124.3, 119.7, 119.4, 110.4, 110.1, 48.3, 48.1, 22.0, 21.7, 21.5, 21.5, 21.2, 21.2.

5-methyl-2-(thiophen-2-yl)-1-(thiophen-2-ylmethyl)-*1H*-benzo[*d*]imidazole & 6-methyl-2-(thiophen-2-yl)-1-(thiophen-2-ylmethyl)-*1H*-benzo[*d*]imidazole (3.5r & 3.5r′).[29] This compound was prepared according to the general procedure A. Reaction was completed after 20 h. Yellow solid, (0.091mg, 59% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.70 (d, J = 8.2 Hz, 1H), 7.61 (s, 1H), 7.51-7.49 (m, 2H), 7.45-7.42 (m, 2H), 7.26-7.23 (m, 3H), 7.15-7.09 (m, 5H), 6.96-6.93 (m, 2H), 6.86-6.85 (m 2H), 5.67 (s, 2H), 5.66 (s, 2H), 2.48 (s, 3H), 2.47 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 147.6, 147.2, 143.4, 141.2, 139.1, 139.1, 136.2, 134.1, 133.6, 132.9, 132.1, 132.1, 128.9, 128.8, 128.0, 128.0, 127.8, 127.4, 127.3, 125.5, 125,5, 125.4, 124.9, 124.8, 119.8, 119.5, 109.8, 109.5, 44.2, 44.1, 22.1, 21.7.

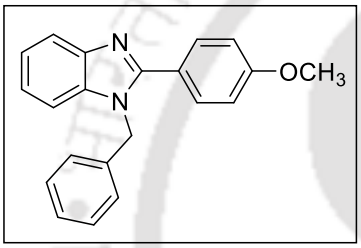


1-benzyl-2-(p-tolyl)-*1H*-benzo[*d*]imidazole (3.12a).[23b]



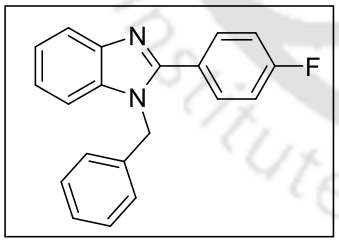
This compound was prepared according to the general procedure C. Reaction was completed after 20 h. White solid, (0.201 mg, 67% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, J = 8.0 Hz, 1H), 7.49 (d, J = 8.1 Hz, 2H), 7.25-7.19 (m, 4H), 7.16 (d, J = 8.0 Hz, 2H), 7.13-7.09 (m, 2H), 7.01 (d, J = 6.8 Hz, 2H), 5.35 (s, 2H), 2.31 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.4, 143.3, 140.1, 136.6, 136.2, 129.5, 129.2, 129.1, 127.8, 127.2, 126.2, 123.0, 122.7, 120.0, 110.5, 48.5, 21.5**.**

1-benzyl-2-(4-methoxyphenyl)-*1H*-benzo[*d*]imidazole (3.12b).[23b]



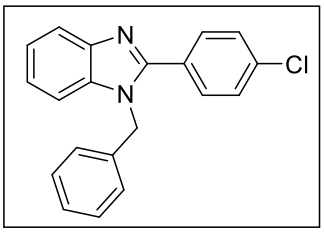
This compound was prepared according to the general procedure C. Reaction was completed after 20 h. White solid, (0.219mg, 70% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.86 (d, J = 8.0 Hz, 1H), 7.63 (d, J = 8.8 Hz, 2H), 7.34- 7.28 (m, 4H), 7.23-7.18 (m, 2H), 7.11(d, J = 7.4 Hz, 2H), 6.96 (d, J = 8.8 Hz, 2H), 5.43 (s, 2H), 3.83 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 161.0, 154.2, 143.2, 136.6, 136.2, 130.7, 129.1, 127.8, 126.0, 122.8, 122.6, 122.4, 119.8, 114.3, 110.5, 55.4, 48.4.

1-benzyl-2-(4-fluorophenyl)-*1H*-benzo[*d*]imidazole (3.12c).[23b]



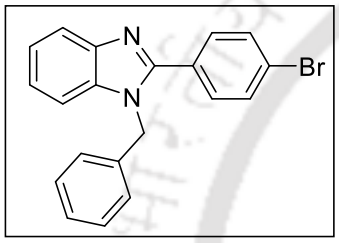
This compound was prepared according to the general procedure C. Reaction was completed after 20 h. White solid, (0.184mg, 61% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.86 (d, J = 8.0 Hz, 1H), 7.68-7.65(m, 2H), 7.35-7.31(m, 4H), 7.26-7.22 (m, 2H), 7.14 (t, J = 8.6 Hz, 2H), 7.09 (d, J = 7.2, 2H), 5.43 (s, 2H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 163.8 (d, J=249 Hz), 153.3, 143.1, 136.3, 136.2, 131.4, 131.3, 129.3, 128.0, 126.3 (d, J=3 Hz), 126.0, 123.1 (d, J=56 Hz), 120.1, 116.1 (d, J=21 Hz), 110.6, 48.4.

1-benzyl-2-(4-chlorophenyl)-*1H*-benzo[*d*]imidazole (3.12d).[23b]



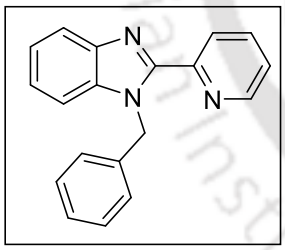
This compound was prepared according to the general procedure C. Reaction was completed after 20 h. White solid, (0.202mg, 64% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.79 (d, J = 8.0 Hz, 1H), 7.55 (d, J = 8.6 Hz, 2H), 7.35 (d, J = 8.6 Hz, 2H), 7.29-7.23 (m, 4H), 7.20-7.15 (m, 2H), 7.01 (d, J = 6.5 Hz, 2H), 5.36 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.1, 143.2, 136.3, 136.3, 136.3, 130.7, 129.3, 129.2, 128.7, 128.1, 126.0, 123.4, 123.0, 120.2, 110.6, 48.5.

1-benzyl-2-(4-bromophenyl)-*1H*-benzo[*d*]imidazole (3.12e).[23b]



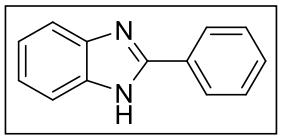
This compound was prepared according to the general procedure C. Reaction was completed after 20 h. White solid, (0.240mg, 66% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86 (d, J = 8.0 Hz, 1H), 7.59-7.53(m, 4H), 7.36-7.30(m, 4H), 7.27-7.21(2H), 7.08 (d, J = 6.5 Hz, 2H), 5.42 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.1, 143.2, 136.3, 132.1, 130.8, 129.3, 129.1, 128.0, 126.0, 124.6, 123.5, 123.0, 120.2, 110.6, 48.5.

1-benzyl-2-(pyridin-2-yl)-*1H*-benzo[*d*]imidazole (3.12f).[38]



This compound was prepared according to the general procedure C. Reaction was completed after 20 h. White solid, (0.226mg, 79% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.50 (d, J = 4.7 Hz, 1H), 8.33 (d, J = 8.0 Hz, 1H), 7.77 (d, J = 8.1 Hz, 1H), 7.69 (t, J = 7.9 Hz, 1H), 7.25-7.05 (m, 9H), 6.08 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 150.6, 150.0, 148.7, 142.8, 137.5, 136.9, 136.9, 128.6, 127.4, 126.9, 124.7, 123.9, 123.6, 122.9, 120.2, 110.8, 49.0.

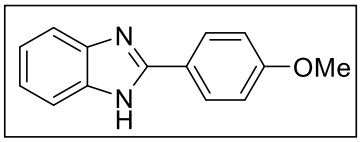
2-phenyl-*1H*-benzo[*d*]imidazole (3.3a).[23f]



This compound was prepared according to the general procedure B. Reaction was completed after 20 h. Pale yellow solid, (0.149mg, 77% yield). ^{1}H NMR (600 MHz, DMSO-d_6) δ 12.95 (br s, 1H), 8.19 (d, J = 7.1 Hz, 2H), 7.67(d, J = 7.0 Hz, 1H), 7.57-7.54 (m, 3H), 7.50-

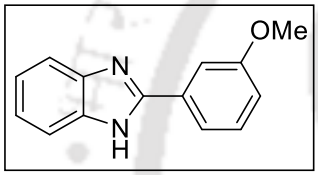
7.48 (m, 1H), 7.23-7.19 (m, 2H), ^{13}C NMR (150 MHz, DMSO-d_6) δ 151.3, 143.8, 135.0, 130.2, 129.9, 129.0, 126.5, 122.6, 121.8, 118.9, 111.4.

2-(4-methoxyphenyl)-*1H*-benzo[*d*]imidazole (3.3b).[23f]



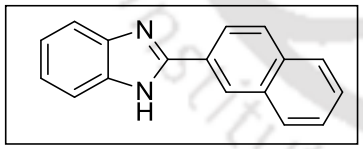
This compound was prepared according to the general procedure B. Reaction was completed after 20 h. White solid, (0.184mg, 82% yield). ^{1}H NMR (600 MHz, DMSO-d_6) δ 12.76 (s, 1H), 8.11 (d, J = 8.8 Hz, 2H), 7.61 (d, J = 7.5 Hz, 1H), 7.49 (d, J = 7.5 Hz, 1H), 7.19 - 7.14 (m, 2H), 7.11(d, J = 8.8 Hz, 2H), 3.84 (s, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 160.6, 151.4, 143.9, 135.0, 128.1, 122.7, 122.2, 121.5, 118.5, 114.4, 111.1, 55.4**.**

2-(3-methoxyphenyl)-*1H*-benzo[*d*]imidazole (3.3c).[23f]



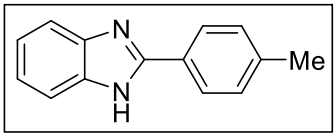
This compound was prepared according to the general procedure B. Reaction was completed after 20 h. White solid, (0.189mg, 85% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.90 (s, 1H), 7.77-7.75 (m, 2H), 7.67 (d, J = 7.4 Hz, 1H), 7.53 (d, J = 7.4 Hz, 1H), 7.46 (t, J = 7.6 Hz, 1H), 7.24-7.17 (m, 2H), 7.07-7.05 (m, 1H), 3.86 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 159.6, 151.1, 143.7, 135.0, 131.5, 130.1, 122.63, 121.7, 118.9, 118.8, 115.9, 111.4, 111.3, 55.3.

2-(naphthalen-2-yl)-*1H*-benzo[*d*]imidazole (3.3d).[23f]



This compound was prepared according to the general procedure B. Reaction was completed after 20 h. Yellow solid, (0.179mg, 73% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 13.08 (s, 1H), 8.75 (s, 1H), 8.32 (d, J = 8.0 Hz, 1H), 8.09-7.99 (m, 3H), 7.70 (d, J = 6.6 Hz, 1H), 7.61-7.59 (m, 3H), 7.23 (s, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 151.3, 143.9, 135.2, 133.5, 132.8, 128.6, 128.5, 127.8, 127.6, 127.1, 126.9, 125.8, 123.9, 122.7, 121.8, 118.9, 111.4.

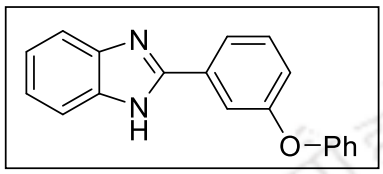
2-(p-tolyl)-*1H*-benzo[*d*]imidazole (3.3e).[23f]



This compound was prepared according to the general procedure B. Reaction was completed after 20 h. White

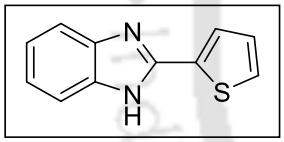
solid, (0.169mg, 81% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.82 (s, 1H), 8.07 (d, J = 8.0 Hz, 2H), 7.64 (d, J = 6.1 Hz, 1H), 7.51 (d, J = 6.1 Hz, 1H), 7.35 (d, J = 8.0 Hz, 2H), 7.18 (d, J = 3.8 Hz, 2H), 2.38 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 151.4, 143.8, 139.6, 135.0, 129.5, 127.5, 126.4, 122.3, 121.6, 118.7, 111.2, 21.0.

2-(3-phenoxyphenyl)-*1H*-benzo[*d*]imidazole (3.3f).[39]



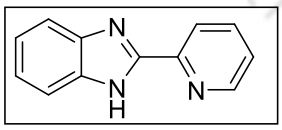
This compound was prepared according to the general procedure B. Reaction was completed after 20 h. Yellow solid, (0.246mg, 86% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.94 (s, 1H), 7.96 (d, J = 7.6 Hz, 1H), 7.81 (s, 1H), 7.65 (d, J = 7.6 Hz, 1H), 7.57 (t, J = 8.0 Hz, 1H), 7.52 (d, J = 7.6 Hz, 1H), 7.45 (t, J = 8.0 Hz, 2H), 7.24-7.11 (m, 6H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 157.4, 156.3, 150.5, 143.6, 135.0, 132.0, 130.8, 130.2, 123.9, 122.7, 121.8, 121.4, 120.0, 119.0, 119.0, 116.0, 111.4.

2-(thiophen-2-yl)-*1H*-benzo[*d*]imidazole (3.3g).[23f]



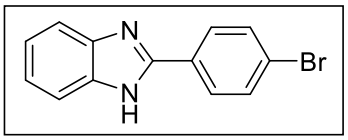
This compound was prepared according to the general procedure B. Reaction was completed after 20 h. Yellow solid, (0.150mg, 75% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.94 (s, 1H), 7.83 (d, J = 3.6 Hz, 1H), 7.72 (d, J = 4.9 Hz, 1H), 7.55 (s, 2H), 7.24 -7.18 (m, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 147.0, 133.7, 128.8, 128.3, 126.7, 122.6, 122.5, 121.9, 118.5, 111.3, 111.1.

2-(pyridin-2-yl)-*1H*-benzo[*d*]imidazole (3.3h).[23f]



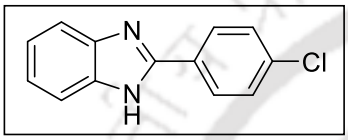
This compound was prepared according to the general procedure B. Reaction was completed after 20 h. Yellow solid, (0.176mg, 90% yield).^{1}H NMR (400 MHz, DMSO-d_6) δ 13.10 (s, 1H), 8.72 (d, J = 4.7 Hz, 1H), 8.33 (d, J = 7.9 Hz, 1H), 7.99 (dt, J = 7.8 Hz, 1.5 Hz, 1H), 7.70 (d, J = 7.6 Hz, 1H), 7.56-7.50 (m, 2H), 7.26-7.19 (m, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 150.8, 149.4, 148.5, 143.9, 137.6, 134.9, 124.7, 123.2, 121.9, 121.4, 119.3, 112.1.

2-(4-bromophenyl)-*1H*-benzo[*d*]imidazole (3.3i).[23f]



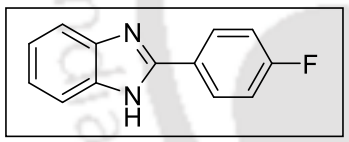
This compound was prepared according to the general procedure B. Reaction was completed after 20 h. Yellow solid, (0.219mg, 80% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.99 (s, 1H), 8.12 (d, J = 8.5 Hz, 2H), 7.76 (d, J = 8.5 Hz, 2H), 7.67 (d, J = 7.0 Hz, 1H), 7.53 (d, J = 6.84 Hz, 1H), 7.22 (s, 2H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 150.2, 143.7, 135.0, 132.0, 129.4, 128.4, 123.3, 122.8, 121.9, 119.0, 111.4.

2-(4-chlorophenyl)-*1H*-benzo[*d*]imidazole (3.3j).[23f]



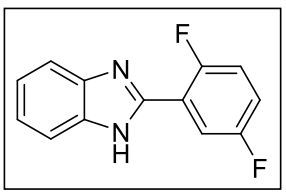
This compound was prepared according to the general procedure B. Reaction was completed after 20 h. White solid, (0.187mg, 82% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.99 (s, 1H), 8.19 (d, J = 8.4 Hz, 2H), 7.62-7.61 (m, 4H), 7.23-7.20 (m, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 150.2, 143.7, 134.6, 129.1, 129.1, 128.2, 122.7, 122.1, 119.0, 111.5.

2-(4-fluorophenyl)-*1H*-benzo[*d*]imidazole (3.3k).[23f]



This compound was prepared according to the general procedure B. Reaction was completed after 20 h. Yellow solid, (0.151mg, 71% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.92 (s, 1H), 8.25-7.21 (m, 2H), 7.67 (d, J = 7.2 Hz, 1H), 7.53 (d, J = 7.3 Hz, 1H), 7.40 (t, J = 8.9 Hz, 2H), 7.24-7.17 (m, 2H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 162.6 (d, J =246 Hz), 150.4, 143.8, 135.0, 128.7 (d, J =9 Hz), 126.8 (d, J =3 Hz), 122.6, 121.7, 118.9, 116.0 (d, J =22 Hz), 111.3.

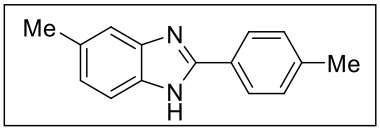
2-(2,5-difluorophenyl)-*1H*-benzo[*d*]imidazole (3.3l).[29]



This compound was prepared according to the general procedure B. Reaction was completed after 20 h. Orange liquid, (0.143mg, 62% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.70 (s, 1H), 8.00-7.96 (m, 1H), 7.66 (s, 2H), 7.54-7.48 (m, 1H), 7.44-7.39 (m, 1H), 7.26-7.24 (m, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 158.3 (dd, J = 239 Hz, 2 Hz), 155.9 (d, J = 245 Hz, 2 Hz), 145.3 (t, 3 Hz), 122.8-122.3 (m), 119.5 (dd, J = 15, 9

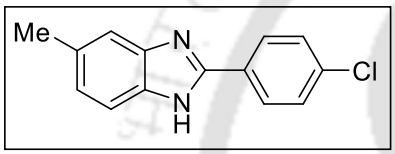
Hz), 118.71, 118.62, 118.58, 118.49, 118.46, 118.37, 118.34, 118.25, 115.8 (dd, J = 23 Hz, 3Hz).

5-methyl-2-(p-tolyl)-*1H*-benzo[*d*]imidazole (3.3m).[40]



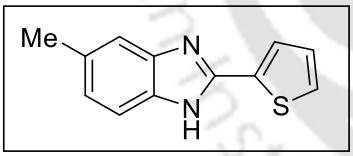
This compound was prepared according to the general procedure B. Reaction was completed after 20 h. White solid, (0.162mg, 74% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.99 (d, J = 8.0 Hz, 2H), 7.48 (d, J = 7.6 Hz, 1H), 7.34 (s, 1H), 7.17 (d, J = 8.0 Hz, 2H), 7.03 (d, J = 8.2 Hz, 1H), 2.42 (s, 3H), 2.33 (s, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 151.2, 139.5, 131.3, 129.6, 127.6, 126.5, 126.4, 123.5, 117.9, 111.3, 21.4, 21.1.

2-(4-chlorophenyl)-5-methyl-*1H*-benzo[*d*]imidazole (3.3n).[40]



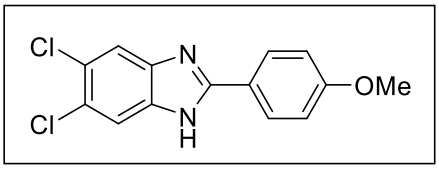
This compound was prepared according to the general procedure B. Reaction was completed after 20 h. White solid, (0.180mg, 74% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.16 (d, J = 8.1 Hz, 2H), 7.60 (d, J = 8.1 Hz, 2H), 7.51-7.31 (m, 2H), 7.03 (d, J = 7.0 Hz, 1H), 2.42 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 149.8, 141.9, 135.3, 134.3, 132.1, 129.2, 129.0, 128.0, 123.5, 118.6, 111.1, 21.3.

5-methyl-2-(thiophen-2-yl)-*1H*-benzo[*d*]imidazole (3.3o).[41]



This compound was prepared according to the general procedure B. Reaction was completed after 20 h. White solid, (0.148mg, 69% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.79 (s, 1H), 7.81 (d, J = 3.2 Hz, 1H), 7.69 (d, J = 4.8 Hz, 1H), 7.47-7.29 (m, 2H), 7.21 (t, J = 4.7 Hz, 1H), 7.01 (s, 1H), 2.41 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 146.6, 141.7, 135.0, 133.9, 132.0, 128.4, 128.2, 126.4, 123.3, 118.1, 110.8, 21.3.

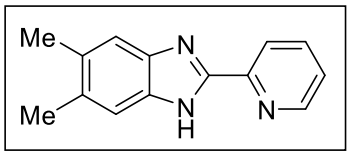
5,6-dichloro-2-(4-methoxyphenyl)-*1H*-benzo[*d*]imidazole (3.3p).[40]



This compound was prepared according to the general procedure B. Reaction was completed after 20 h. White solid, (0.223mg, 76% yield). ^{1}HNMR (400 MHz, DMSO-d_6) δ 13.07 (s, 1H), 8.09 (d, J =

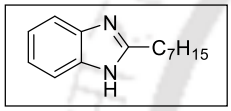
8.8 Hz, 2H), 7.78 (s, 2H), 7.11 (d, *J* = 8.9 Hz, 2H), 3.83 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 161.1, 154.0, 128.4, 124.1, 121.8, 114.5, 55.4.

5,6-dimethyl-2-(pyridin-2-yl)-*1H*-benzo[*d*]imidazole (3.3q).[42]



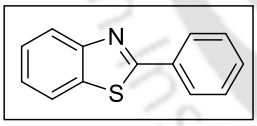
This compound was prepared according to the general procedure B. Reaction was completed after 20 h. Orange solid, (0.194mg, 87% yield). ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.85 (s, 1H), 8.68 (d, *J* = 4.7 Hz, 1H), 8.28 (d, *J* = 7.9 Hz, 1H), 7.96 (dt, *J*= 7.6 Hz, 1.52 Hz 1H), 7.46 (t, *J* = 6.2 Hz, 2H), 7.31 (s, 1H), 2.31 (s, 6H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 149.9, 149.3, 148.8, 142.6, 137.4, 133.5, 132.0, 130.3, 124.4, 121.2, 119.2, 112.0, 20.1, 20.1.

2-heptyl-*1H*-benzo[*d*]imidazole (3.3r).[26]



This compound was prepared according to the general procedure B. Reaction was completed after 72 h. White solid, (0.076mg, 35% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48-7.46 (m, 2H), 7.17-7.11 (m, 2H), 2.88(t, *J* = 7.8 Hz, 2H), 1.82-1.74 (m, 2H), 1.30-1.22 (m, 2H), 1.20-1.11 (m, 6H), 0.74 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.8, 138.7, 122.2, 114.7, 31.8, 29.5, 29.4, 29.1, 28.5, 22.7, 14.1.

2-Phenylbenzo[*d*]thiazole (3.4a) [24a]



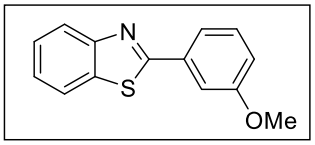
This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (177 mg, 84%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11-8.08 (m, 3H), 7.90 (d, *J* = 8.0 Hz, 1H), 7.51-7.48 (m, 4H), 7.40 - 7.37 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.2, 154.3, 135.2, 133.8, 131.1, 129.1, 127.7, 126.4, 125.3, 123.4, 121.7.

2-(4-methoxyphenyl)benzo[*d*]thiazole (3.4b) [24a]

This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (210 mg, 87%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05-8.03 (m,

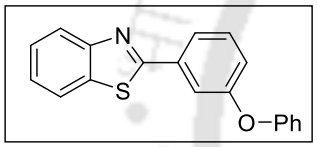
3H), 7.87 (d, *J* = 7.9 Hz, 1H), 7.47 (td, *J* = 7.7, 1.04 Hz, 1H), 7.35 (td, *J* = 7.6, 0.9 Hz, 1H), 7.02-6.98 (m, 2H), 3.88 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.0, 162.1, 154.4, 135.0, 129.2, 126.6, 126.3, 124.9, 123.0, 121.6, 114.5, 55.6.

2-(3-methoxyphenyl)benzo[*d*]thiazole (3.4c) [24a]



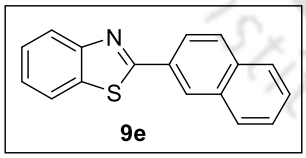
This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (205 mg, 85%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 (d, *J* = 8.2 Hz 1H), 7.89 (d, *J* = 8.0 Hz, 1H), 7.67 (t, *J* = 2.3 Hz, 1H), 7.64 (d, *J* = 7.7 Hz, 1H), 7.49 (td, *J* = 7.7, 1.0 Hz 1H), 7.41 - 7.37 (m, 2H), 7.03 (dd, *J* = 8.2, 2.5 Hz 1H) 3.91 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.1, 160.2, 154.2, 135.2, 135.0, 130.2, 126.4, 125.3, 123.4, 121.7, 120.4, 117.5, 112.1, 55.6.

2-(3-phenoxyphenyl)benzo[*d*]thiazole (3.4d) [24b]



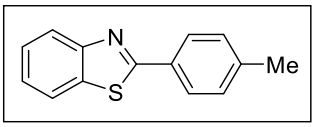
This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (252 mg, 83%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06 (d, *J* = 8.2 Hz, 1H), 7.89 (d, *J* = 8.0 Hz, 1H), 7.83 - 7.89 (m, 2H), 7.51 - 7.43 (m, 2H), 7.41 - 7.36 (m, 3H), 7.17 - 7.12 (m, 2H) ,7.10-7.08 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.4, 158.0, 156.9, 154.2, 135.5, 135.2, 130.5, 130.0, 126.5, 125.5, 123.8, 123.5, 122.5, 121.7, 121.3, 119.2, 117.8.

2-(naphthalen-2-yl)benzo[*d*]thiazole (3.4e) [24a]



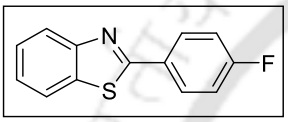
This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (222 mg, 85%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.57 (s, 1H), 8.22 (dd, *J* = 8.4, 1.6 Hz, 1H), 8.13 (d, *J* = 8.2 Hz, 1H), 7.98 - 7.87 (m, 4H), 7.56 - 7.50 (m, 3H), 7.42-7.38 (t, *J* = 8.0, Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.2, 154.4, 135.2, 134.7, 133.3, 131.1, 128.9, 128.0, 127.7, 127.6, 127.0, 126.5, 125.4, 124.6, 123.4, 121.8.

2-(p-tolyl)benzo[*d*]thiazole (3.4f) [24c]



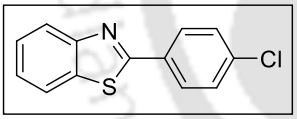
This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (192 mg, 85%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06 (d, J = 8.2 Hz, 1H), 7.99 (d, J = 8.1 Hz, 2H), 7.89 (d, J = 8.0 Hz, 1H), 7.48 (t, J = 8.2 Hz, 1H), 7.37(t, J = 7.4 Hz, 1H), 7.30 (d, J = 8.0 Hz, 2H), 2.43 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.4, 154.3, 141.6, 135.1, 131.1, 129.9, 127.6, 126.4, 125.1, 123.2, 121.7, 21.7.

2-(4-fluorophenyl)benzo[*d*]thiazole (3.4g) [24a]



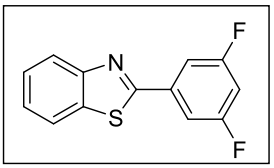
This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (174 mg, 76%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.10 - 8.05 (m, 3H), 7.89 (d, J = 7.8 Hz, 1H), 7.49 (t, J = 8.2 Hz, 1H), 7.38 (t, J = 8.0 Hz, 1H), 7.18 (t, J = 8.6 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.9, 165.8, 163.3, 154.2, 135.2, 130.1 (d, J = 3 Hz), 129.6 (d, J = 9 Hz), 126.5, 125.4, 123.3, 121.7, 121.6, 116.3 (d, J = 22 Hz).

2-(4-chlorophenyl)benzo[*d*]thiazole (3.4h) [24a]



This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (201 mg, 82%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.07 (d, J = 8.2 Hz, 1H), 8.03 - 8.01 (m, 2H), 7.90 (d, J = 8.0 Hz, 1H), 7.52 - 7.45 (m, 3H), 7.42 - 7.36 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.8, 154.2, 137.2, 135.2, 132.2, 129.4, 128.8, 126.6, 125.5, 123.4, 121.8.

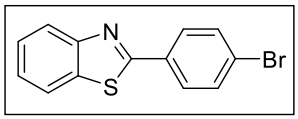
2-(3,5-difluorophenyl)benzo[*d*]thiazole (3.4i) [24d]



This compound was prepared according to the general procedure D. Reaction was completed after 20 h. Yellow solid (173 mg, 70%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (d, J = 8.1 Hz, 1H), 7.91 (d, J = 7.9 Hz, 1H), 7.62 (d, J = 6.0 Hz, 2H), 7.52 (t, J = 7.5 Hz, 1H), 7.42 (t, J = 7.5 Hz, 1H), 6.93 (t, J = 8.6 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.2 (t, J = 3 Hz), 163.4 (d, J = 248 Hz), 163.3 (d, J = 248 Hz), 154.0, 136.7 (t, J = 10

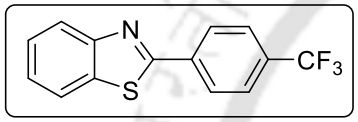
Hz), 135.3, 126.8, 126.0, 123.8, 121.9, 110.6 (d, *J* = 27 Hz), 110.5 (d, *J* = 12 Hz), 106.2 (t, *J* = 25 Hz).

2-(4-bromophenyl)benzo[*d*]thiazole (3.4j) [24c]



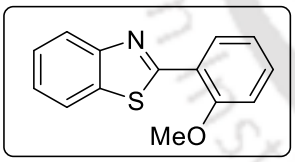
This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (229 mg, 79%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.07 (d, *J* = 8.2 Hz, 1H), 7.93 - 7.86 (m, 3H), 7.60 - 7.59 (m, 2H), 7.50 (t, *J* = 7.6 Hz, 1H), 7. 40 (t, *J* = 7.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.7, 154.1, 135.1, 132.6, 132.3, 128.9, 126.6, 125.5, 125.5, 123.4, 121.7.

2-(4-(trifluoromethyl)phenyl)benzo[*d*]thiazole (3.4k) [24a]



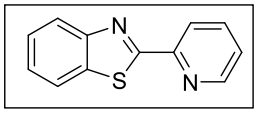
This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (209 mg, 75%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.18 (d, *J* = 8.1 Hz, 2H), 8.10 (d, *J* = 8.2 Hz, 1H), 7.90 (d, *J* = 8.0 Hz, 1H), 7.73 (d, *J* = 8.2 Hz, 2H), 7.52 (t, *J* = 7.4 Hz, 1H), 7.42 (t, *J* = 7.4 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.1, 154.1, 136.8, 135.3, 132.5, (q, *J* = 33 Hz), 127.8, 126.8, 126.1, (q, *J* = 33 Hz), 125.9, 123.9 (q, *J* = 270 Hz), 123.7, 121.8.

2-(2-methoxyphenyl)benzo[*d*]thiazole (3.4l) [24e]



This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (198 mg, 82%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.54 (dd, *J* = 7.8, 1.4 Hz, 1H), 8.10 (d, *J* = 8.1 Hz, 1H), 7.93 (d, *J* = 7.9 Hz, 1H), 7.51 - 7.41 (m, 2H), 7.39 - 7.36 (m, 1H), 7.15 - 7.13 (m, 1H), 7.07 (d, *J* = 8.3 Hz, 1H), 4.06 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 163.3, 157.3, 152.2, 136.2, 131.9, 129.6, 126.0, 124.7, 122.9, 122.3, 121.3, 121.3, 111.8, 55.8.

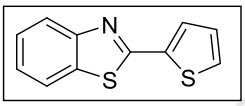
2-(pyridin-2-yl)benzo[*d*]thiazole (3.4m) [24c]



This compound was prepared according to the general procedure D. Reaction was completed after 20 h. Yellow solid (163 mg, 77%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.67 (d, *J* = 4.8 Hz, 1H),

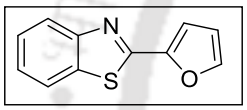
8.36 (d, *J* = 7.9 Hz, 1H), 8.09 (d, *J* = 8.2 Hz, 1H), 7.95 (d, *J* = 7.9 Hz, 1H), 7.82 (td, *J* = 7.8, 1.6 Hz, 1H), 7.51 - 7.47 (m, 1H), 7.41 (d, *J* = 7.9 Hz, 1H), 7.40 - 7.34 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.5, 154.4, 151.5, 149.7, 137.1, 136.2, 126.4, 125.7, 125.4, 123.7, 122.1, 120.8.

2-(thiophen-2-yl)benzo[*d*]thiazole (3.4n) [24a]



This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (154 mg, 71%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (d, *J* = 8.2 Hz, 1H), 7.85 (d, *J* = 8.0, Hz, 1H), 7.65 (dd, *J* = 3.7, 1.1 Hz, 1H), 7.51 - 7.45 (m, 2H), 7.38 - 7.34 (m, 1H), 7.13 (dd, *J* = 5.0, 3.8 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 161.5, 153.8, 137.4, 134.8, 129.4, 128.7, 128.2, 126.5, 125.3, 123.1, 121.6.

2-(furan-2-yl)benzo[*d*]thiazole (3.4o) [24a]



This compound was prepared according to the general procedure D. Reaction was completed after 20 h. White solid (139 mg, 69%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05 (d, *J* = 8.2 Hz, 1H), 7.88 (d, *J* = 8.0 Hz, 1H), 7.59 (d, *J* = 1.0 Hz, 1H), 7.50 - 7.46 (m, 1H), 7.39 - 7.35 (m, 1H), 7.19 (d, *J* = 3.5 Hz, 1H), 6.58 (dd, *J* = 3.4, 1.7 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.7, 153.8, 148.8, 144.8, 134.4, 126.6, 125.3, 123.2, 121.7, 112.6, 111.5.

3.7. References:

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3.8. Selected NMR spectra of products:

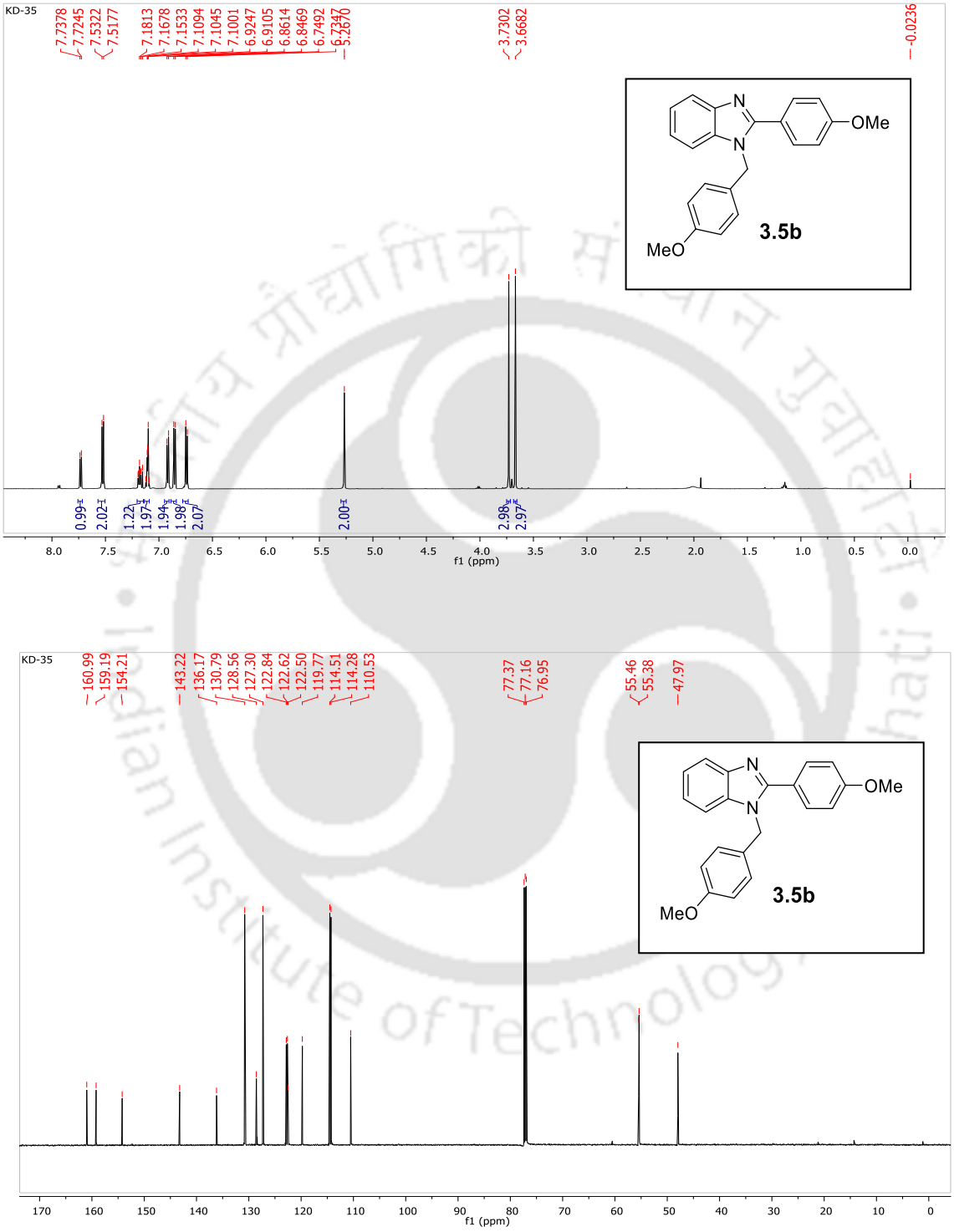


Figure 3.2: ^{1}H and ^{13}C NMR of compound **3.5b**.

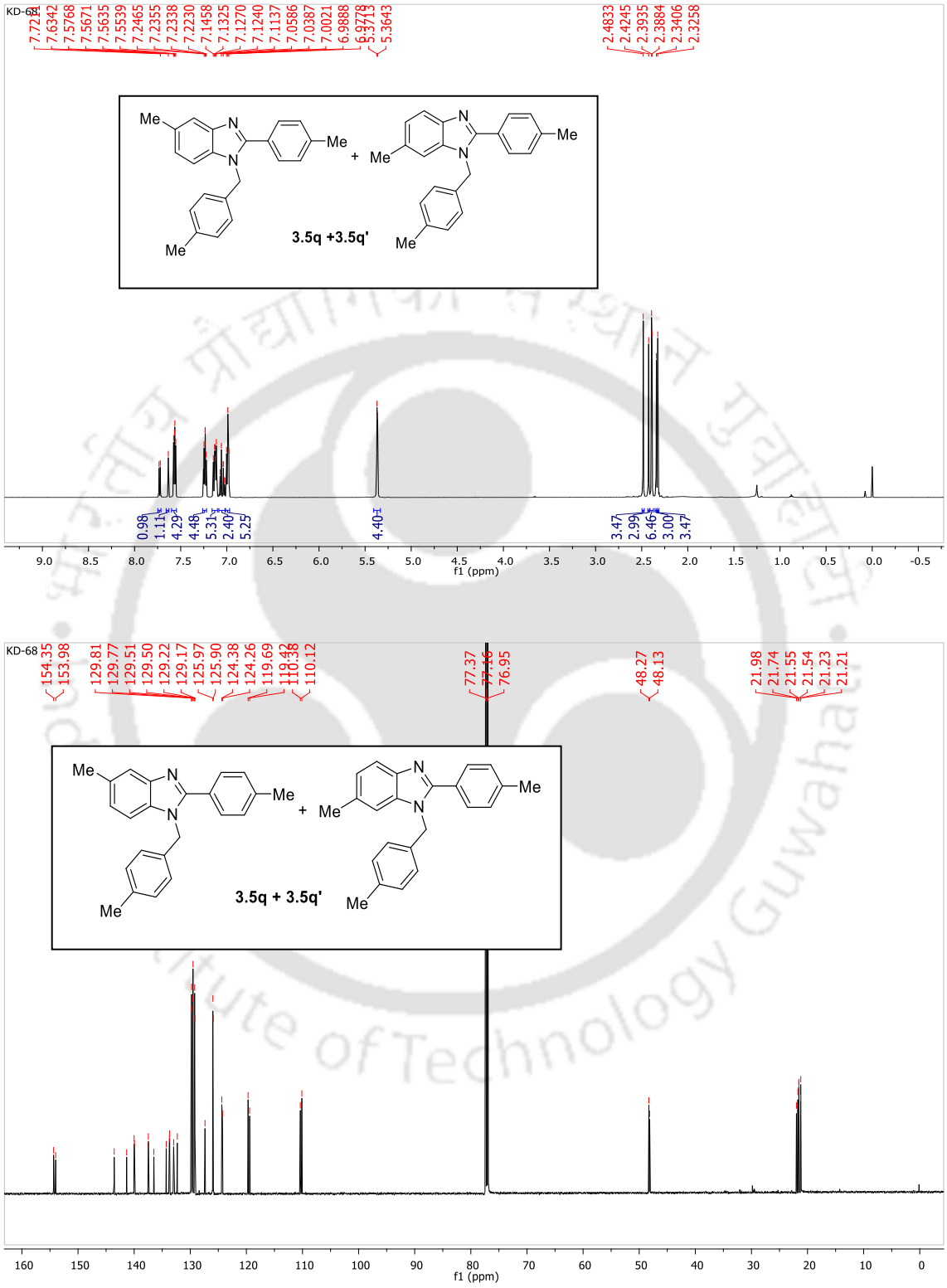


Figure 3.3: ^{1}H and ^{13}C NMR of compound **3.5q + 3.5q**.

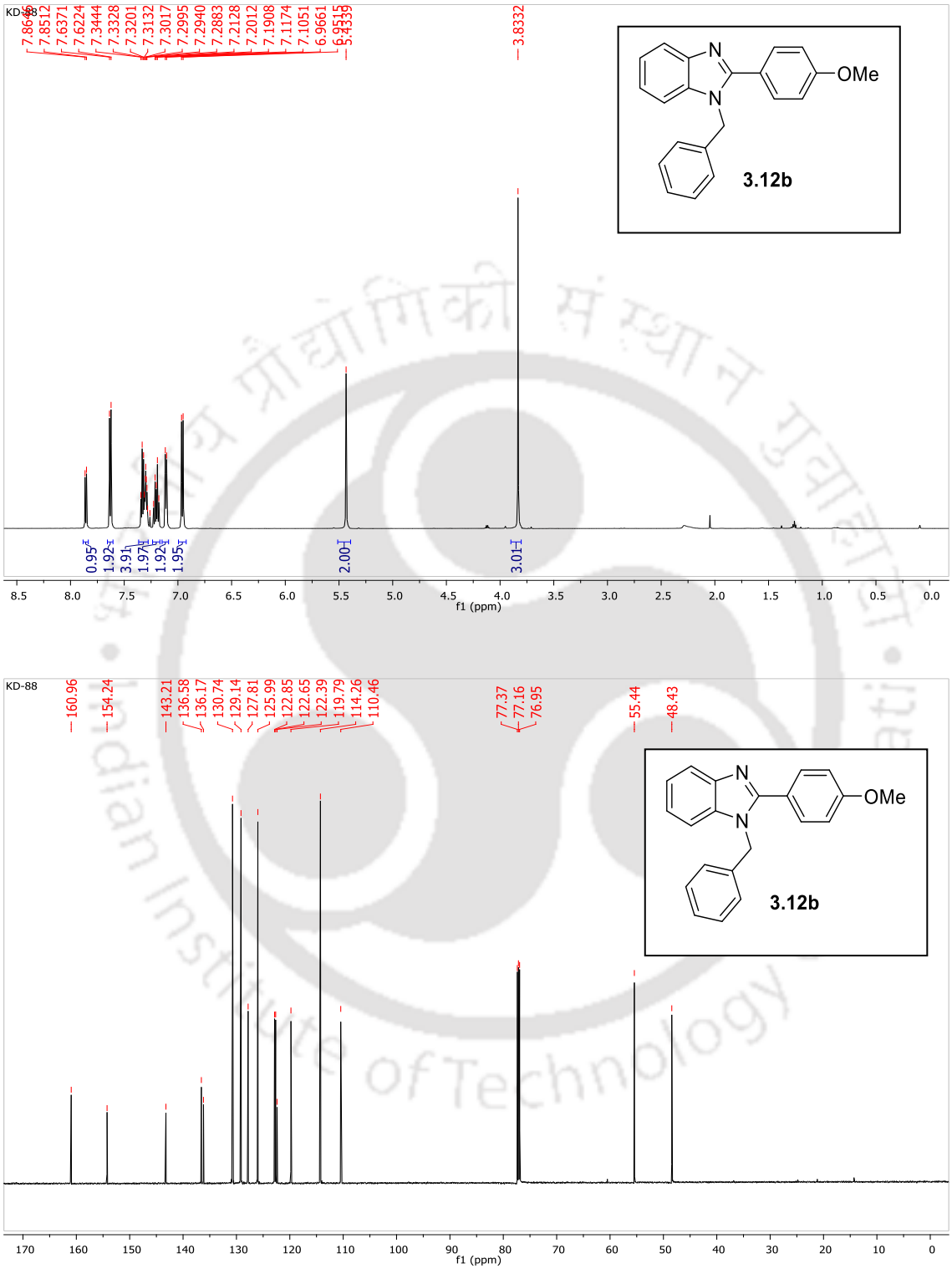


Figure 3.4: ^{1}H and ^{13}C NMR of compound **3.12b**.

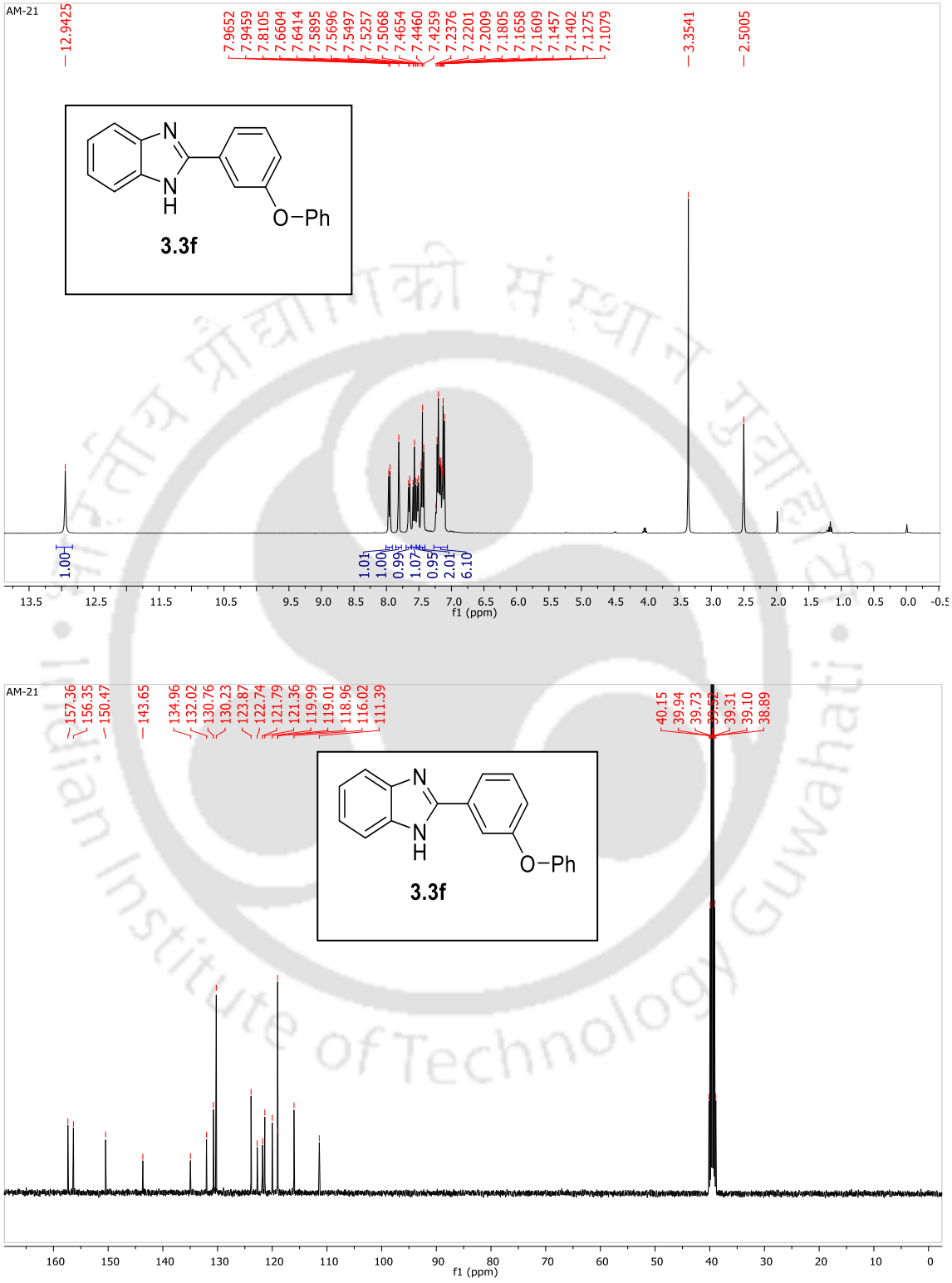


Figure 3.5: ^{1}H and ^{13}C NMR of compound **3.3f**.

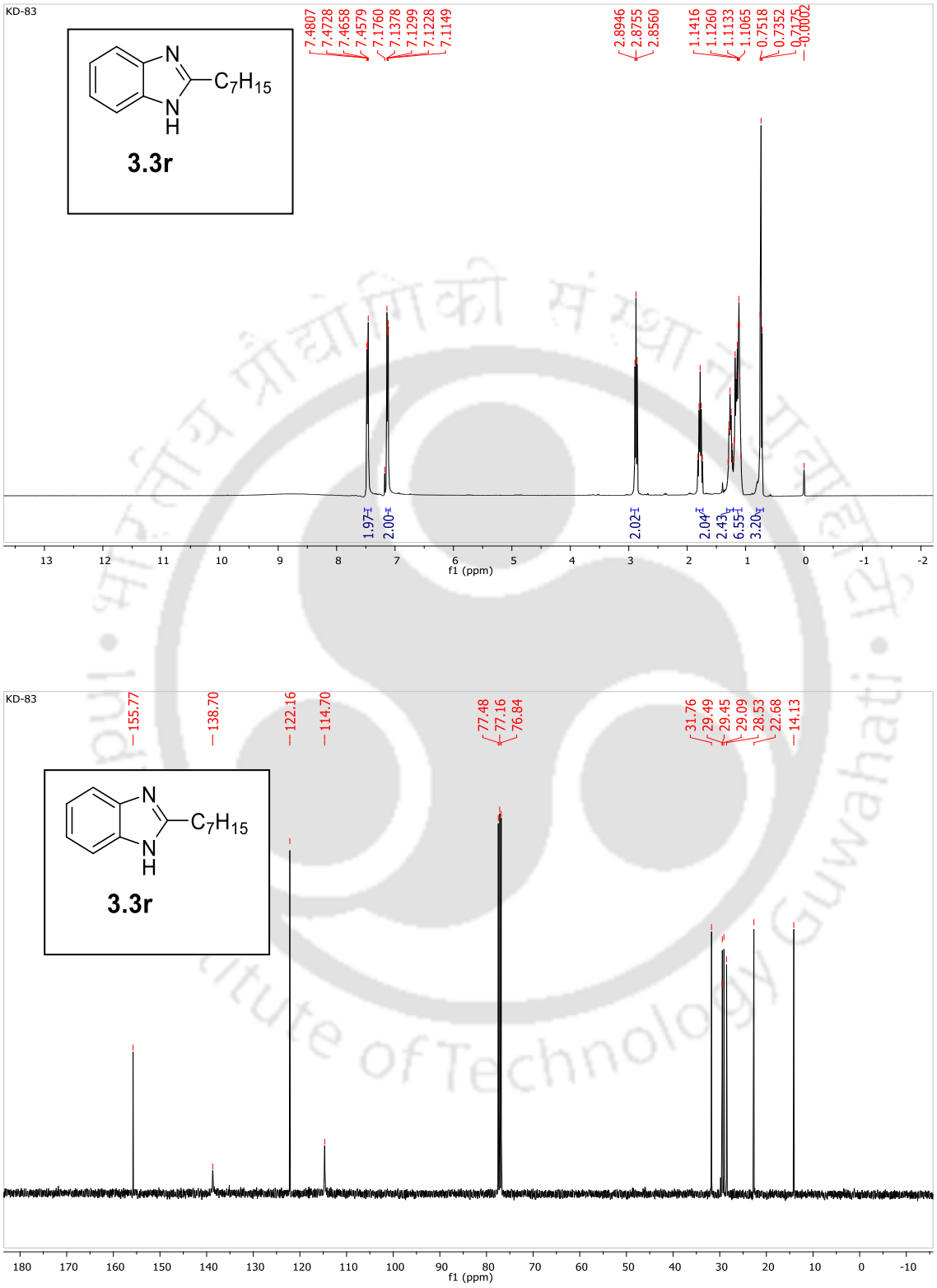


Figure 3.6: ^{1}H and ^{13}C NMR of compound **3.3r**.

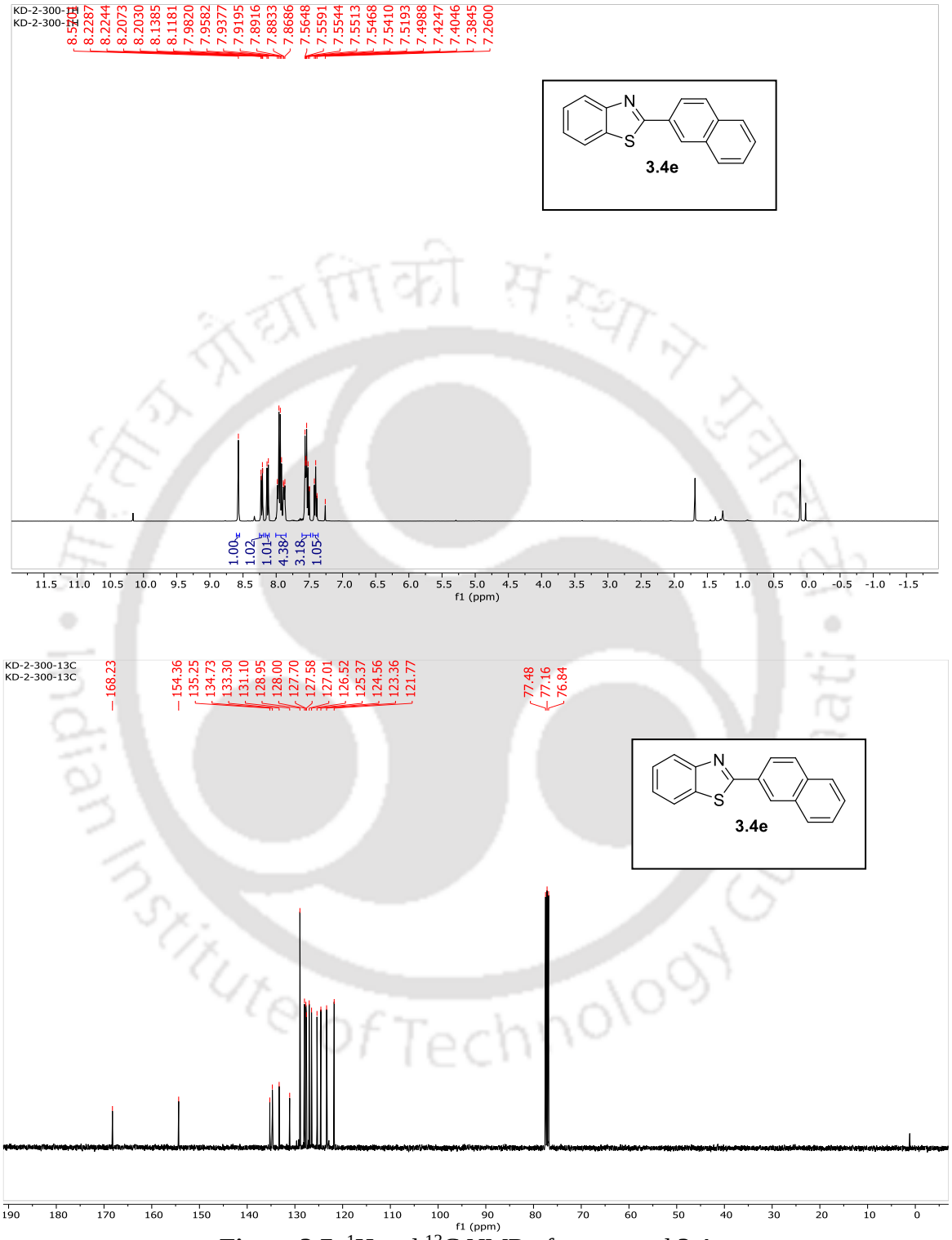


Figure 3.7: ^{1}H and ^{13}C NMR of compound **3.4e**.

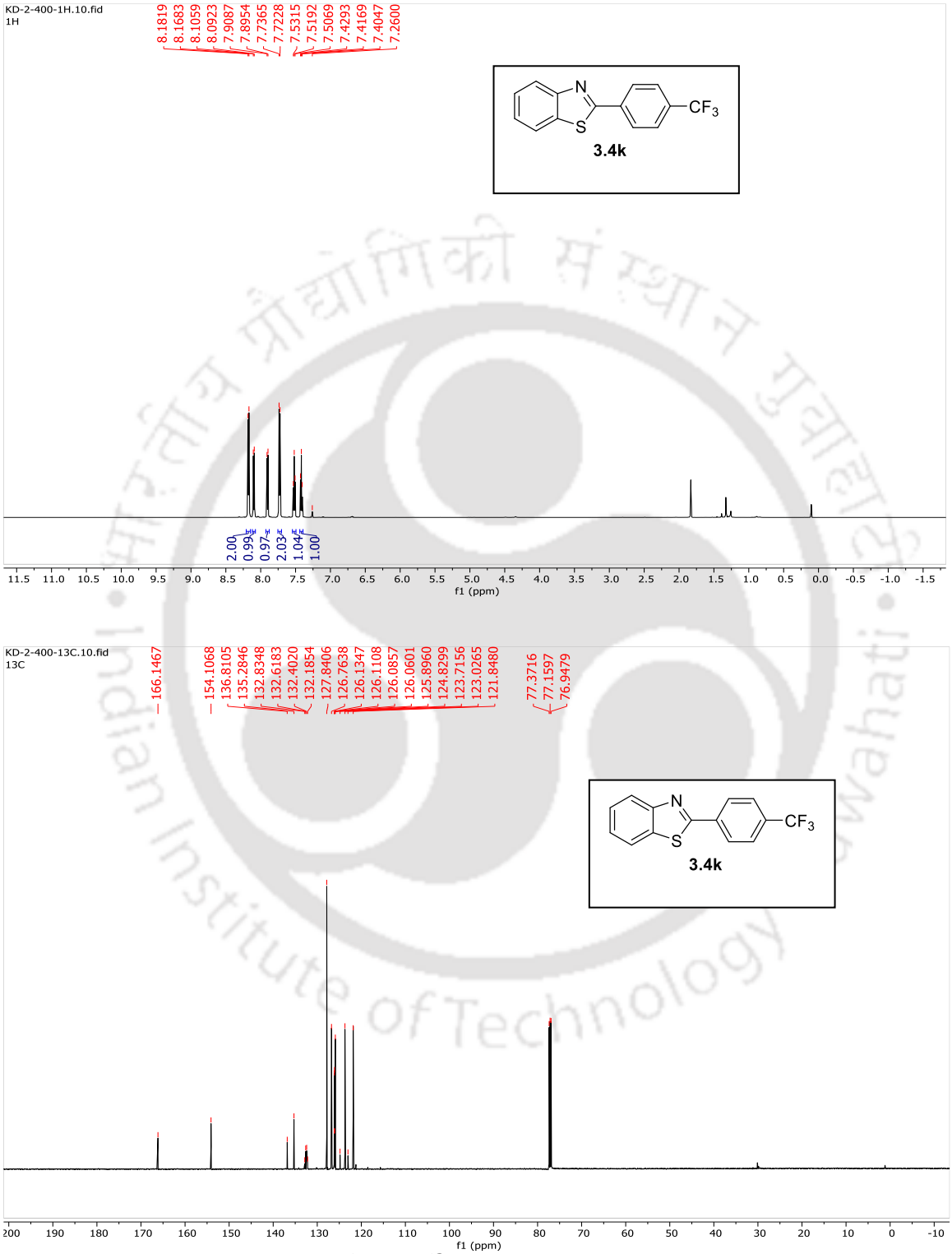


Figure 3.8: ^{1}H and ^{13}C NMR of compound **3.4k**.

Chapter 4

A Sustainable Approach to Synthesize Quinoxaline, Pyrazine and Quinoline Derivatives

4.1. Introduction:

Nitrogen containing six-member heterocycles such as quinoxaline, pyrazine and quinoline has attracted significant attention, as they are present in a large number of bioactive molecules.[1-4] Quinoxalines derivatives have shown a wide range of medicinal activity including antitumor,[1] antiviral,[2] antituberculosis,[5] anti-inflammatory,[6,7] anti-protozoal, anti-HIV,[8,9] anticancer and anthelmintic activities[10]. Quinoxaline moieties are present in many dyes,[11] cavitands[12] and also found application as efficient electroluminescent materials,[13] building blocks in the synthesis of organic semiconductors,[14] chemically controllable switches,[15] and dehydroannulenes.[16] Quinoline derivatives also exhibit a broad spectrum of biological and pharmacological activities such as anti-inflammatory,[17] antimalarial,[3] antibacterial,[4] antiasthmatic,[18] antihypertensive,[19] anti-Alzheimer,[20] and anticancer[21] activities.

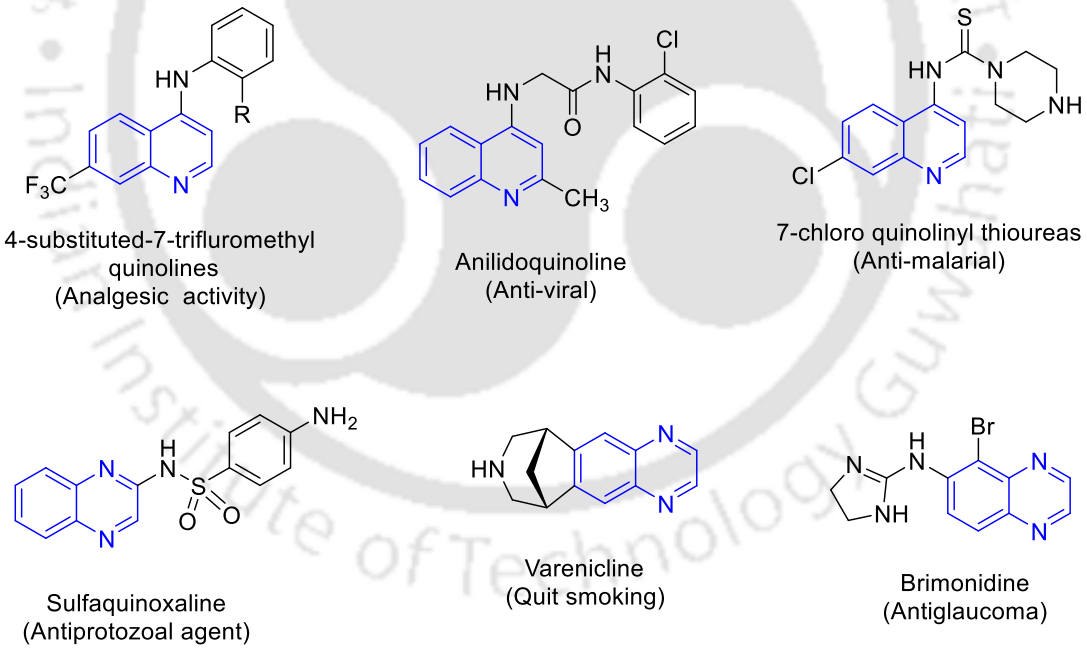
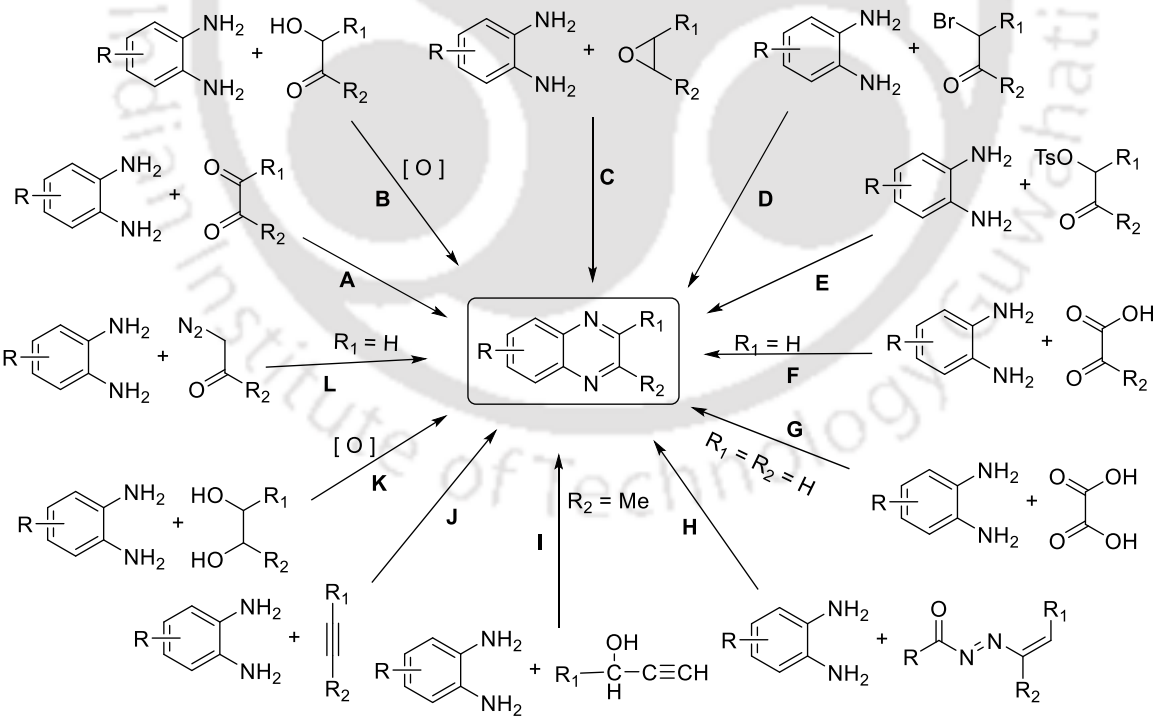


Figure 4.1: Selected examples of quinoxaline and quinoline containing drug molecules.

Thus, there is a growing interest to develop new sustainable, one-pot synthetic strategies for the preparation of highly functionalized *N*-heterocycles.

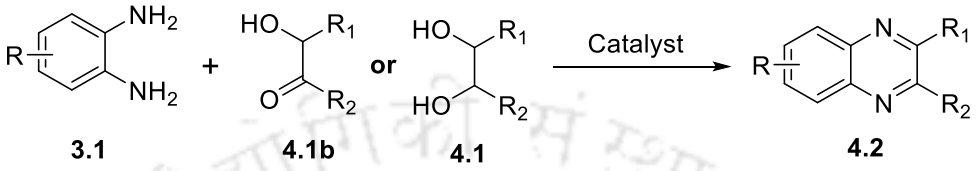
4.2. Strategies for quinoxaline and quinoline synthesis:

Conventionally, quinoxalines are prepared by the acid catalysed condensation of *o*-phenylenediamines with 1,2-dicarbonyl compounds[22] (**Scheme 4.1**, **A**). Several strategies for the synthesis of quinoxalines derivatives are reported in literature. These strategies are included the reaction of *o*-phenylenediamines with α-hydroxy ketones[23] (**Scheme 4.1**, **B**), epoxides[24] (**Scheme 4.1**, **C**), *α*-bromoketones[25] (**Scheme 4.1**, **D**), *α*-tosyloxy ketones[26] (**Scheme 4.1**, **E**), α-ketocarboxylic acids[27] (**Scheme 4.1**, **F**), oxalic acid[28] (**Scheme 4.1**, **G**), diazenyl butenes,[29] (**Scheme 4.1**, **H**), hydroxy acetylenes[30] (**Scheme 4.1**, **I**), alkynes,[31] (**Scheme 4.1**, **J**), *vicinal* diols[32] (**Scheme 4.1**, **K**), or diazoketones[33] (**Scheme 4.1**, **L**). However, most of these reactions have their own limitations such as the involvement of the heavy metal catalysts, the use stoichiometric amount of oxidant/base, incompatibility with pre-functionalized substrates and the use of harsh reaction conditions. Thus, these cannot be largely applied because of their environmental and/or economic issues.



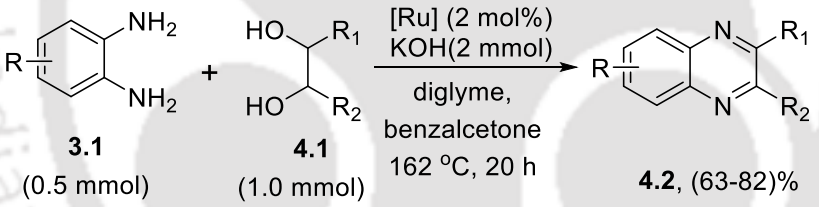
Scheme 4.1: Different conventional methods for the synthesis of quinoxaline.

Very recently, acceptorless dehydrogenation approach has been largely applied to synthesize quinoxalines[34] in presence of metal catalyst through metal-ligand cooperation process. These protocols do not require stoichiometric oxidant and hence these are considered as waste-free processes (**Scheme 4.2**).



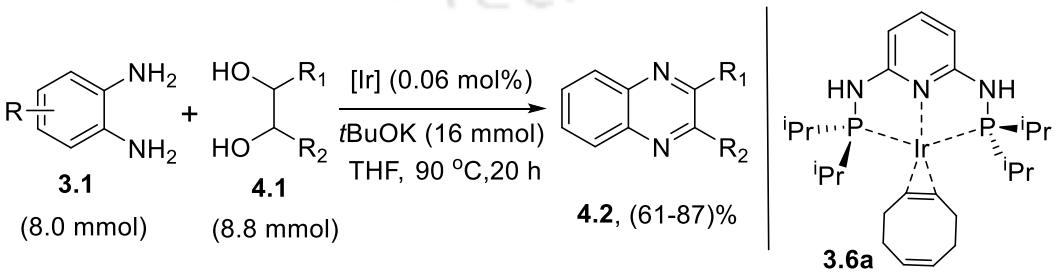
Scheme 4.2: Acceptorless dehydrogenation approach for the synthesis of quinoxaline.

In 2006, *Cho and co-worker* reported[35] $RuCl_2(PPh_3)_3$ catalysed oxidative cyclization *o*-phenylenediamines with various 1,2-diols to give quinoxaline derivatives in moderate to good yield (**Scheme 4.3**). Excess amount of KOH (4 equiv. with respect to 1,2-diaminobenzene) was used for these transformations.



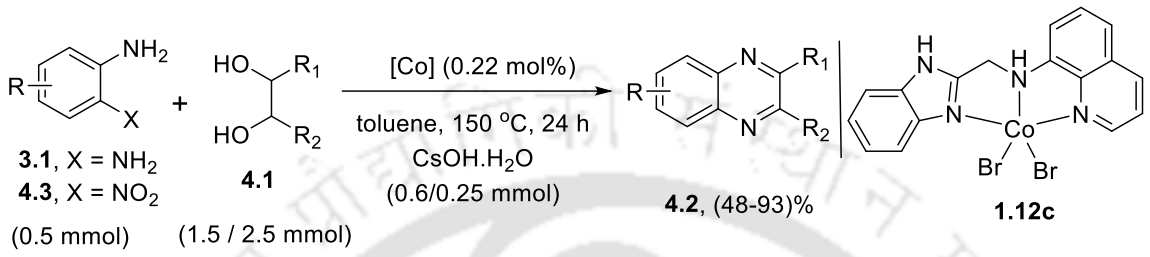
Scheme 4.3: The synthesis of quinoxaline by Ru-complex from 1,2-diaminobenzene and 1,2-diol.

In 2014, *Kempe and co-workers* developed tridentate Ir-PNP pincer complex **3.6a** catalysed[36] dehydrogenative syntheses of quinoxaline derivatives at relatively lower reaction temperature (90 °C).



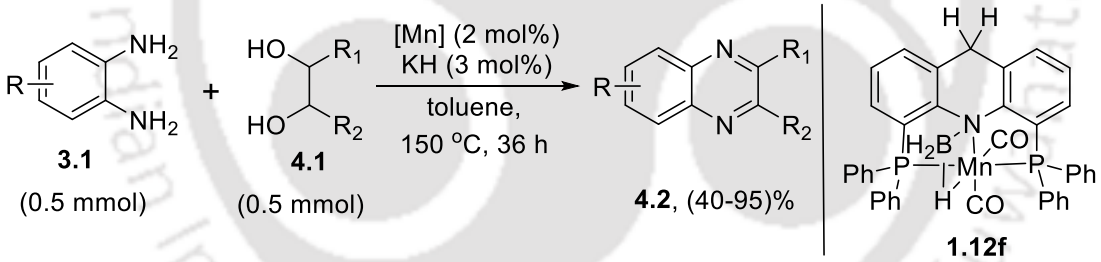
Scheme 4.4: The synthesis of quinoxaline by Ir-complex from 1,2-diaminobenzene and 1,2-diol.

Very recently, *Kundu and co-workers* demonstrated earth-abundant Co(II) complex **1.12c** catalysed[37] synthesis of quinoxalines *via* dehydrogenative coupling of *vicinal* diols with *o*-phenylenediamine or 2-nitroanilines at 150 °C in presence of relatively lower amount of base.



Scheme 4.5: The synthesis of quinoxaline by Co-complex from 1,2-diaminobenzene and 1,2-diol.

In the same year, the group of *Milstein* developed the acridine PNP based manganese complex **1.12f** to synthesize such type of compounds[38] in presence of a catalytic amount of base at 150°C.

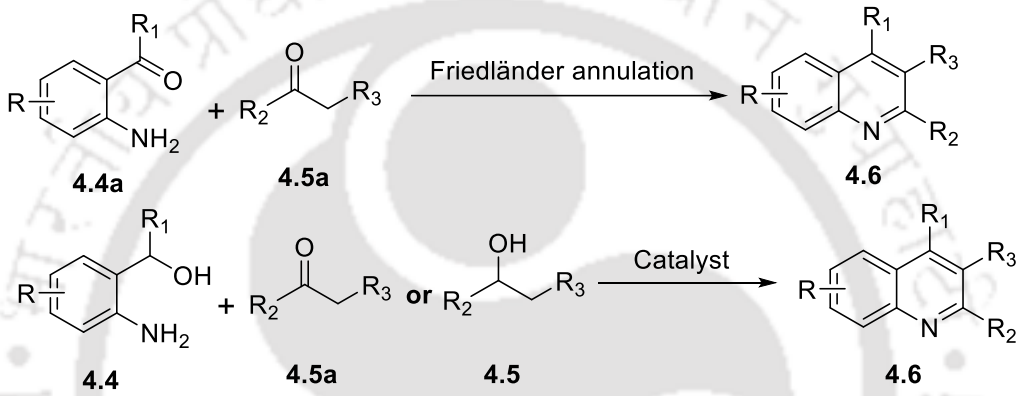


Scheme 4.6: The synthesis of quinoxaline by Mn-complex from 1,2-diaminobenzene and 1,2-diol.

Consequently, the construction of quinolines have also been developed over the past few years using various efficient strategies such as the *Skraup* synthesis, *Friedländer* synthesis, *Gould-Jacobs* synthesis, *Conrad-Limpach* and *Doebner-von Miller* synthesis. Among them, the *Friedländer annulation*[39] has attracted much attention as it involves straightforward condensation of 2-aminobenzaldehydes/ketones with different carbonyl compounds having an active *α*-methylene group followed by intramolecular cyclization. However, limited availability *o*-aminobenzaldehydes and harsh reaction condition are the two major drawbacks of this synthetic strategy.

Moreover, 2-aminobenzaldehydes are prone to self-condensation and hence highly unstable.

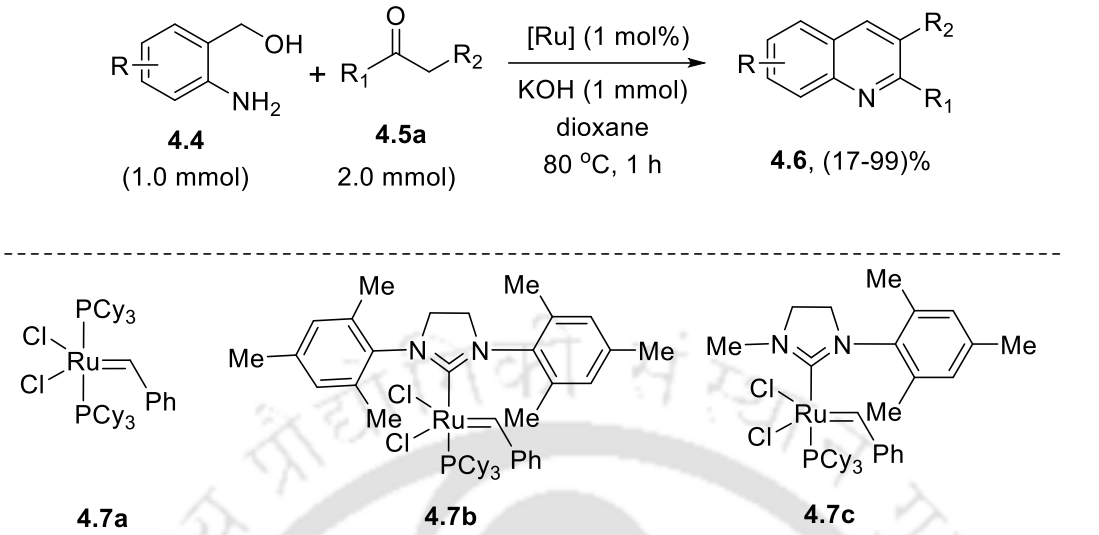
An alternative environmentally benign and atom-economical approach to synthesize quinoline derivatives is the dehydrogenative coupling[40] of 2-aminobenzyl alcohols with ketones/alcohols (**Scheme 4.7**). The reaction occurs without the involvement of toxic strong oxidants and it generates environmentally benign hydrogen gas and H_2O as by-products.



Scheme 4.7: The synthesis of quinoline *via* dehydrogenative annulations.

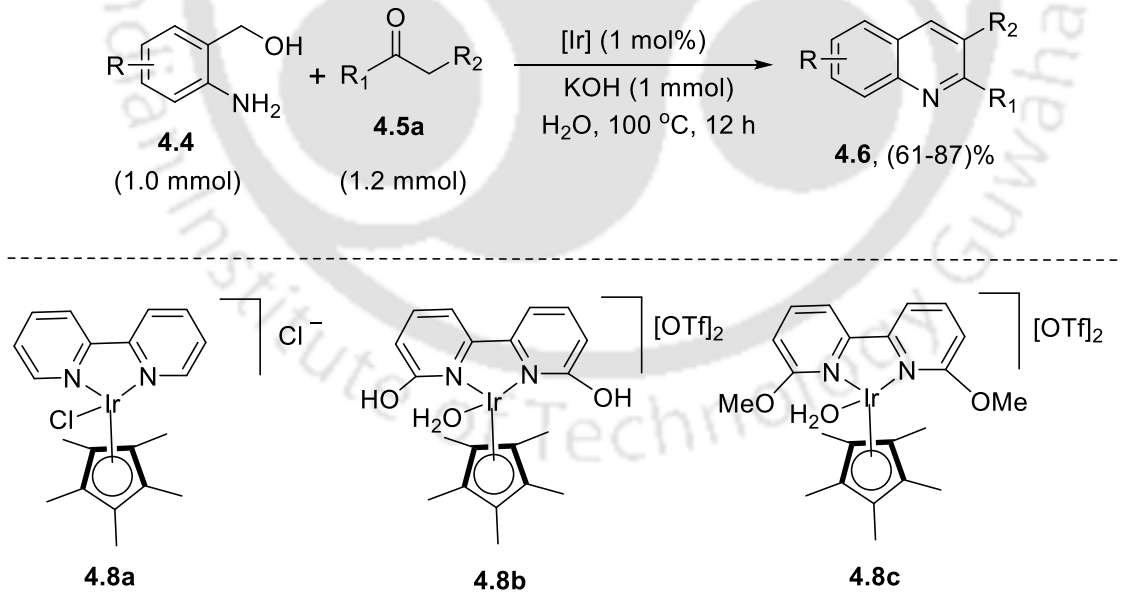
Over the past few decades, different transition metal complexes have been utilized for the dehydrogenative synthesis of various differently substituted quinoxaline, pyrazine and quinoline derivatives. Among them, the novel metal complexes (Ru, Ir etc) have been found to be most suitable for the synthesis of such heterocycles. Recently, earth-abundant transition metal complexes (Fe, Co, Mn) are also utilised for similar kind reaction to avoid the high cost and limited availability of noble metal salts. Some of the reported strategies are shown here.

In 2007, *Verpoort et al.* reported Ru-catalysed[41] synthesis of quinoline derivatives from 2-aminobenzylalcohol and ketones derivatives in presence of KOH in dioxane medium. They have used 2 equivalent of ketone with respect to the 2-aminobenzylalcohol.



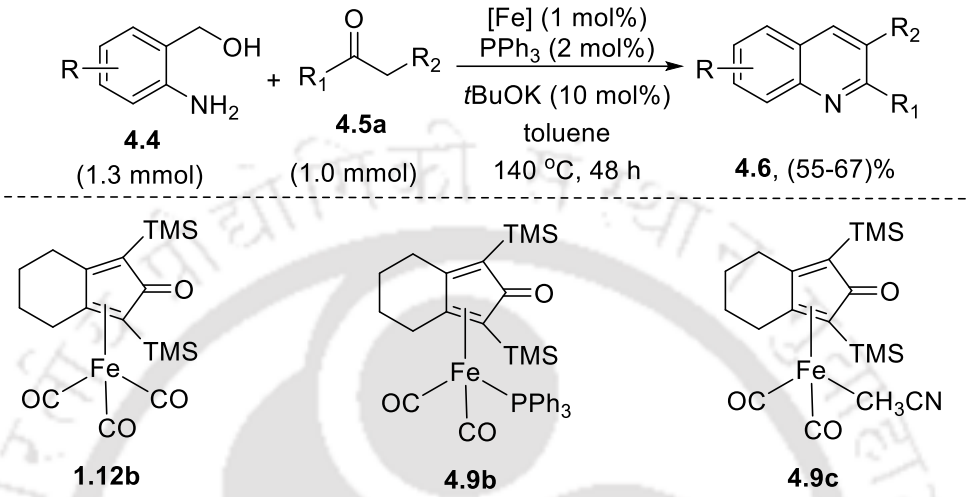
Scheme 4.8: Synthesis of quinoline by Ru-complexes from 2-aminobenzyl alcohol and ketone derivatives

Li et al. developed tridentate Ir-complexes[40a] **4.8a-c** to catalyse dehydrogenative *Friedländer* synthesis in water, using almost an equimolar amount of 2-aminobenzylalcohol and ketones.

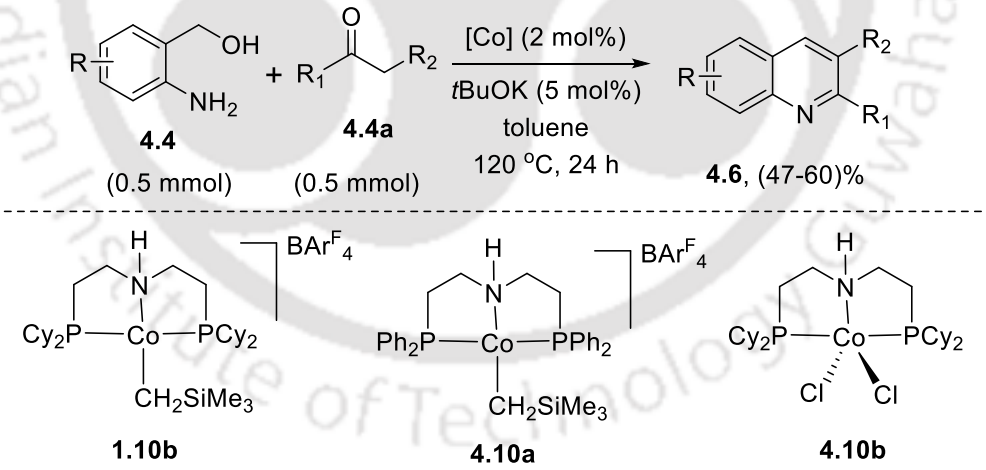


Scheme 4.9: Dehydrogenative quinoline synthesis by Ir-complexes from 2-aminobenzyl alcohol and ketone derivatives.

In 2015, *Sortais and co-workers* reported iron catalysed[42] modified *Friedländer* annulation. There protocol offers limited substrate scope with moderate yield of the product.



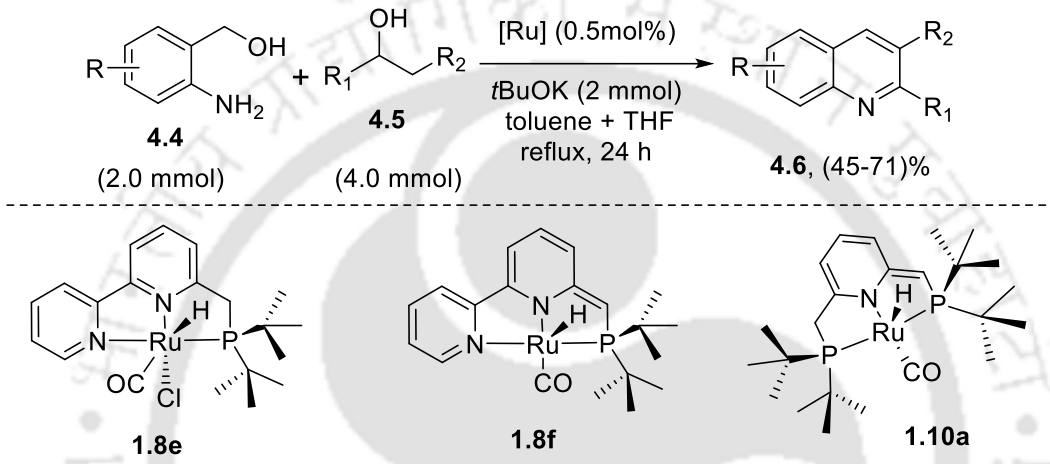
Scheme 4.10: Fe-complexes catalysed synthesis of quinoline from 2-aminobenzyl alcohol and ketone derivatives.



Scheme 4.11: Cobalt catalysed modified Friedländer annulation reaction from 2-aminobenzyl alcohol and ketone derivatives.

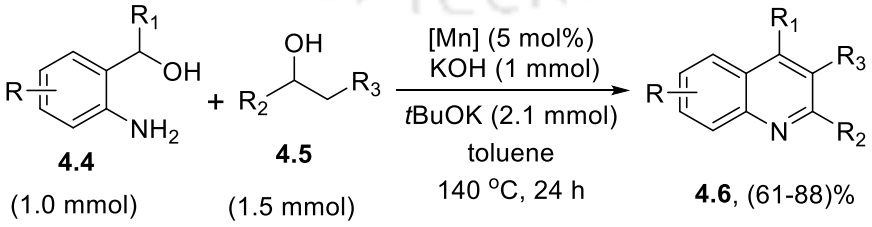
In 2017, *Zheng and co-workers* illustrated Co-catalysed[43] dehydrogenative *Friedländer* synthesis of quinoline in toluene medium and got only 46-60 % yields the

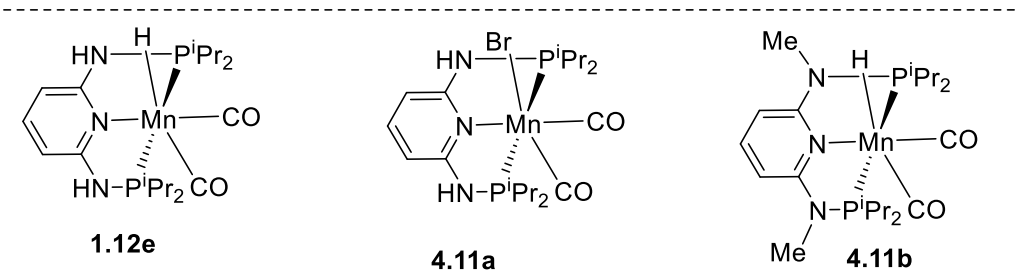
quinoline derivatives (**Scheme 4.11**). Very recently, the dehydrogenative annulation reactions for the synthesis of quinoline directly from 2-aminobenzyl alcohol and a secondary alcohol are reported. In 2013, the group of *Milstein*[40b] developed an elegant method to synthesize quinoline from 2-aminobenzyl alcohol and secondary alcohol using Ru-PNP complex in traditional solvent with higher amount of base (2 mmol) respect to the substrate.



Scheme 4.12: Synthesis of quinoline by Ru-complexes from 2-aminobenzyl alcohol and secondary alcohol.

In 2016, *Kirchner and groups* first reported Mn-based PNP-pincer complexes[44] **1.12e**, **4.11a-b** catalysed dehydrogenative condensation 2-aminobenzyl alcohol and secondary alcohol to form quinoline derivatives. The mixture of *t*BuOK (2.1 mmol) and KOH (1 mmol) is highly essential for this reaction and they found a significant decrease in the yield of the desired product in the absence of KOH.





Scheme 4.13: Mn-complexes catalysed dehydrogenative synthesis of quinoline from 2-aminobenzyl alcohol and secondary alcohol.

Many metal complexes were applied for the dehydrogenative synthesis of quinoxaline, pyrazine and quinoline. However, the use of earth-abundant non-toxic manganese complexes towards the synthesis of these heterocycles are limited and mainly effective in presence of highly sophisticated phosphine containing ligands. Thus, there is an ample scope to study the dehydrogenative synthesis of such type of heterocycles in presence of newly synthesized NNS-Mn complexes.

4.3. Present work:

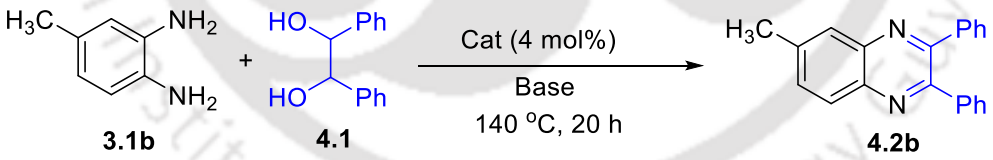
Chapter 4 describes the catalytic efficacy the NNS-Mn(I) complexes toward the synthesis of quinoxaline and pyrazine via dehydrogenative coupling of 1,2-diamine and 1,2-diol. The scope and limitations of the synthesis of quinoline derivatives directly from 2-aminobenzyl alcohols and secondary alcohols *via* the concurrent formation of a C-C and C-N bond are also discussed here.

4.3.1. Optimization of reaction conditions for quinoxaline:

Initially, the phosphine-free manganese complexes **2.12a-c** were selected to examine the scope of dehydrogenative coupling reaction between 1,2-diaminobenzene and 1,2-diol to form quinoxaline derivatives. First, the reaction between *o*-phenylenediamine and 1,2-diphenylethane-1,2-diol was taken as a model system to find out the optimum reaction conditions for the synthesis of quinoxaline. Thus, refluxing a toluene solution containing *o*-phenylenediamine (1.0 mmol), 1,2-diphenylethane-1,2-diol (1.3 mmol), cat **2.12a** (0.04 mmol) and KOH (0.27 mmol) for 20 h gave 53 % isolated

yield of the desired quinoxaline (**Table 4.1**, entry 1). Keeping the other conditions unaltered, when xylene was used as solvent, the yield was improved to 57% (**Table 4.1**, entry 2). Under similar conditions using xylene solvent, catalyst **2.12b** gave 66% yield whereas cat **2.12c** gave 50% yield of the desired product (**Table 4.1**, entries 4 and 5). Thus, cat **2.12b** was found to be the best choice for this reaction. Next, the reaction was performed under neat condition in the presence of cat **2.12b**. Gratifyingly, 79% desired quinoxaline was isolated, which is the optimum reaction condition (**Table 4.1**, entry 6) for the synthesis of quinoxaline. When, the *o*-phenelenediamine and 1,2-diphenylethane-1,2-diol were taken in 1:1 ratio the yield was dropped from 79% to 60% (**Table 4.1**, entry 7). Instead of KOH, when NaOH was employed as base the yield of the targeted product (**Table 4.1**, entry 8) is decreased from 79% to 52%. The yield of the desired product was also decreased with low catalyst loading (**Table 4.1**, entry 12) or with lower amount of base (**Table 4.1**, entry 13) or shorter reaction time (**Table 4.1**, entry 14). When the weaker bases such as $NaHCO_3$, Na_2CO_3 and K_2CO_3 were used, the yields of the desired product are 19%, 23% and 34% respectively (**Table 4.1**, entries 9, 10 and 11). Under the optimized reaction condition, $MnBr(CO)_5$ gave significantly lower amount of the desired compound.

Table 4.1: Screening Table:[a,b]



Entry No.	Catalyst	Solvent (ml)	Base (mmol)	% of yield[b]
1	Cat **2.12a**	toluene (3)	KOH (0.27)	53
2	Cat **2.12a**	xylene (3)	KOH (0.27)	57
3	Cat **2.12b**	toluene (3)	KOH (0.27)	62
4	Cat **2.12b**	xylene (3)	KOH (0.27)	66
5	Cat **2.12c**	xylene (3)	KOH (0.27)	50

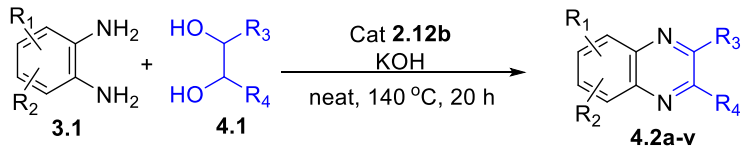
6	**Cat 2.12b**	**neat**	**KOH (0.27)**	**79**
7[c]	Cat **2.12b**	neat	KOH (0.27)	60
8	Cat **2.12b**	neat	NaOH (0.27)	52
9	Cat **2.12b**	neat	$NaHCO_3$ (0.27)	19
10	Cat **2.12b**	neat	Na_2CO_3 (0.27)	23
11	Cat **2.12b**	neat	K_2CO_3 (0.27)	34
12[d]	Cat **2.12b**	neat	KOH (0.27)	46
13	Cat **2.12b**	neat	KOH (0.13)	52
14[e]	Cat **2.12b**	neat	KOH (0.27)	51
15	$Mn(CO)_5Br$	neat	KOH (0.27)	14

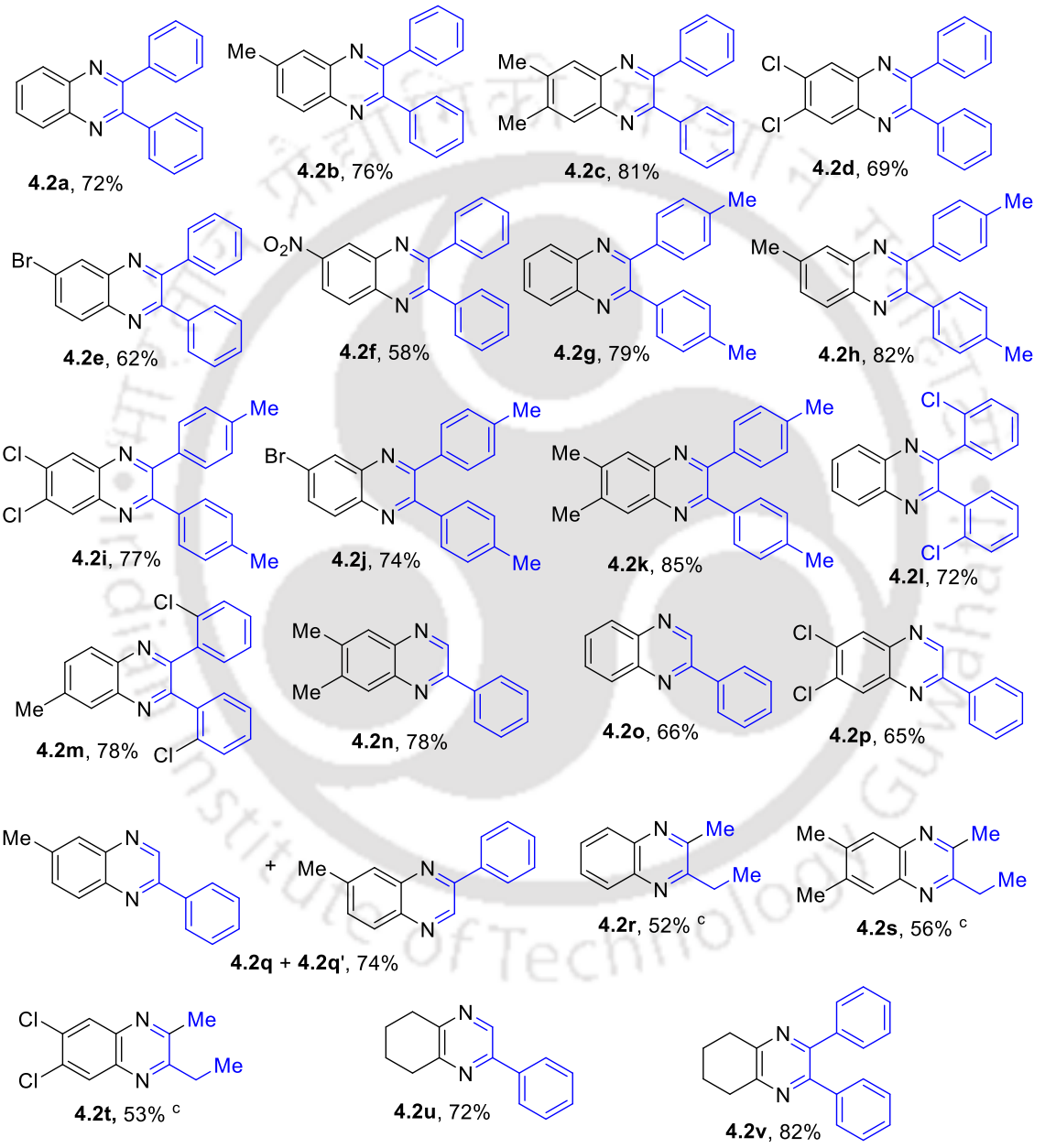
[a] Reaction conditions: 3,4-diaminotoluene (1.0 mmol), 1,2-diphenylethane-1,2-diol (1.3 mmol), base (0.27 mmol), cat. (0.04 mmol), 20 h, under argon, [b] isolated yield. [c] 1 : 1 ratio of **3.1b** and **4.1**, [d] 2 mol% cat. **2.12b**, [e] 10 h.

4.3.2. Substrate scope for the synthesis of quinoxaline:

After attaining optimized conditions, the present protocol has been applied to synthesize a diverse range of quinoxaline and pyrazine from 1,2-diamine and 1,2-diols. Initially, 1,2-disubstituted vicinal diols were reacted with different electron-donating and electron withdrawing 1,2-diaminobenzene and it was observed that 1,2-diaminobenzene having electron donating group gave slightly better yield compared to electron withdrawing group. Under the optimized reaction condition monosubstituted *vicinal* diols reacted smoothly with *o*-phelenediamine, 4,5-dichloro-*o*-phenylenediamine, 4,5-dimethyl-1,2-phenylene diamine and 3,4-diaminotoluene and led to the desired product (**Table 4.2**) **4.2n-p** in good yield. Notably, 3,4-diaminotoluene gave a mixture of two isomeric quinoxaline derivatives **4.2q** and **4.2q′**. Furthermore, employing 1,2-dicyclohexyl amine as substrate led to the formation pyrazine derivatives in excellent yield (72%-82%). The more challenging aliphatic alcohol, butane-1,2-diol gave moderate yields (52%-56%) of **4.2r-4.2t** after 36 h.

Table 4.2: Scope of the substrate to synthesize quinoxaline from 1,2-diamine and 1,2-diol derivatives[a,b]



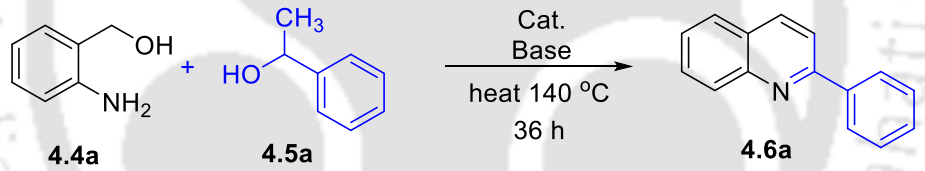


[a] Reaction conditions: 1,2-diamine (1.0 mmol), 1,2-diol (1.3 mmol), KOH (0.27 mmol), cat. **2.12b** (0.04 mmol), neat, 20 h, under an argon atmosphere, [b] isolated yield, [c] 36 h.

4.3.3. Optimization of reaction conditions for quinoline:

Next, the synthesis of quinoline derivatives *via* simultaneous C-C and C-N bond formation through dehydrogenation and condensation reaction between 2-aminobenzyl alcohols and secondary alcohols was attempted. Thus, when 2-aminobenzyl alcohol (1.0 eq.) and 1-phenylethanol (1.3 eq.) were heated at 140 °C in presence 5 mol% cat **2.12b** and KOH (1.2 eq.) for 36 h, 70% of the desired quinoline was isolated (**Table 4.3**, entry 1). The yield was further enhanced to 81% using 1.2 eq. tBuOK (**Table 4.3**, entry 2). Here the excess amount of base is required probably to assist the condensation reaction. When cat **2.12a** was used instead of cat **2.12b** the yield of the desired product decreases (**Table 4.3**, entry 4)**.** When the reaction was performed in the toluene solvent or with the lower amount of *t*BuOK (0.56 equiv.), the yield was dropped to 72% and 56% respectively (**Table 4.3**, entries 3 and 7).

Table 4.3: Screening Table:[a,b]



4.4a **4.5a** **4.6a**

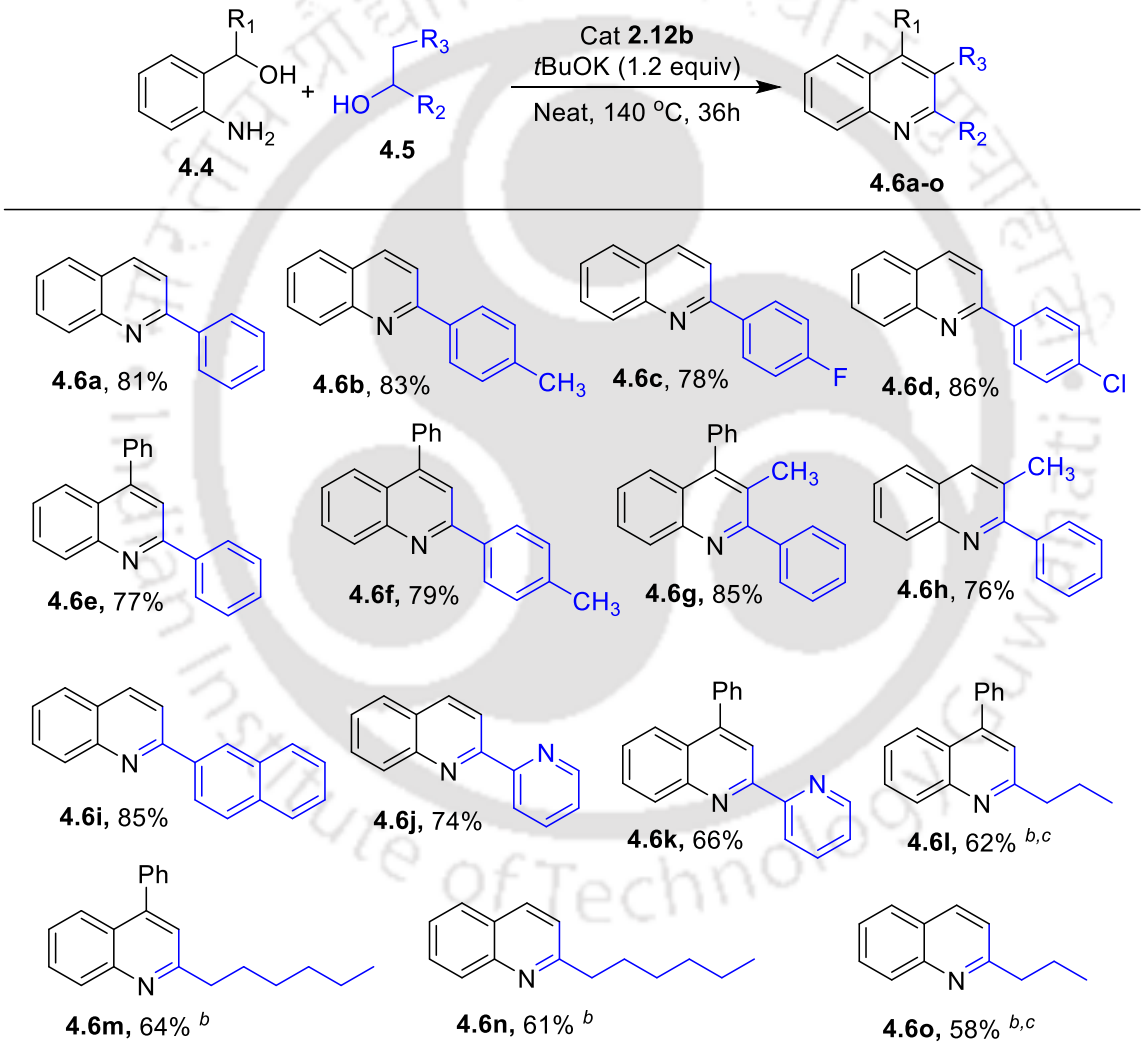
Entry No.	Catalyst	Base (mmol)	Solvent/neat	**4.4a :4.5a**	% of yield [b]
1	Cat **2.12b**	KOH-1.2	Neat	1 : 1.3	70
2	**Cat 2.12b**	***t*BuOK-1.2**	**Neat**	**1 : 1.3**	**81**
3	Cat **2.12b**	*t*BuOK-1.2	Toluene(2mL)	1 : 1.3	72
4	Cat **2.12a**	*t*BuOK-1.2	Neat	1 : 1.3	76
5	Cat **2.12b**	*t*BuOK-1.2	Neat	1 : 1.1	72
6	Cat **2.12b**	*t*BuOK-1.2	Neat	1 : 1.5	81
7	Cat **2.12b**	*t*BuOK-0.56	Neat	1 : 1.3	56
8	Cat **2.12b**	*t*BuOK-1.5	Neat	1 : 1.3	80

[a] Reaction conditions: 2-amino benzyl alcohol (1.0 mmol), secondary alcohol (1.3 mmol), cat. (0.05 mmol), neat, 36 h, under an argon atmosphere, [b] isolated yield.

4.3.4. Substrate scope for the synthesis of quinoline:

To study the scope of the reaction, different 1-aryl ethanol having both electron withdrawing as well as electron donating group has been tested. In all the cases good to excellent yield was observed (**Table 4.4**). Next, to synthesize 2,3,4-trisubstituted

Table 4.4: Scope of the substrate to synthesize quinoline from 2-aminobenzyl alcohol and secondary alcohol derivatives[a,b]



[a] Reaction conditions: 2-aminobenzyl alcohol (1.0 mmol), secondary alcohol (1.3 mmol), *t*BuOK (1.2 mmol), cat. **2.12b** (0.05 mmol), under an argon atmosphere. [b] Isolated yield. [c] 48 h. [d] 1.5 mmol secondary alcohol.

quinoline derivative, 1-phenyl-1-propanol was treated with 2-aminobenzhydrol, gratifyingly 85% 3-methyl-2,4-diphenylquinoline was obtained. The performance of cat **2.12b** was further investigated toward more challenging aliphatic alcohols. Thus, 2-aminobenzyl alcohol reacted with 2-octanol to give 61% of the desired quinoline after 48 hour. The reaction with aliphatic alcohols were found to be slower compared to those of the benzyl alcohols and moderate to good yields of the corresponding quinoline derivatives were obtained. In all the cases, the C-C condensation occurred at less hindered side of the in situ formed carbonyl compound.

4.4. Conclusion:

Here, the environmentally benign sustainable protocol to synthesize quinoxalines and pyrazine catalysed by well-defined air stable Mn(I) complex are reported. A wide ranges of functional groups are well survived under the optimized reaction condition. This expedient protocol has been successfully applied to synthesize variety of quinoline derivatives *via* concurrent formation of C-C and C-N bond.

4.5. Experimental section:

General Information

Unless otherwise mentioned, all chemicals were purchased from common commercial sources and used as received. All solvents were dried by using standard procedure. The preparation of catalyst was carried out under argon atmosphere with freshly distilled dry THF. All catalytic reactions were carried out under argon atmosphere using dried glassware and standard syringe/septa techniques. DRX-400 Varian spectrometer and Bruker Avance III 600 and 400 spectrometers were used to record ^{1}H and ^{13}C NMR spectra using $CDCl_3$ as solvent and TMS as an internal standard. Chemical shifts (δ) are reported in ppm and spin-spin coupling constant (J) are expressed in Hz, and other data are reported as follows: s = singlet, d = doublet, dd = doublet of doublet, dt = doublet of triplet, t = triplet, m = multiplet, q = quartet, and br s = broad singlet. SRL silica gel (100-200 mesh) was used for column chromatography.

A. General experimental procedure for the synthesis of quinoxalines:

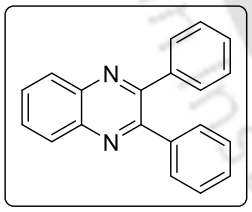
A mixture of 1,2-diaminobenzene (1.0 mmol), diol (1.3 mmol), KOH (0.27 mmol) was stirred under neat condition at 140 °C in an open system under argon in the presence of 4 mol% catalyst **2.12b**. After the specified time, the reaction mixture was cooled to room temperature and chloroform was added to dilute the mixture. Then it was filtered through celite and filtrate was concentrated under reduced pressure. The crude residue was purified further by silica gel column chromatography using 2%-5% ethyl acetate in hexane as an eluent.

B. General experimental procedure for the synthesis of quinolines:

A mixture of 2-amino benzyl alcohol (1.0 mmol), secondary alcohol (1.3 mmol), *t*BuOK (1.2 mmol) and catalyst **2.12b** (0.05 mmol) was stirred under neat condition at 140 °C for 36 h in an open system under argon. After cooling to room temperature, chloroform was added and filtered through celite. The filtrate was concentrated to get the crude residue, which was purified further by column chromatography using silica gel as stationary phase and 2%-5% ethyl acetate in hexane as an eluent.

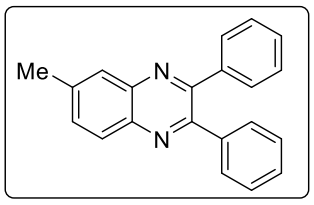
4.6. Characterization data of products:

2,3-diphenylquinoxaline (4.2a)[45a]



This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (203 mg, 72%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.21- 8.17 (m, 2H), 7.80 - 7.75 (m, 2H), 7.54-7.52 (m, 4H), 7.39 - 7.31 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.6, 141.4, 139.2, 130.1, 130.0, 129.3, 128.9, 128.4.

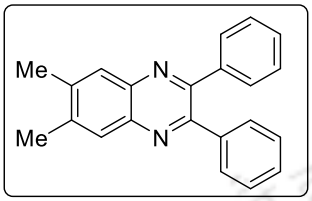
6-methyl-2,3-diphenylquinoxaline (4.2b)[45a]



This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (225 mg, 76%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.07 (d, J = 8.5 Hz, 1H), 7.96 (s, 1H), 7.60 (dd, J = 8.6, 1.8 Hz, 1H), 7.55 -

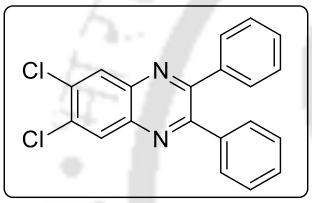
7.48 (m, 4H), 7.39 - 7.29 (m, 6H), 2.62 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.4, 152.7, 141.4, 140.6, 139.8, 139.3, 132.4, 130.0, 129.9, 128.8, 128.8, 128.7, 128.3, 128.1, 22.0.

6,7-dimethyl-2,3-diphenylquinoxaline (4.2c)[45a]



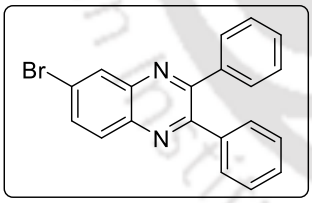
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (252 mg, 81%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93 (s, 2H), 7.50 (dd, *J* = 7.5, 2.1 Hz, 4H), 7.35 - 7.29 (m, 6H), 2.52 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.6, 140.6, 140.3, 139.5, 130.0, 128.6, 128.3, 128.3, 20.5.

6,7-dichloro-2,3-diphenylquinoxaline (4.2d)[45b]



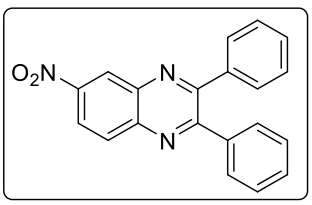
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. Brown solid (299 mg, 77%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.20 (s, 2H), 7.43 - 7.41 (m, 4H), 7.32 - 7.30 (m, 2H), 7.27-7.25 (m, *J* = 7.6 Hz, 4H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 154.6, 140.0, 138.5, 134.5, 129.9, 129.9, 129.4, 128.5.

6-bromo-2,3-diphenylquinoxaline(4.2e)[45c]



This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (287 mg, 74%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.36 (d, *J* = 2.1 Hz, 1H), 8.03 (d, *J* = 8.9 Hz, 1H), 7.83 (dd, *J* = 8.9, 2.0 Hz, 1H), 7.51 (d, *J* = 7.2 Hz, 4H), 7.40-7.37 (m, 2H), 7.35-7.33 (m, 4H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 154.3, 153.8, 141.8, 140.0, 138.8, 138.7, 133.6, 131.5, 130.6, 129.9, 129.9, 129.2, 129.1, 128.4, 128.4, 123.9.

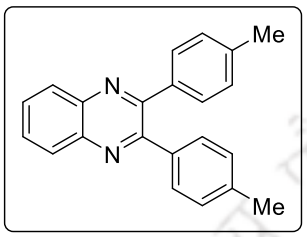
6-nitro-2,3-diphenylquinoxaline (4.2f)[45a]



This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. Yellow solid (191 mg, 58%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 9.07 (d, *J* = 2.4 Hz, 1H), 8.58-8.47(m, 1H), 8.29 (d, *J* = 9.1 Hz, 1H), 7.59 -

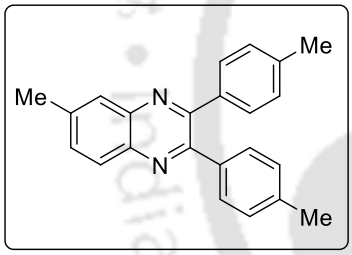
7.52 (m, 4H), 7.49-7.41 (m, 2H), 7.37 (t, *J* = 7.5 Hz, 4H). ^{13}C NMR (150, MHz, $CDCl_3$) δ 154.3, 153.8, 141.8, 140.0, 138.8, 138.7, 133.6, 131.5, 130.6, 129.9, 129.9, 129.2, 129.1, 128.4, 128.4, 123.9.

2,3-di-p-tolylquinoxaline (4.2g)[45a]



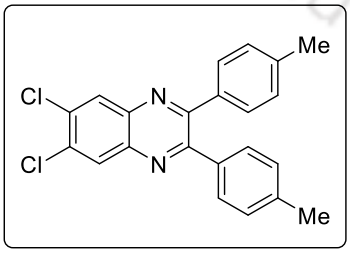
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (245 mg, 79%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.16 (dd, *J* = 6.4, 3.4 Hz, 2H), 7.33 (dd, *J* = 6.4, 3.4 Hz, 2H) 7.45 (d, *J* = 8.0 Hz, 4H), 7.16 (d, *J* = 7.9 Hz, 4H), 2.37 (s, 6H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 153.5, 141.2, 138.8, 136.4, 129.8, 129.7, 129.1, 129.0, 21.4.

6-methyl-2,3-di-p-tolylquinoxaline (4.2h)[45a]



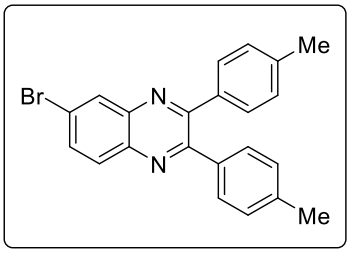
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (266 mg, 82%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.04 (d, *J* = 8.5 Hz, 1H), 7.93 (s, 1H), 7.56 (d, *J* = 8.5 Hz, 1H), 7.47 - 7.41 (m, 4H), 7.14 (d, *J* = 8.1 Hz, 4H), 2.60 (s, 3H), 2.37 (s, 6H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 153.3, 152.6, 141.2, 140.1, 139.6, 138.6, 138.5, 136.5, 132.0, 129.8, 129.7, 129.0, 128.6, 128.0, 21.9, 21.4.

6,7-dichloro-2,3-di-p-tolylquinoxaline (4.2i):



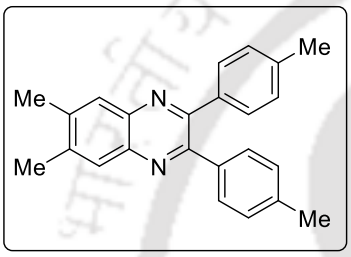
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (299 mg, 77%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.23 (s, 2H), 7.41 (d, *J* = 8.2 Hz, 4H), 7.15 (d, *J* = 8.0 Hz, 4H), 2.38 (s, 6H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 154.5, 139.9, 139.4, 135.7, 134.0, 129.8, 129.7, 129.1, 21.5. HRMS (ESI) calcd for $C_{22}H_{17}N_2Cl_2$ $[M + H]^+$: 379.0769; found, 379.0770.

6-bromo-2,3-di-p-tolylquinoxaline (4.2j)[45d]



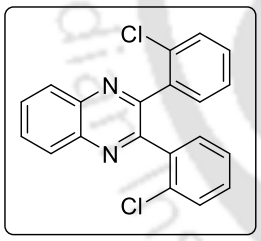
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (287 mg, 74%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.33 (d, *J* = 2.1 Hz, 1H), 8.00 (d, *J* = 8.9 Hz, 1H), 7.79 (dd, *J* = 8.9, 1.9 Hz, 1H), 7.43 (d, *J* = 8.1 Hz, 4H), 7.15 (d, *J* = 8.0 Hz, 4H), 2.37 (s, 6H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 154.3, 153.8, 141.7, 139.9, 139.22, 139.1, 136.1, 136.0, 133.2, 131.4, 130.5, 129.8, 129.7, 129.1, 129.1, 123.5, 21.5.

6,7-dimethyl-2,3-di-p-tolylquinoxaline (4.2k)[45a]



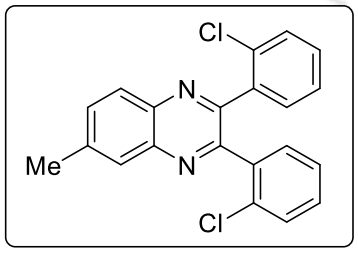
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (287 mg, 85%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.90 (s, 2H), 7.42 (d, *J* = 8.0 Hz, 4H), 7.13 (d, *J* = 8.0 Hz, 4H), 2.49 (s, 6H), 2.36 (s, 6H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 152.5, 140.2, 140.1, 138.4, 136.7, 129.7, 128.9, 128.1, 21.4, 20.4.

2,3-bis(2-chlorophenyl)quinoxaline (4.2l)[45e]



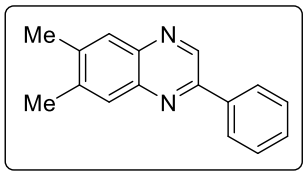
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (253 mg, 72%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.15 (dd, *J* = 6.4, 3.4 Hz, 2H), 7.76 (dd, *J* = 6.0, 3.2 Hz, 2H), 7.37 (s, 2H), 7.22 (d, *J* = 7.8 Hz, 2H), 7.18-7.13 (m, 4H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 152.7, 141.3, 137.3, 131.3, 130.7, 130.2, 129.6, 129.5, 126.5.

2,3-bis(2-chlorophenyl)-6-methylquinoxaline (4.2m)



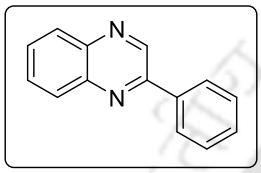
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (284 mg, 78%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.11 (d, *J* = 8.6 Hz, 1H), 8.00 (s, 1H), 7.67 (d, *J* = 8.5 Hz, 1H), 7.44 (s, 2H), 7.30 (d, *J* = 7.5 Hz, 2H), 7.24-7.19 (m, 4H), 2.62 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 152.5, 151.7, 141.3, 141.3, 139.8, 137.4, 137.4, 133.0, 131.3, 131.2, 130.09, 130.07, 129.6, 128.9, 128.2, 126.4, 126.4, 22.0.

6,7-dimethyl-2-phenylquinoxaline (4.2n)[45f]



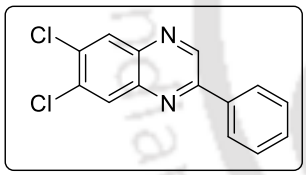
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. Yellow solid (182 mg, 78%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.20 (s, 1H), 8.15 (d, *J* = 7.0 Hz, 2H), 7.88 (s, 1H), 7.83 (s, 1H) 7.56 - 7.47 (m, 3H), 2.48 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 151.1, 142.5, 141.3, 140.9, 140.6, 140.2, 137.2, 129.9, 129.2, 128.7, 128.2, 127.5, 20.5, 20.4.

2-phenylquinoxaline (4.2o)[45f]



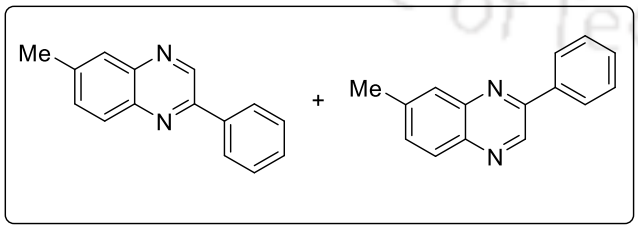
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (136 mg, 66%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.32 (s, 1H), 8.20 - 8.11 (m, 4H), 7.80 - 7.73 (m, 2H), 7.59 - 7.51 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.0, 143.5, 142.4, 141.7, 136.9, 130.4, 130.3, 129.8, 129.7, 129.29, 129.26, 127.7.

6,7-dichloro-2-phenylquinoxaline (4.2p)[45f]



This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. Pale yellow solid (176 mg, 64%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.32 (s, 1H), 8.27 (s, 1H), 8.23 (s, 1H), 8.18 (dd, *J* = 7.8, 1.7 Hz, 2H), 7.61 - 7.52 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.7, 144.3, 141.1, 140.3, 136.0, 134.9, 134.0, 130.8, 130.2, 129.8, 129.3, 127.6.

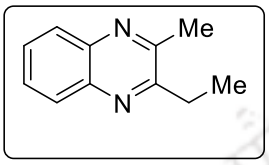
6-methyl-2-phenylquinoxaline & 7-methyl-2-phenylquinoxaline (4.2q : 4.2q′ = 45: 55)[45f]



This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. Brown solid (161 mg, 74%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 9.28 (s, 1H), 9.26 (s, 1H), 8.18 (dd, *J* = 7.0, 4.1 Hz, 4H), 8.05 (d, *J* = 8.5 Hz, 1H), 8.01 (d, *J* = 8.5 Hz, 1H), 7.93 (s, 1H), 7.89 (s, 1H), 7.61 (d, *J* = 8.5 Hz, 1H), 7.57 (t, *J* = 7.0 Hz, 5H), 7.52

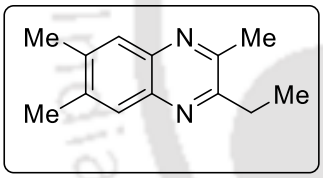
(dd, *J* = 6.9, 3.5 Hz, 2H), 2.61 (s, 6H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 151.8, 151.1, 143.3, 142.5, 142.4, 141.6, 140.9, 140.8, 140.2, 140.1, 137.0, 132.7, 131.9, 130.1, 130.0, 129.2, 128.6, 128.5, 128.0, 127.6, 127.5, 21.9, 21.9.

2-ethyl-3-methylquinoxaline (4.2r)[45e]



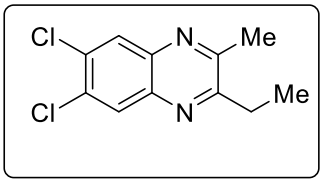
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 36 h. White solid (89 mg, 52%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.95 - 7.90 (m, 2H), 7.60 - 7.57 (m, 2H), 2.94 (q, *J* = 7.6 Hz, 2H), 2.76 (s, 3H), 1.34 (t, *J* = 7.5 Hz, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 157.5, 153.0, 141.2, 140.8, 128.8, 128.7, 128.5, 128.2, 29.0, 22.7, 12.0.

2-ethyl-3,6,7-trimethylquinoxaline (4.2s)[45g]



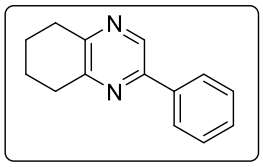
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 36 h. White solid (114 mg, 56%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.74 (s, 1H), 7.70 (s, 1H), 2.97 (q, *J* = 7.5 Hz, 2H), 2.70 (s, 3H), 2.44 (s, 6H), 1.37 (t, *J* = 7.5 Hz, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 156.6, 152.0, 140.2, 139.9, 139.1, 139.0, 127.8, 127.5, 29.0, 22.7, 20.4, 20.3, 12.2.

6,7-dichloro-2-ethyl-3-methylquinoxaline (4.2t)[45h]



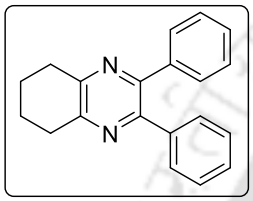
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 36 h. Yellow solid (128 mg, 53%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.09 (s, 1H), 8.04 (s, 1H), 2.99 (q, *J* = 7.4 Hz, 2H), 2.71 (s, 3H), 1.39 (t, *J* = 7.4 Hz, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 158.9, 154.7, 140.1, 139.7, 133.1, 133.0, 129.5, 129.1, 29.0, 22.9, 11.6.

2-phenyl-5,6,7,8-tetrahydroquinoxaline (4.2u)[45i]



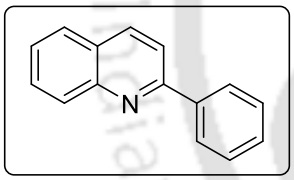
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. Colourless Oil (151mg, 72%) ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.74 (s, 1H), 7.98-7.96 (m, 2H), 7.49-7.47 (m, 2 H), 7.44 - 7.42 (m, 1H), 3.03-2.99 (m, 4H), 1.96-1.95 (m, 4H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 152.4, 151.2, 149.7, 138.8, 137.0, 129.3, 129.0, 126.8, 32.2, 31.7, 22.7.

2,3-diphenyl-5,6,7,8-tetrahydroquinoxaline (4.2v)[45j]



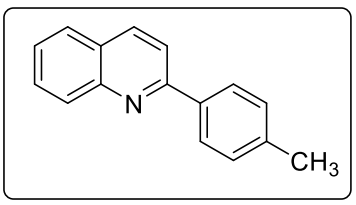
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 20 h. White solid (236 mg, 82%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.40 - 7.39 (m, 4H), 7.29 - 7.27 (m, 6H), 3.08 - 3.05 (m, 4H), 2.00 - 1.98 (m, 4 H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 150.6, 149.6, 139.1, 129.7, 128.3, 128.2, 31.9, 22.9.

2-phenylquinoline (4.6a)[46a]



This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (166 mg, 81%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.22 (d, *J* = 8.6 Hz, 1H), 8.20 - 8.16 (m, 3H), 7.88 (d, *J* = 8.6 Hz, 1H), 7.83 (d, *J* = 8.1 Hz, 1H), 7.74 (ddd, *J* = 8.4, 6.9, 1.4 Hz, 1H), 7.55 - 7.52 (m, 3H), 7.49 - 7.46 (m, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 157.5, 148.4, 139.8, 136.9, 129.9, 129.8, 129.4, 129.0, 127.7, 127.6, 127.3, 126.4, 119.2.

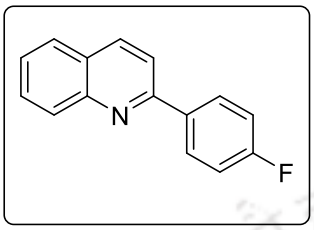
2-(4-Tolyl)quinoline (4.6b) [46a]



This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. Pale yellow oil (180 mg, 83%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.20 (d, *J* = 8.4 Hz, 1H), 8.17 (d, *J* = 8.6 Hz, 1H), 8.10 (d, *J* = 8.1 Hz, 2H), 7.85 (d, *J* = 8.6 Hz, 1H), 7.81 (d, *J* = 8.0 Hz, 1H), 7.74 (t, *J* = 7.5 Hz, 1H), 7.52 (t, *J* = 7.3 Hz, 1H), 7.35 (d, *J* = 8.0 Hz, 2H), 2.45 (s, 3H). ^{13}C NMR (150 MHz,

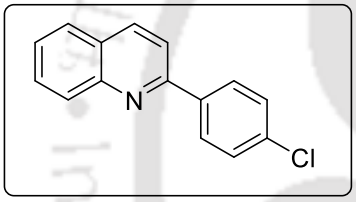
$CDCl_3$) δ 157.4, 148.3, 139.5, 136.9, 136.7, 129.7, 129.6, 127.5, 127.5, 127.1, 126.1, 118.9, 21.4.

2-(4-fluorophenyl)quinoline (4.6c) [46a]



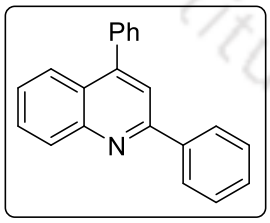
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. Pale yellow solid (173 mg, 78%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.19 - 8.14 (m, 4H), 7.82 - 7.79 (m, 2H), 7.73 (ddd, *J* = 8.4, 6.8, 1.4 Hz, 1H), 7.54-7.51 (m, 1H), 7.23-7.19 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 163.8 (d, *J* = 249.2 Hz), 156.2, 148.2, 136.9, 135.8 (d, *J* = 2.9 Hz), 129.8, 129.6, 129.5 (d, *J* = 8.6 Hz), 127.6, 127.1, 126.4, 118.7, 115.9 (d, J = 21.6 Hz).

2-(4-chlorophenyl)quinoline (4.6d) [46a]



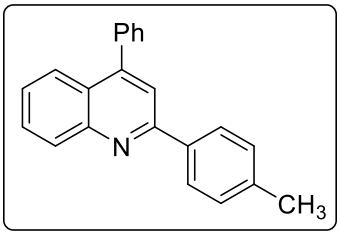
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (205 mg, 86%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.20 (d, *J* = 8.5 Hz, 1H), 8.16 (d, *J* = 8.5 Hz, 1H), 8.11 (d, *J* = 8.6 Hz, 2H), 7.85 - 7.78 (m, 2H), 7.74 (ddd, *J* = 8.4, 6.8, 1.5 Hz, 1H), 7.54 (t, *J* = 7.5 Hz, 1H), 7.49 (d, *J* = 8.5 Hz, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 156.1, 148.3, 138.1, 137.1, 135.6, 129.9, 129.8, 129.1, 128.9, 127.6, 127.3, 126.6, 118.7.

2,4-diphenylquinoline (4.6e) [44]



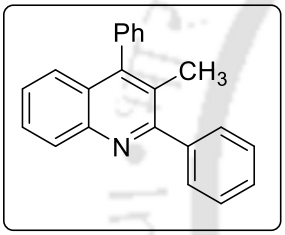
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. Brown solid (216 mg, 77%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.28 (d, *J* = 8.4 Hz, 1H), 8.22 (d, *J* = 7.2 Hz, 2H), 7.93 (d, *J* = 8.4 Hz, 1H), 7.84 (s, 1H), 7.75 (ddd, *J* = 8.3, 6.9, 1.3 Hz, 1H), 7.62 - 7.51 (m, 7H), 7.51 - 7.46 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 156.0, 149.3, 148.9, 139.7, 138.5, 130.2, 129.7, 129.6, 129.4, 128.9, 128.7, 128.5, 127.7, 126.4, 125.8, 125.7, 119.5.

4-phenyl-2-(p-tolyl)quinoline (4.6f) [44]



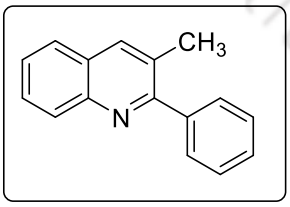
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. Slightly yellow solid (233 mg, 79%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.32 - 8.28 (m, 1H), 8.15 (app. t, *J* = 7.7 Hz, 2H), 7.95 - 7.92 (m, 1H), 7.84 (s, 1H), 7.76 (app. t, *J* = 7.5 Hz, 1H), 7.60-7.52 (m, 5H), 7.48 (app. t, *J* = 7.6 Hz, 1H), 7.37 - 7.36 (m, 2H), 2.47 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 156.8, 149.0, 148.8, 139.4, 138.5, 136.8, 130.1, 129.6, 129.5, 128.6, 128.4, 127.5, 126.2, 125.7, 125.6, 119.2, 21.4.

3-methyl-4-phenyl-2-(p-tolyl)quinoline (4.6g)[44]



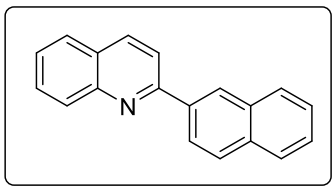
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. Yellow solid (251 mg, 85%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.17 (d, *J* = 8.4 Hz, 1H), 7.66-7.64 (m, 1H), 7.62 - 7.61 (m, 2H), 7.55 (app. t, *J* = 7.4 Hz, 2H), 7.51-7.48 (m, 3H), 7.44 (app. t, *J* = 7.4 Hz, 1H), 7.40 - 7.39 (m, 2H), 7.32 - 7.31 (m, 2H), 2.15 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 161.0, 147.9, 146.3, 141.6, 137.8, 129.5, 129.4, 129.0, 128.8, 128.7, 128.5, 128.2, 128.0, 127.2, 126.9, 126.4, 126.1, 18.7.

3-methyl-2-(p-tolyl)quinoline (4.6h)[46b]



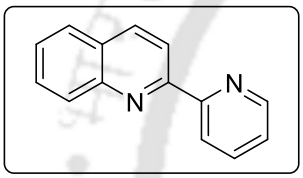
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. Yellow oil (165 mg, 75%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.14 (d, *J* = 8.4 Hz, 1H), 8.01 (s, 1H), 7.78 (d, *J* = 8.1 Hz, 1H), 7.68 - 7.65 (m, 1H), 7.60 (d, *J* = 7.9 Hz, 2H), 7.53 - 7.48 (m, 3H), 7.44 (t, *J* = 7.4 Hz, 1H), 2.49 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 160.6, 146.7, 140.9, 136.8, 129.3, 129.3, 128.9, 128.8, 128.4, 128.3, 127.7, 126.8, 126.5, 20.7.

2-(naphthalen-2-yl)quinoline (4.6i)[46b]



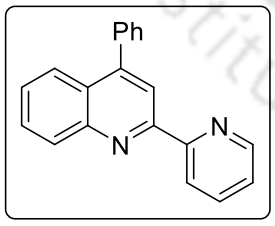
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (216 mg, 85%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.62 (s, 1H), 8.38 (dd, *J* = 8.6, 1.7 Hz, 1H), 8.25 (t, *J* = 7.6 Hz, 2H), 8.05 - 7.99 (m, 3H), 7.91 (dd, *J* = 5.9, 3.4 Hz, 1H), 7.85 (d, *J* = 7.8 Hz, 1H), 7.78 - 7.75 (m, 1H), 7.56 - 7.53 (m, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 157.3, 148.5, 137.1, 136.0, 134.0, 133.6, 129.9, 129.8, 128.9, 128.7, 127.8, 127.6, 127.3, 127.3, 126.8, 126.5, 126.5, 125.2, 119.3.

2-(pyridin-2-yl)quinoline (4.6j)[46b]



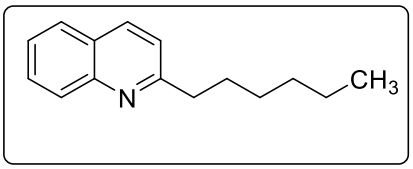
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. Yellow solid (152 mg, 75%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.74 (d, *J* = 4.7 Hz, 1H), 8.65 (d, *J* = 7.9 Hz, 1H), 8.56 (d, *J* = 8.6 Hz, 1H), 8.28 (d, *J* = 8.6 Hz, 1H), 8.18 (d, *J* = 8.5 Hz, 1H), 7.87 - 7.84 (m, 2H), 7.73 (t, *J* = 7.6 Hz, 1H), 7.55 (t, *J* = 7.5 Hz, 1H), 7.36 - 7.34 (m, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 156.4, 156.2, 149.3, 148.0, 137.1, 136.9, 129.9, 129.7, 128.3, 127.7, 126.9, 124.1, 121.9, 119.1.

2-(4-phenylnaphthalen-2-yl)pyridine (4.6k)[46c]



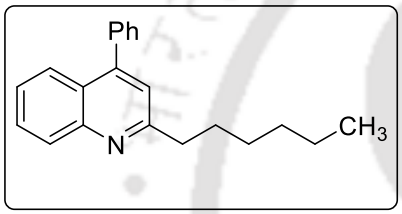
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. Yellow solid (186 mg, 66%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.73 (d, *J* = 4.0 Hz, 1H), 8.70 (d, *J* = 7.9 Hz, 1H), 8.53 (s, 1H), 8.26 (d, *J* = 8.4 Hz, 1H), 7.96 (d, *J* = 8.3 Hz, 1H), 7.89 (td, *J* = 7.8, 1.7 Hz, 1H), 7.77 - 7.72 (m, 1H), 7.62 - 7.58 (m, 2H), 7.56 - 7.46 (m, 4H), 7.40 - 7.34 (m, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 156.5, 155.7, 149.4, 149.3, 148.6, 138.5, 137.1, 130.3, 129.8, 129.5, 128.6, 128.4, 126.9, 126.9, 125.9, 124.2, 122.0, 119.4.

2-hexylquinoline (4.6l)[46d]



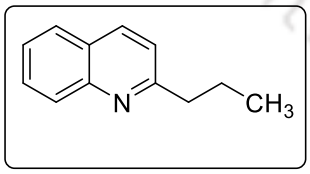
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 48 h. Pale yellow oil (130 mg, 61%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.97 - 7.94 (m, 2H), 7.66 (d, *J* = 8.1 Hz, 1H), 7.59 - 7.56 (m, 1H), 7.39 - 7.36 (m, 1H), 7.19 (dd, *J* = 8.9, 3.3 Hz, 1H), 2.87 (t, *J* = 8.0, Hz, 2H), 1.74 - 1.68 (m, 2H), 1.35 - 1.30 (m, 2H), 1.26 - 1.20 (m, 4H), 0.79 (t, *J* = 7.0 Hz, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 163.2, 147.9, 136.3, 129.4, 128.8, 127.55, 126.8, 125.7, 121.4, 39.5, 31.8, 30.2, 29.3, 22.7, 14.2.

2-hexyl-4-phenylquinoline (4.6m)[46e]



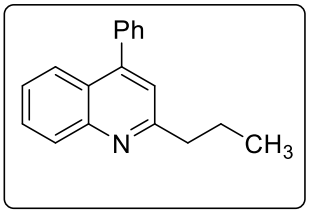
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 48 h. Pale yellow oil (185 mg, 64%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.12 (d, *J* = 8.5 Hz, 1H), 7.87 (d, *J* = 8.4 Hz, 1H), 7.70 - 7.67 (m, 1H), 7.54 - 7.47 (m, 5H), 7.43 (t, *J* = 7.6 Hz, 1H), 7.25 (s, 1H), 3.02 - 2.99 (m, 2H), 1.87-1.82 (m, 2H), 1.78 - 1.43 (m, 2H), 1.36 - 1.31 (m, 4H), 0.89 (t, *J* = 6.9 Hz, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 162.8, 148.6, 148.5, 138.4, 129.6, 129.3, 129.3, 128.6, 128.4, 125.8, 125.7, 125.4, 121.7, 39.5, 31.9, 30.2, 29.4, 22.7, 14.2.

2-propylquinoline (4.6n)[46a]



This compound was prepared using general experiential procedure-**B**. Reaction was completed after 48 h. Colorless oil (101 mg, 58%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.04 (dd, *J* = 8.4, 3.2 Hz, 2H), 7.75 (d, *J* = 8.1 Hz, 1H), 7.67 (t, *J* = 7.7 Hz, 1H), 7.46 (t, *J* = 7.5 Hz, 1H), 7.28 (d, *J* = 8.4 Hz, 1H), 3.08 - 2.83 (m, 2H), 1.87 - 1.81 (m, 2H), 1.01 (t, *J* = 7.4 Hz, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 163.0, 147.9, 136.3, 129.4, 128.8, 127.6, 126.8, 125.7, 121.5, 41.4, 23.4, 14.1.

4-phenyl-2-propylquinoline (4.6o)[46f]



This compound was prepared using general experiential procedure-**B**. Reaction was completed after 48 h. Colorless oil (153mg, 62%). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.12 (d, *J* = 8.4 Hz, 1H), 7.87 (d, *J* = 8.3 Hz, 1H), 7.69 (t, *J* = 7.3 Hz, 1H), 7.54 - 7.47 (m, 5H), 7.43 (t, *J* = 7.5 Hz, 1H), 7.25 (s, 1H), 3.05 - 2.92 (m, 2H), 1.92 - 1.85 (m, 2H), 1.05 (t, *J* = 7.4 Hz, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 162.5, 148.6, 148.5, 138.4, 129.6, 129.3, 129.3, 128.6, 128.4, 125.8, 125.7, 125.4, 121.8, 41.4, 23.5, 14.2.

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4.8. Selected NMR spectra of products:

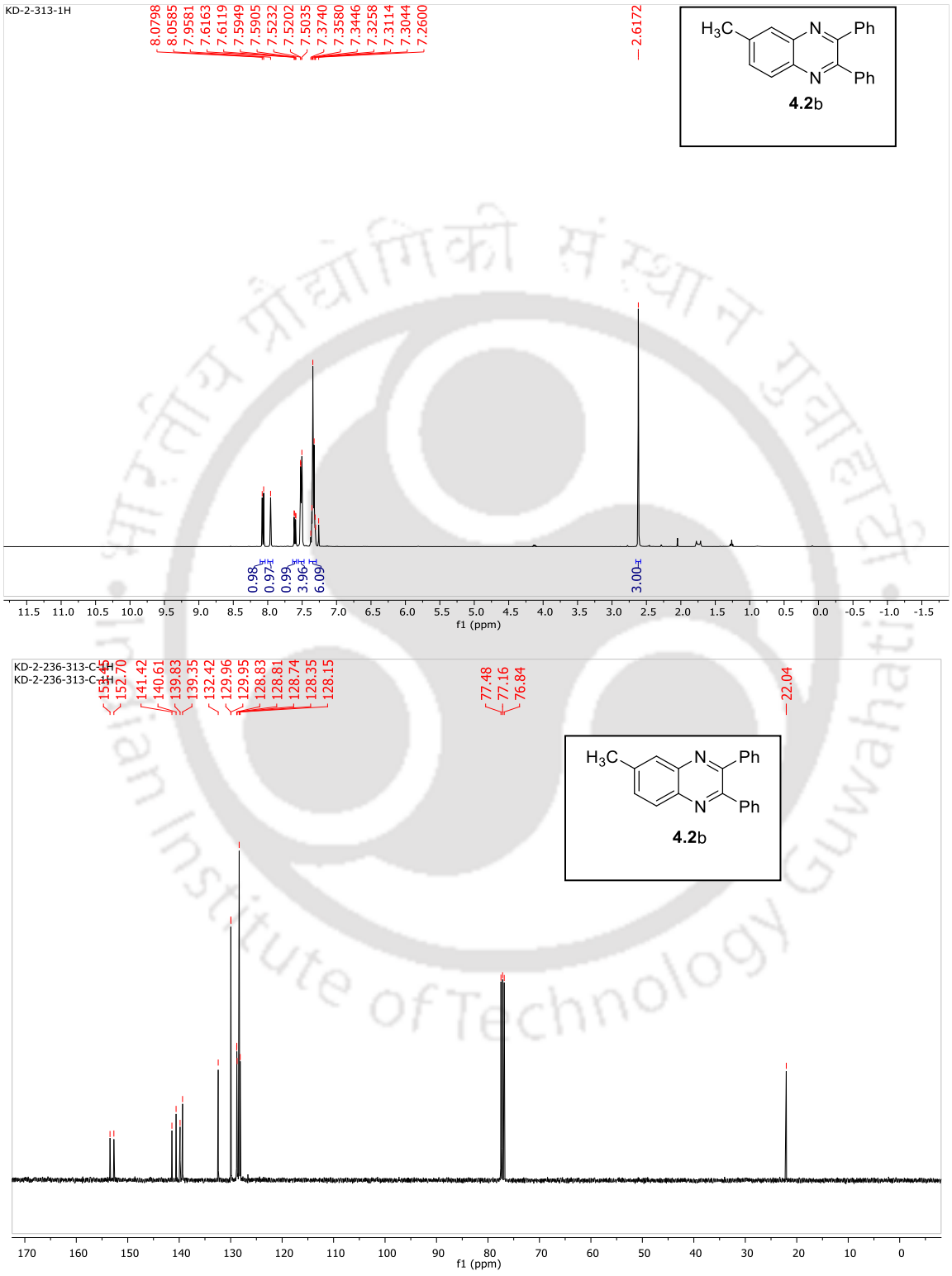


Figure 4.2: ^{1}H and ^{13}C of compound **4.2b**.

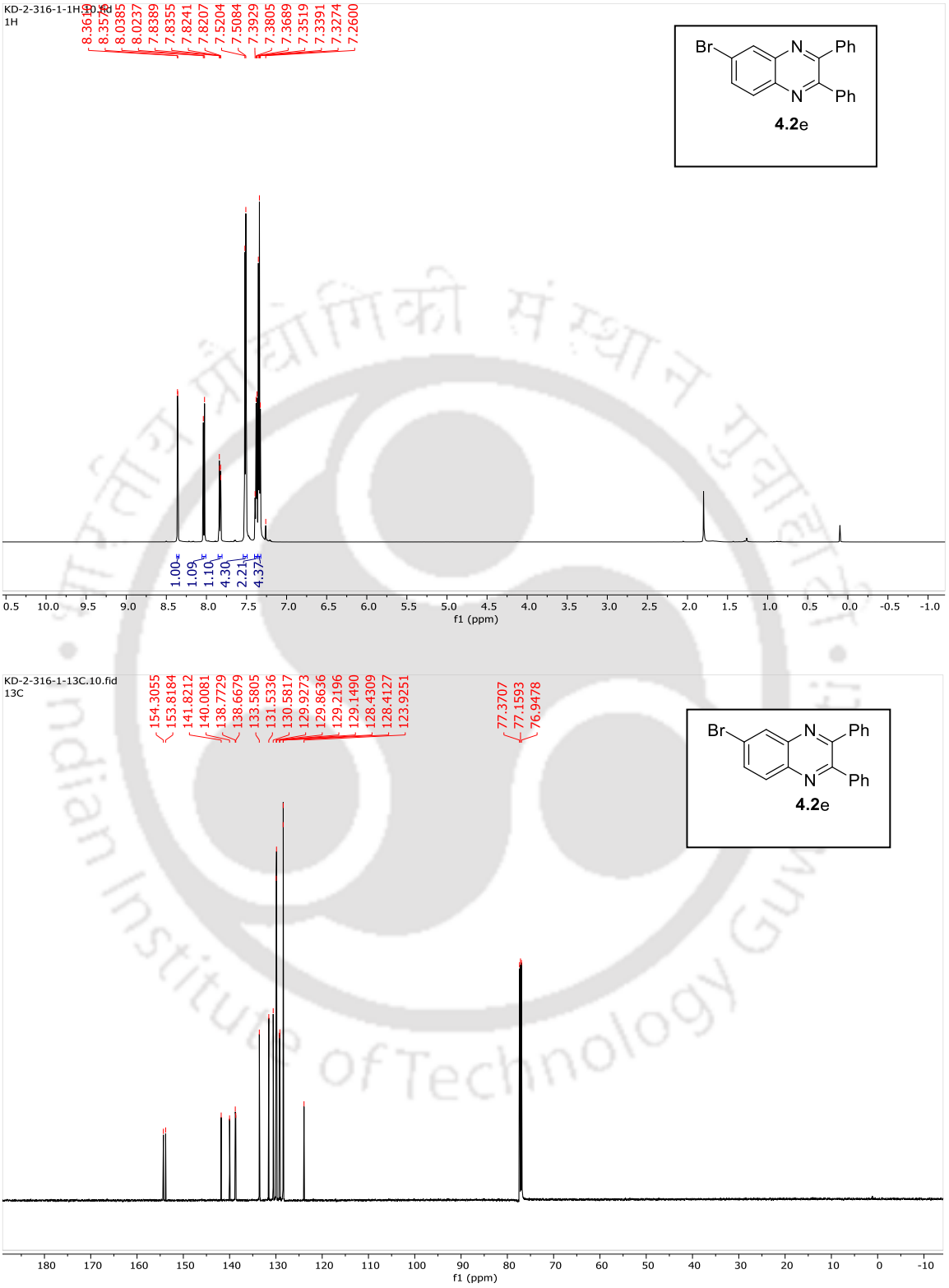


Figure 4.3: ^{1}H and ^{13}C of compound **4.2e**.

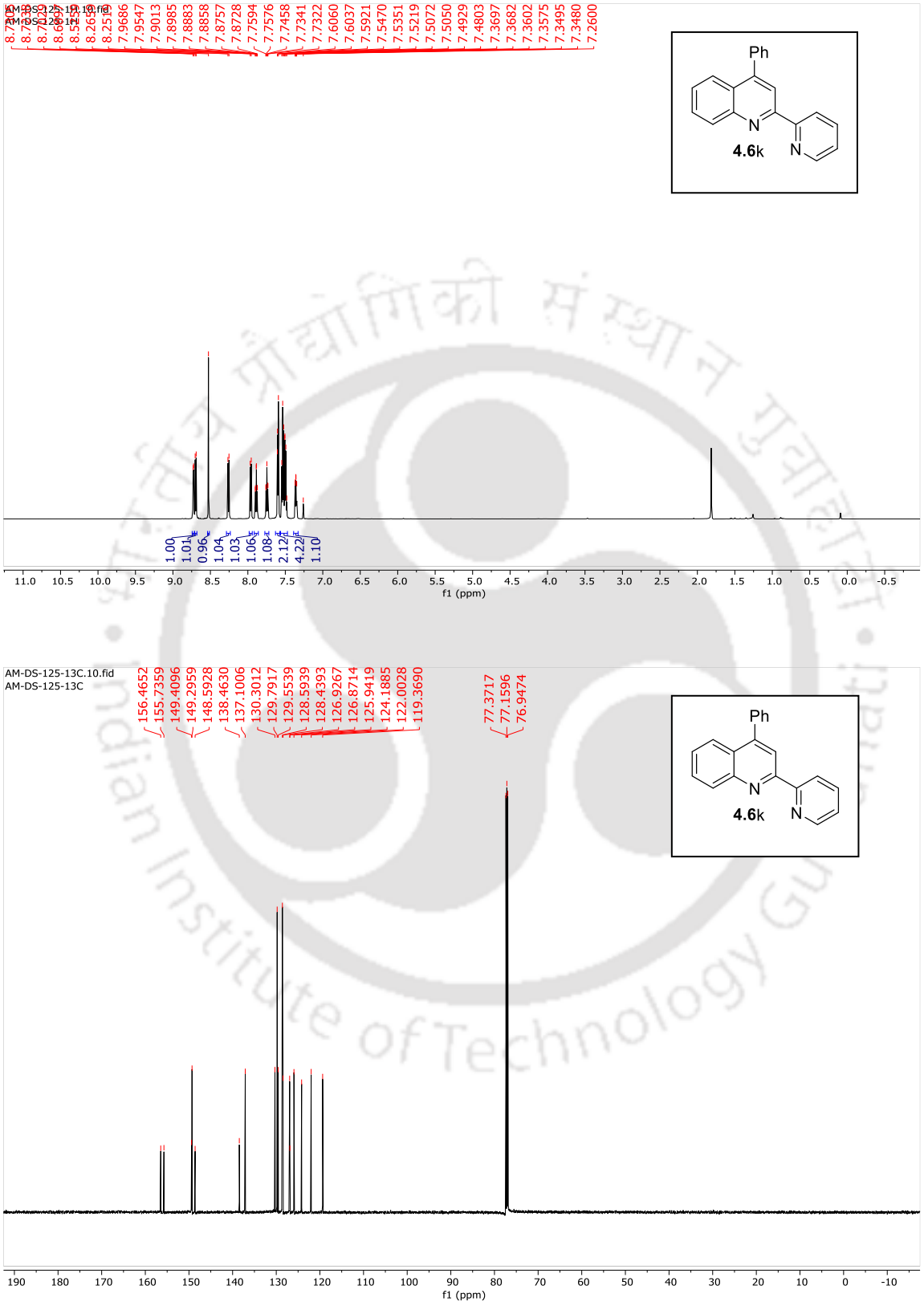


Figure 4.4: ^{1}H and ^{13}C of compound **4.6k**.

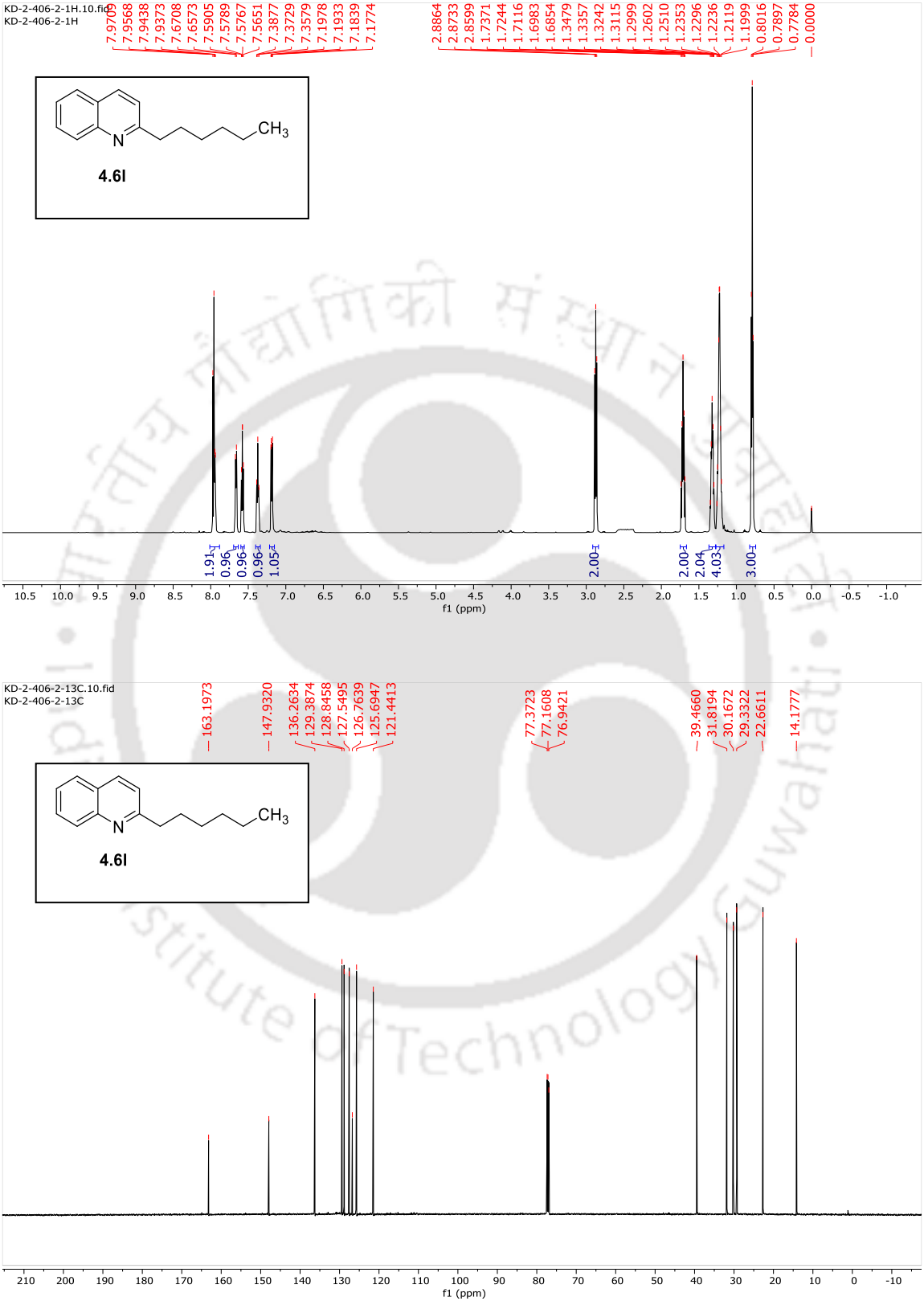


Figure 4.5: ^{1}H and ^{13}C of compound **4.6l**.

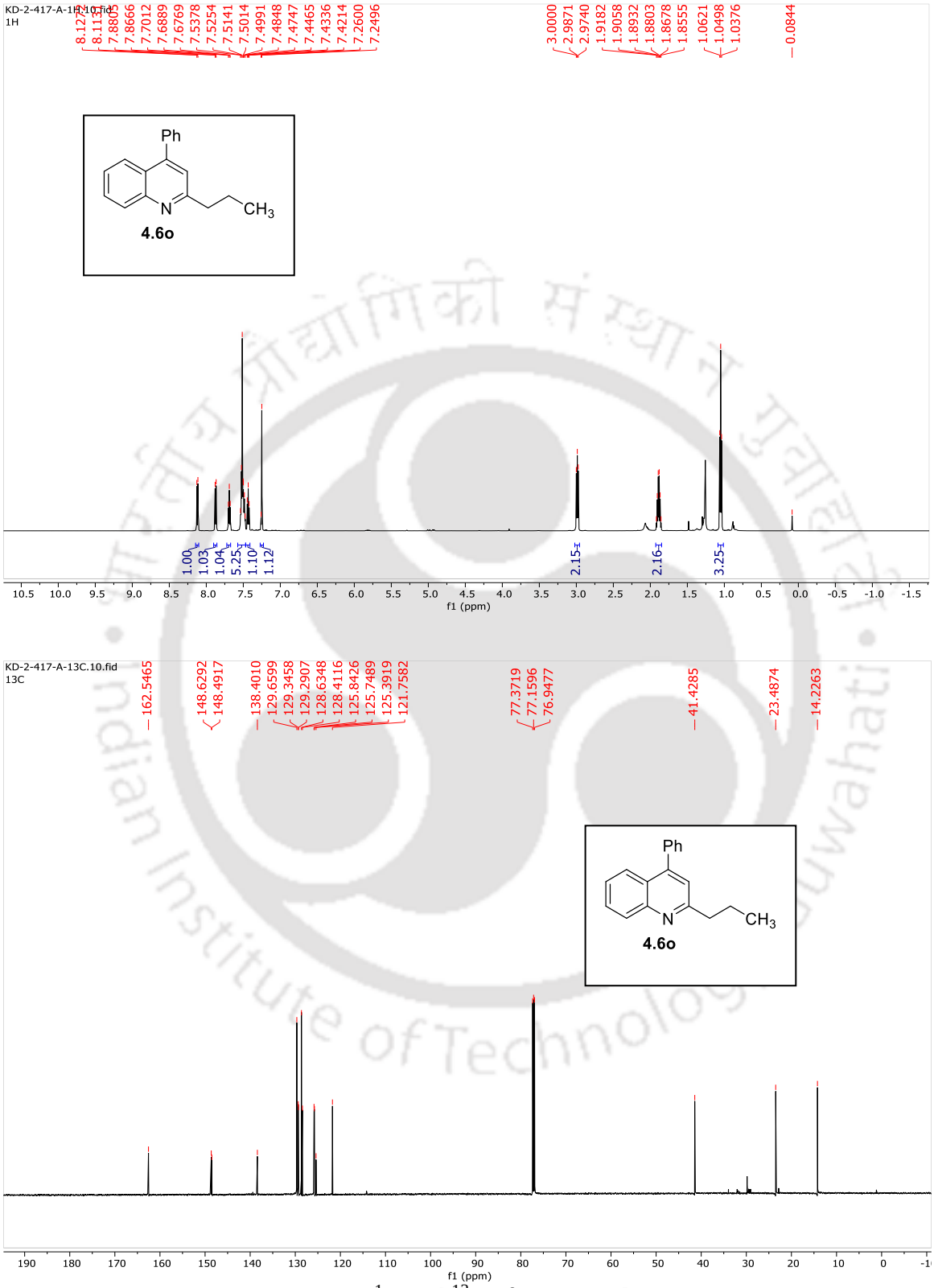


Figure 4.6: ^{1}H and ^{13}C of compound **4.6o**.

Chapter 5

Sustainable Synthesis of Quinazoline and 2-aminoquinoline via Dehydrogenative Coupling of 2-aminobenzyl alcohol and Nitrile Catalysed by Phosphine-free Manganese Pincer Complexes

5.1. Introduction:

In this chapter, I have demonstrated the sustainable synthesis of various heterocyclic building blocks such as quinazoline, 2-aminoquinoline and 2-alkylaminoquinoline derivatives *via* acceptorless dehydrogenative strategy. Quinazoline and its derivatives have attracted significant attention in organic synthesis as these structural scaffolds are found in many bio-active compounds.[1-6] Conventionally, various approaches for the synthesis of these heterocyclic compounds have been explored. But most of the synthetic methods require stoichiometric or excess amounts of strong oxidants, pre-functionalized starting materials or multistep reaction sequences. As these scaffolds are ubiquitous in many drugs[7-10] and due to their wide application in medicinal chemistry,[11-17] the development of new, green and atom-efficient synthetic protocols for accessing such compounds from renewable starting materials is highly demandable.

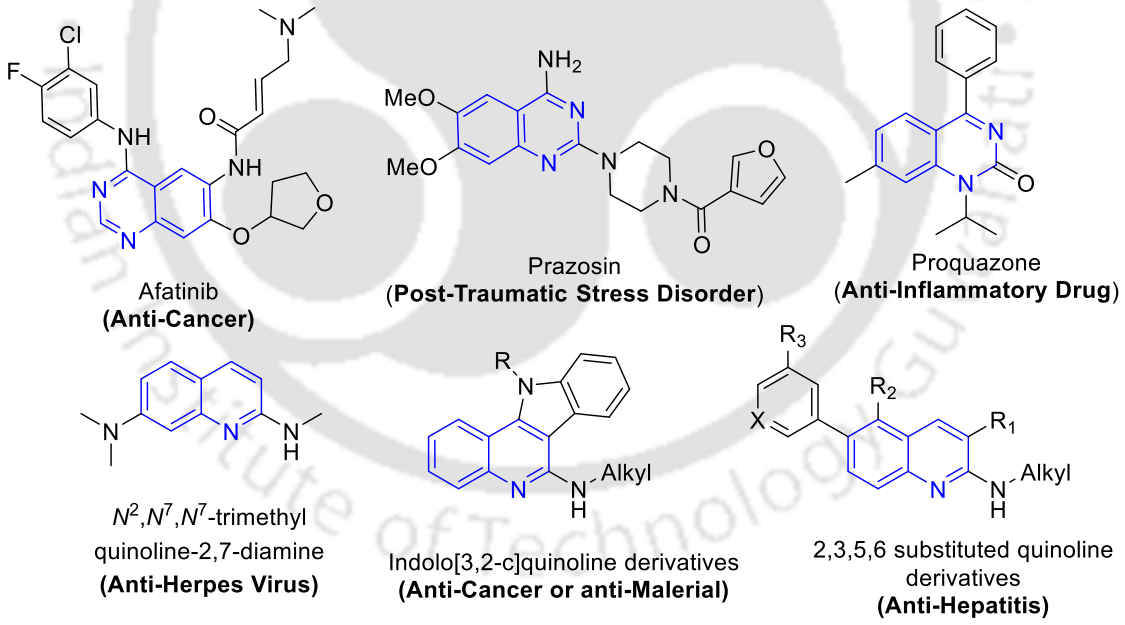


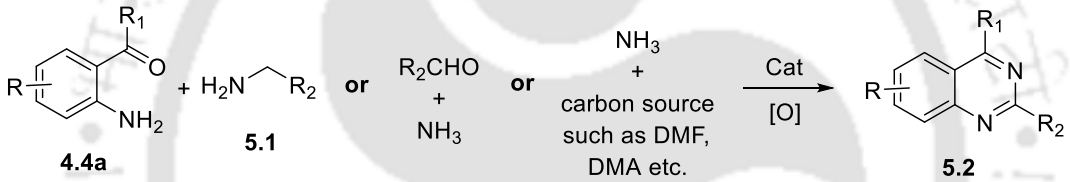
Figure 5.1: Some selected quinazoline and 2-alkylaminoquinoline containing drug molecules.

5.2. Strategies for quinazolines synthesis:

In the past few years, several different approaches have been developed to synthesize this type of compound. These mainly occur *via* (i) the oxidative condensation

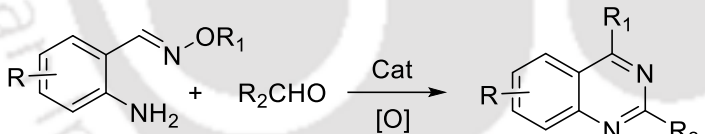
of *ortho*-carbonyl anilines with benzyl amines (**Scheme 5.1**, I)[18a,b] or ammonia and with various carbon sources;[18c-e] (ii) condensation reaction between oxime derivatives and aldehydes (**Scheme 5.1**, II);[19] (iii) oxidative coupling of *ortho*-carbonyl haloarenes with ammonia and aldehydes (**Scheme 5.1**, III);[20] (iv) intermolecular cyclization reaction of amidines with different *ortho*-carbonyl halobenzenes[21a] (**Scheme 5.1**, IV), 2-halobenzyl halides (**Scheme 5.1**, IV) [21b] or 2-halobenzyl tosylates (**Scheme 5.1**, IV),[21c] and 2-halobenzyl amines (**Scheme 5.1**, IV);[21d] (v) oxidative coupling of amidines with benzyl alcohols or arylaldehyde (**Scheme 5.1**, V)[21e] and hypervalent iodine-substituted alkynes (**Scheme 5.1**, V)[21f] and (vi) intramolecular oxidative annulation of *N*-alkylated arylamidines (**Scheme 5.1**, VI).[22]

I. Oxidative condensation:[18]



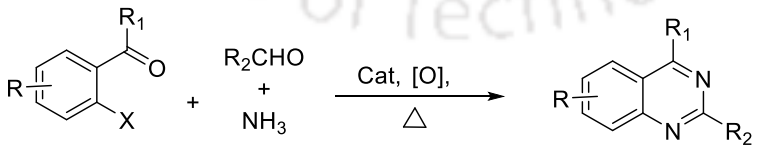
4.4a **5.1** **5.2**

II. Condensation of oxime:[19]



5.3a, R_1 = H
5.3b, R_1 = Ph
2.2a **5.2**

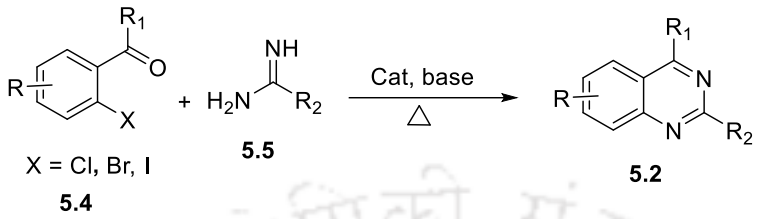
III. Oxidative coupling of *ortho*-carbonyl haloarenes:[20]



4.4a **5.2**

IV. Ullmann or Buchwald-Hartwig amination:[21a-d]

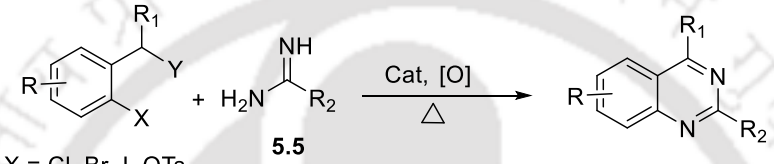
a)



X = Cl, Br, I

5.4 **5.5** **5.2**

b)

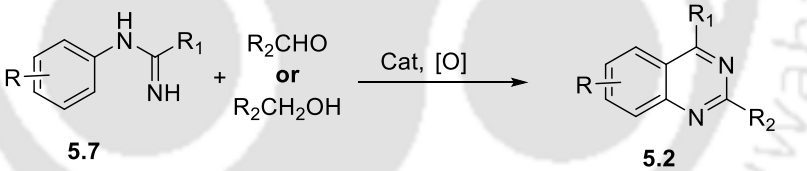


X = Cl, Br, I, OTs
Y = NH_2, Cl, Br,or I

5.6 **5.5** **5.2**

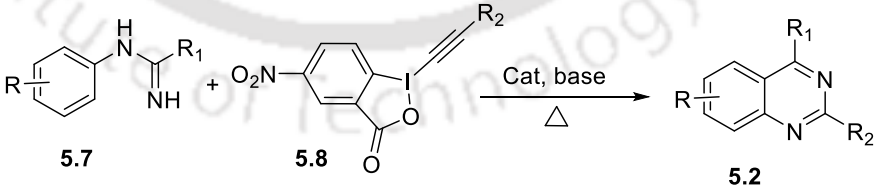
V. Oxidative coupling of amidine:[21e,f]

a)



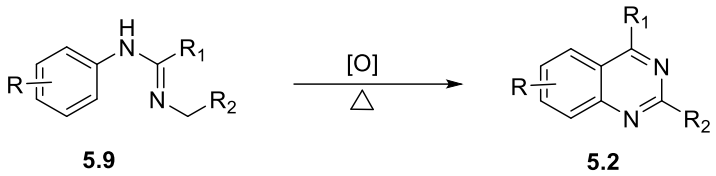
5.7 **5.2**

b)



5.7 **5.8** **5.2**

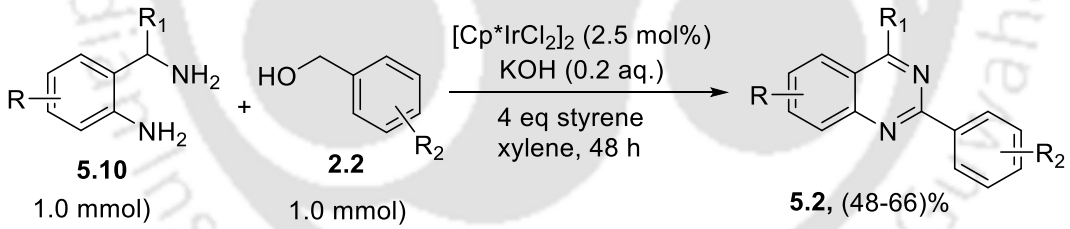
VI. Intramolecular oxidative cyclization:[22]



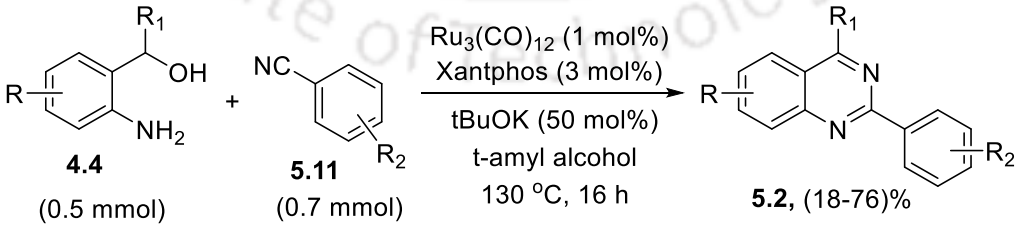
Scheme 5.1: Representative methods for synthesis of quinazolines.

Despite these contributions, most of these protocols involve less environmentally benign halogenated reagents or the use of special prefunctionalized starting material and/or the use of excess oxidants, which result in the preparation difficulties or create an adverse effect on the environment. Very recently, atom economical, environmentally benign dehydrogenative strategies have been accomplished to synthesize such type of heterocyclic compounds.

In 2013, *Zhou and groups* developed Ir-catalysed[23] quinazoline synthesis using 2-aminobenzylamine and benzyl alcohol. They have used excess amount of styrene as hydrogen acceptor to promote the reaction.



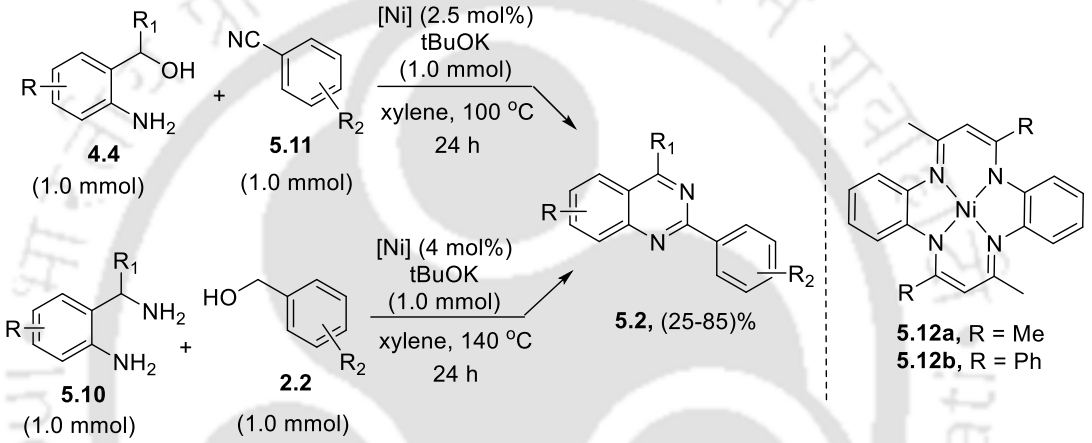
Scheme 5.2: Synthesis of quinazoline by Ir-catalyst from 2-aminobenzylamine and primary alcohol.



Scheme 5.3: Dehydrogenative synthesis of quinazoline by Ru-catalyst from 2-aminobenzylalcohol and nitrile.

In 2014, *Zhang and co-workers* have illustrated the synthesis of 2-arylquinazoline derivatives *via* acceptorless dehydrogenative coupling 2-aminobenzylalcohol and benzonitrile. The reaction is catalysed by 1 mol% $Ru_3(CO)_{12}$ [24] in presence of 3 mol% Xantphos ligand.

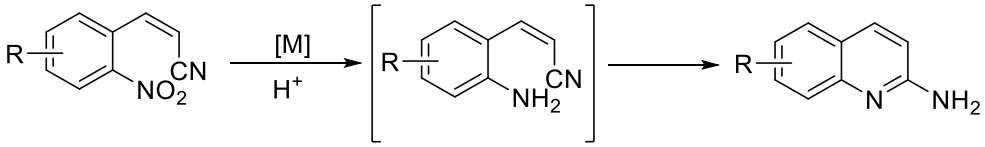
Very recently, earth-abundant Ni-complexes[25] **5.12a-b** have been applied for the synthesis of quinazoline derivative through the dehydrogenative coupling of 2-aminobenzylalcohol with benzonitrile or 2-aminobenzylamine with benzyl alcohol.



Scheme 5.4: Ni-catalysed synthesis of quinazoline from 2-aminobenzylamine and primary alcohol or 2-aminobenzylalcohol and nitrile.

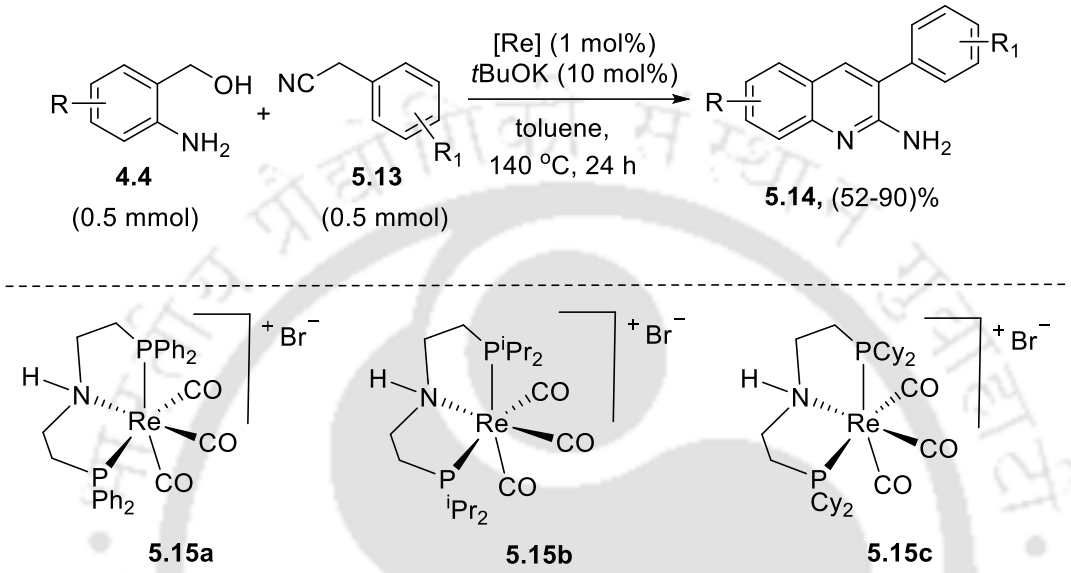
5.3. Strategies for 2-aminoquinoline synthesis:

Conventionally, 2-aminoquinoline framework (**Scheme 5.5**) is synthesized by reductive cyclization of nitrophenyl acrylonitrile in the presence of a suitable reducing metal[26] under acidic conditions. The reaction is believed to proceed *via* insitu formation

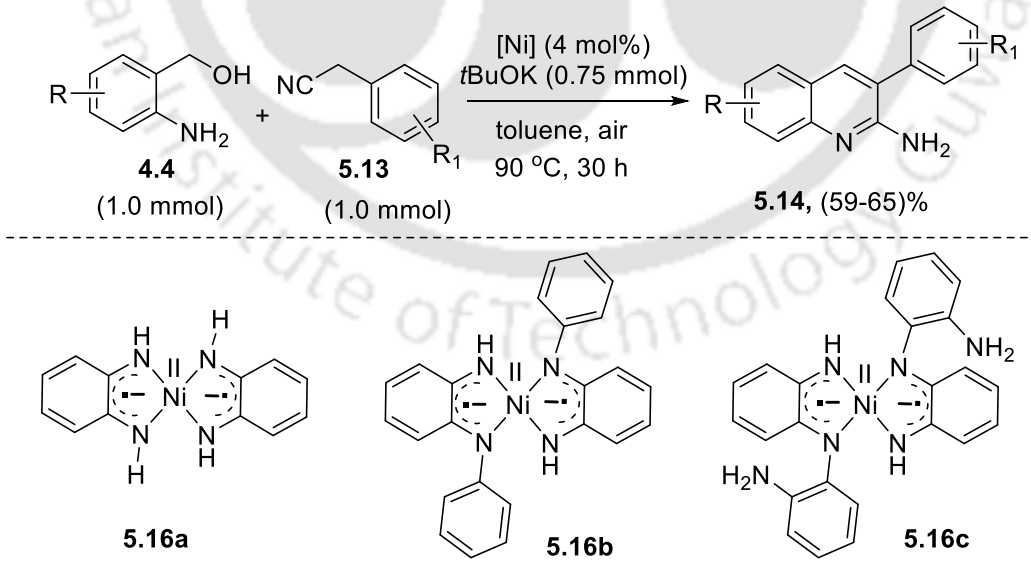


Scheme 5.5: Synthesis of 2-aminoquinoline by reductive cyclization of nitro phenyl acrylonitrile.

of aminocyano-olefin molecule. Recently, dehydrogenative synthesis of 2-aminoquinoline catalysed by rhenium PNP pincer complexes [27] was reported by *Sortais and co-workers*. The reaction gave moderate to excellent yield in presence of catalyst **5.15a** and 10 mol% *t*BuOK (**Scheme 5.6**).



Scheme 5.6: Synthesis of 2-aminoquinoline by Re-catalyst from 2-aminobenzylalcohol and phenyl acetonitrile derivatives.

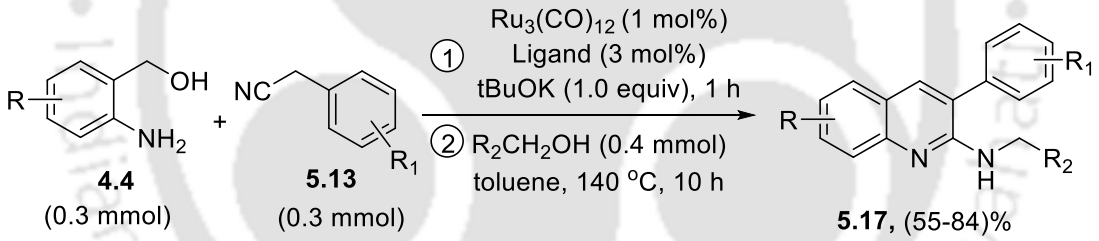


Scheme 5.7: Dehydrogenative synthesis of 2-aminoquinoline by Ni-catalyst from 2-aminobenzyl alcohol and phenyl acetonitrile derivatives.

Very recently, dehydrogenative annulation of 2-aminobenzylalcohol and nitrile was achieved by the use of Ni-catalysts[28] **5.16a-c** in toluene solvent. The catalyst **5.16c** was found to be the best among the three catalysts depicted in **Scheme 5.7**. They have found that 0.75 equivalents of *t*BuOK and O_2 are essential to promote the reaction.

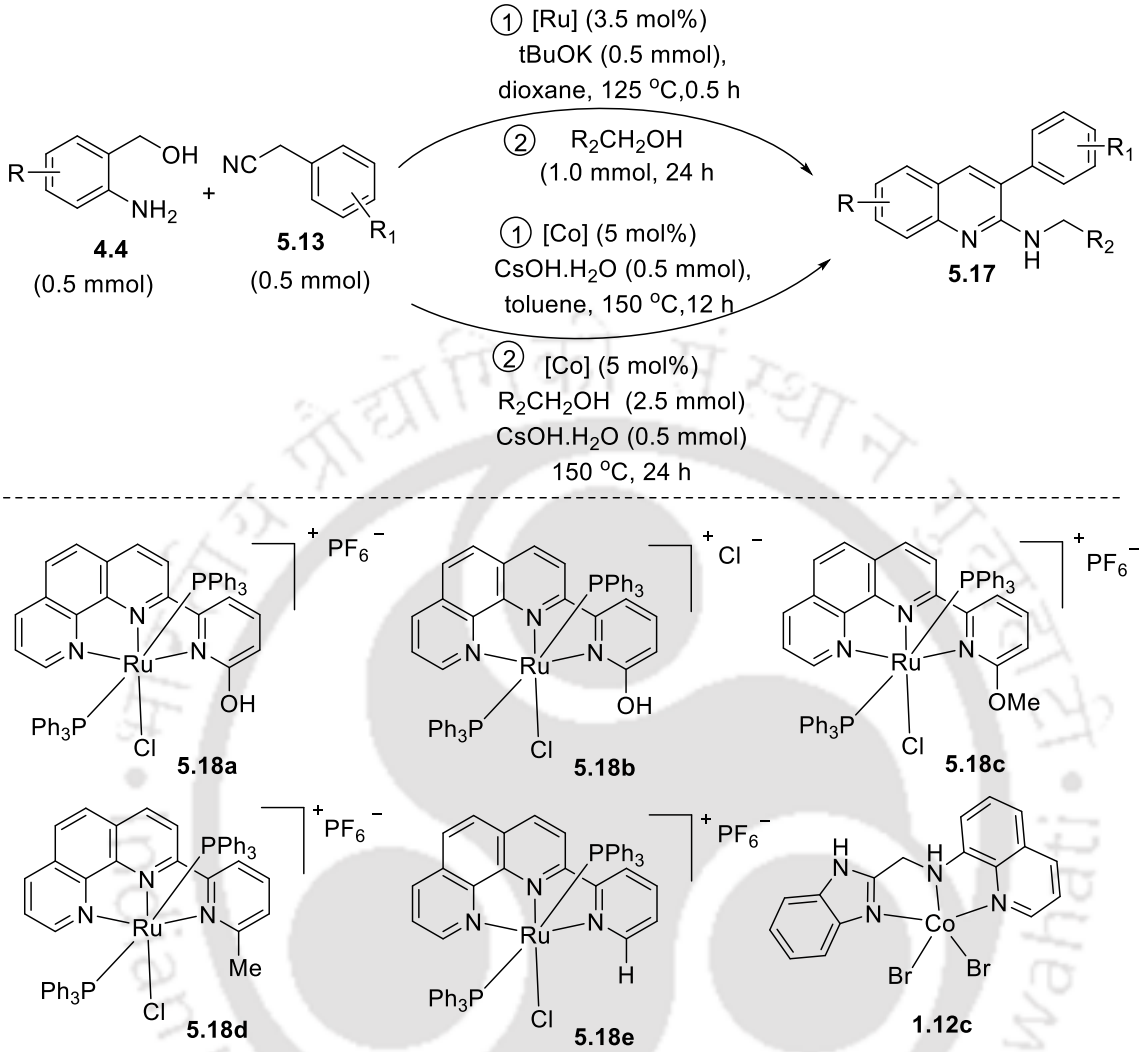
5.4. Synthesis of 2-alkylaminoquinolines through sequential dehydrogenative annulation and *N*-alkylation reaction:

In recent years, new efficient protocols to synthesize 2-alkylaminoquinolines were achieved *via* successive metal catalysed dehydrogenative annulation and *N*-alkylation processes. In 2017, *Zhang and group* synthesised 2-alkylaminoquinolines in a one-pot reaction from 2-aminobenzyl alcohol and nitrile followed by addition of alcohol in the presence of 1 mol% $Ru_3(CO)_{12}$ and 3 mol% ligand (*BINAP*) [31] in toluene at 140 °C temperature.



Scheme 5.8: Synthesis of 2-alkylaminoquinoline by Ru-catalyst from 2-aminobenzylalcohol, phenyl acetonitrile and primary alcohol derivatives.

In 2018, *Kundu and co-workers* applied a series of air and moisture stable bifunctional Ru-complexes **5.18a-e** to synthesize such types of 2-alkylaminoquinolines[32] in presence of 3.5 mol% catalyst and 0.5 mmol of *t*BuOK in dioxane medium. In the same year, they also demonstrated the catalytic efficacy of the earth-abundant cobalt complex **1.12c** toward the one-pot synthesis of 2-alkylaminoquinolines[33] in the presence $CsOH.H_2O$ (0.5 mmol) as a base. In that case they have used high temperature (150 °C).



Scheme 5.9: Synthesis of 2-alkylaminoquinoline by Ru-catalyst/Co-catalyst from 2-aminobenzylalcohol, phenyl acetonitrile and primary alcohol derivatives.

A number of catalytic systems were developed for the synthesis of quinazoline and 2-aminoquinoline. However, the application of earth-abundant, biocompatible manganese toward the dehydrogenative coupling of 2-aminobenzyl alcohol and nitrile to synthesize such heterocycles is unexplored. Thus, study of the catalytic activity of different Mn-complexes toward such type of transformations is highly desirable.

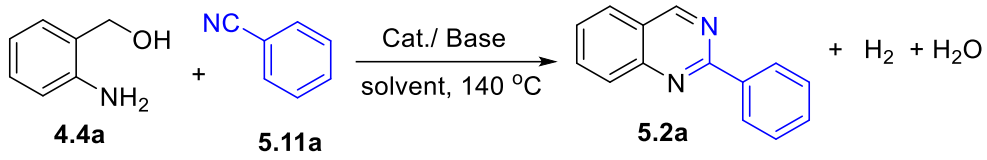
5.5. Present work:

Herein, Mn-catalyzed synthesis of quinazoline and 2-aminoquinoline through the dehydrogenative condensation of 2-aminobenzyl alcohol and nitriles were presented. In addition, synthesis of 2-alkylaminoquinolines has also been demonstrated *via* ADC reaction followed by *N*-alkylation process.

5.5.1. Optimisation reaction condition for the synthesis of quinazoline:

Initially, to find out the optimum conditions for the synthesis of quinazoline, various reaction parameters were varied, taking 2-aminobenzyl alcohol and benzonitrile as model substrates. First, a xylene solution containing an equimolar mixture 2-aminobenzyl alcohol and benzonitrile was refluxed in presence of 5 mol % cat **2.12a** and 0.5 mmol *t*BuOK. 68% desired quinazoline was isolated after 36 hours (**Table 5.1**, entry 1). The yield was further improved to 86% just by increasing the ratio of 2-aminobenzyl alcohol and benzonitrile (**Table 5.1**, entry 2). When the reaction was performed under in toluene solvent or neat condition, the yield of the desired product was decreased (**Table 5.1**, entries 6 and 8). An investigation on the influence of base showed that *t*BuOK was more effective than KOH or Cs_2CO_3, whereas K_3PO_4 showed comparable activity (**Table 5.1**, entries 9-11). Under the similar reaction condition, the catalyst **2.12b** and **2.12c** gave lower yield (70% and 58% respectively) of the desired 2-phenyl quinazoline (**Table 5.1**, entries 13 and 14). The reaction either in the absence of a catalyst or in the absence of base gave no detectable conversion (**Table 5.1**, entries 15, 16). Thus, the presence of both are essential for this protocol. Keeping the other conditions unaltered, when the catalyst loading was decreased from 5 mol% to 2 mol% the yield of desired product was dropped from 86% to 56% (**Table 5.1**, entries 12). $MnBr(CO)_5$ gave only 14% yield under the similar reaction condition.

Table 5.1: **Screening Table:**[a,b]



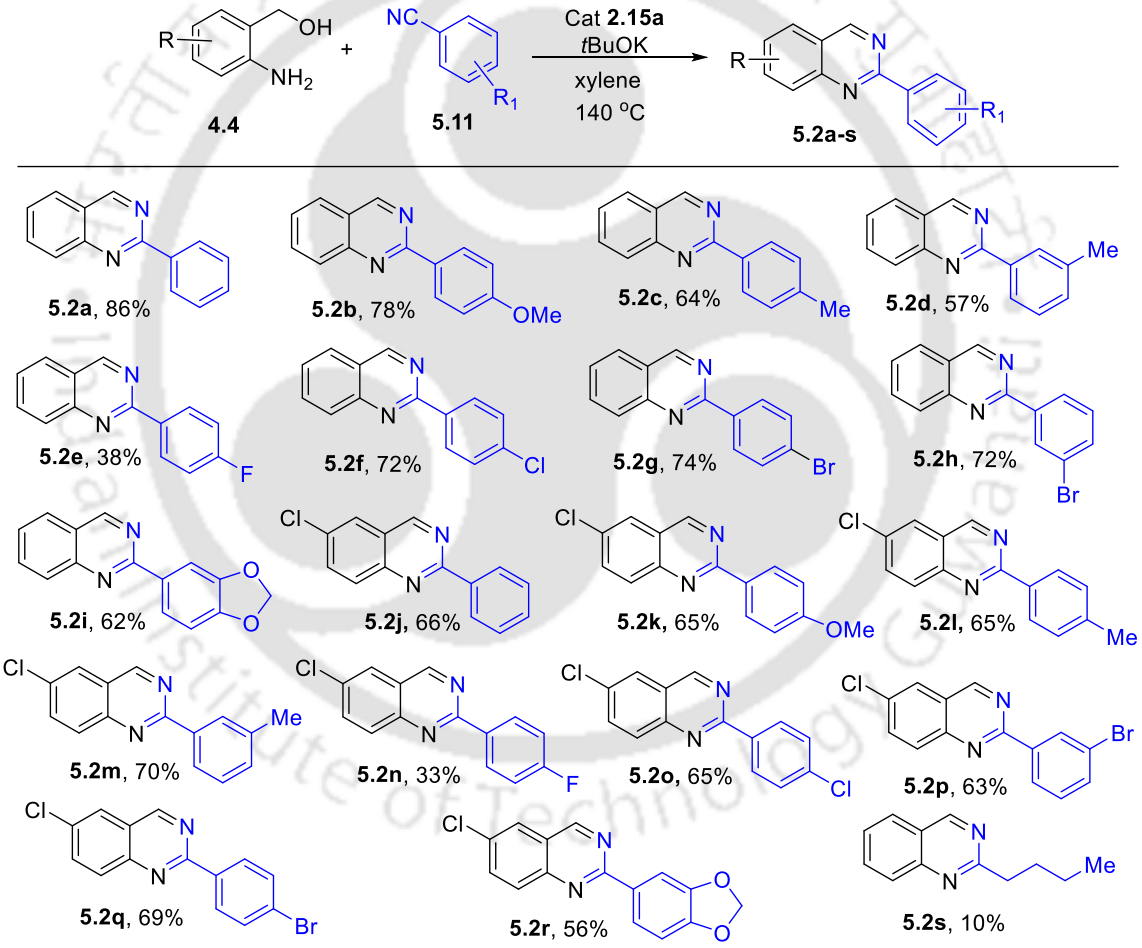
Exp. No.	Catalyst (mmol)	Solvent (1 ml)	Base (mmol)	Alcohol : nitrile (mmol)	Time (hours)	% of yield[b]
1	Cat **2.12a**	xylene	*t*BuOK	1 : 1	36	68
2	Cat 2.12a	xylene	*t*BuOK	1 : 1.5	36	86
3	**Cat 2.12a**	**xylene**	***t*BuOK**	**1 : 1.5**	**30**	**86**
4	Cat **2.12a**	xylene	*t*BuOK	1 : 1.2	30	69
5	Cat **2.12a**	xylene	*t*BuOK	1 : 1.5	15	38
6	Cat **2.12a**	toluene	*t*BuOK	1 : 1.5	30	62
7[c]	Cat **2.12a**	xylene	*t*BuOK	1 : 1.5	30	58
8	Cat **2.12a**	neat	*t*BuOK	1 : 1.5	30	65
9	Cat **2.12a**	xylene	KOH	1 : 1.5	30	72
10	Cat **2.12a**	xylene	Cs_2CO_3	1 : 1.5	30	52
11	Cat **2.12a**	xylene	K_3PO_4	1 : 1.5	30	84
12[d]	Cat **2.12a**	xylene	*t*BuOK	1 : 1.5	30	56
13	Cat **2.12b**	xylene	*t*BuOK	1 : 1.5	30	70
14	Cat **2.12c**	xylene	*t*BuOK	1 : 1.5	30	58
15	…….	xylene	*t*BuOK	1 : 1.5	30	trace
16	Cat **2.12a**	xylene	…….	1 : 1.5	30	trace
17	$Mn(CO)_5Br$	xylene	*t*BuOK	1 : 1.5	30	14

[a] Reaction conditions: 2-aminobenzyl alcohol (0.5 mmol), benzonitrile (0.5-1.5 mmol), base (0.5 mmol), cat (5 mol%), solvent (1 ml), 140 ^{0}C, under argon, [b] isolated yield. [c] 0.2 mmol *t*BuOK, [d] 2 mol% cat **2.12a**.

5.5.2. Substrate scope for quinazoline:

After optimizing the reaction condition, I tried to explore the generality and the limitations of this protocol. At first, 2-aminobenzyl alcohol was reacted with the nitriles bearing electron withdrawing and electron donating functionalities in the aromatic nucleus. In most of the cases, good yields of the desired quinazoline were isolated (**Table 5.2**). Chlorosubstituted 2-aminobenzyl alcohol also reacted well with various

Table 5.2: Synthesis of quinazolines from 2-aminobenzylalcohol derivatives and phenyl benzonitrile derivatives.[a,b]



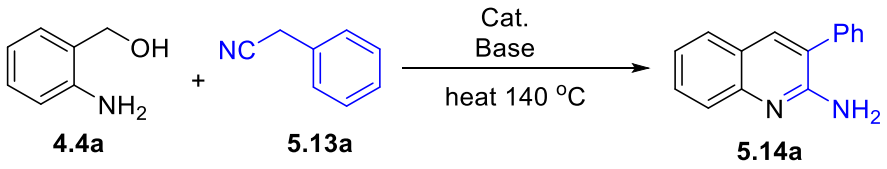
[a] Reaction conditions: 2-aminobenzyl alcohol (0.5 mmol), benzonitrile (0.75 mmol), *t*BuOK (0.5 mmol), cat **2.12a** (5 mol%), under argon in xylene (1 mL) at 140 °C (oil bath temp), 30 h, [b] isolated yield.

nitriles to afford the desired quinazoline in good yield. It is worth mentioning that the halo-substituted quinazolines were obtained in good yield, which could be further used for functionalization. Surprisingly, 4-fluorobenzonitrile gave only 38% yield of the desired product. The reaction with aliphatic nitrile such as valeronitrile gave a complicated mixture from which only 10% desired product was isolated. It is important to note that all the obtained quinazolines molecules offer the potential for C-H functionalization to synthesize complex building blocks.[18]

5.5.3. Optimisation reaction condition for the synthesis of 2-aminoquinoline:

At first, to examine the potential of the Mn-catalyst, dehydrogenative annulation of 2-aminobenzyl alcohol and benzyl cyanide were studied. Thus, when a toluene solution containing 2-aminobenzyl alcohol (1.0 mmol) and benzyl cyanide (1.2 mmol) was refluxed in presence of 5 mol% cat **2.12a** and KOH (1.0 mmol), 48% 3-phenylquinolin-2-amine was obtained after 24 h in an open system under argon atmosphere. When the reaction was carried out in pressure tube keeping the other conditions unaltered, the yield was further improved to 52%. Increasing the reaction time (36 h) the yield of the desired 2-aminoquinoline was further enhanced. The catalyst **2.12a** was found to be better compared to **2.12b** or **2.12c** (**Table 5.3**, entries 3, 4 and 5)**.** The yield of the desired product further was further improved to 86% when 1.5 equivalent of benzyl cyanide was used with respect to 2-aminobenzyl alcohol. It was found that the particular amount of KOH is important to get the maximum yield. Lower or higher amount of KOH has detrimental effect on the yield of the desired product (**Table 5.3**, entries 6 and 9). Other bases such as *t*BuOK and Cs_2CO_3 are found to be less effective for this reaction.

Table 5.3: Screening Table:[a,b]



4.4a **5.13a** **5.14a**

Exp. No.	Catalyst (mmol)	Solvent (2 ml)	Base (mmol)	**4.4a : 5.13a** (mmol)	Time (hours)	% of yield[b]
1[c]	Cat **2.12a**	toluene	KOH-1.0	1 : 1.2	24	48
2	Cat **2.12a**	toluene	KOH-1.0	1 : 1.2	24	52
3	Cat **2.12a**	toluene	KOH-1.0	1 : 1.2	36	67
4	Cat **2.12b**	toluene	KOH-1.0	1 : 1.2	36	64
5	Cat **2.12c**	toluene	KOH-1.0	1 : 1.2	36	51
6	Cat **2.12a**	toluene	KOH-1.5	1 : 1.2	36	54
7	Cat **2.12a**	xylene	KOH-1.0	1 : 1.2	36	61
8	**Cat 2.12a**	**toluene**	**KOH-1.0**	**1 : 1. 5**	**36**	**86**
9	Cat **2.12a**	toluene	KOH-0.5	1 : 1. 5	36	69
10[d]	Cat **2.12a**	toluene	KOH-1.0	1 : 1. 5	36	45
11	Cat **2.12a**	toluene	*t*BuOK-1.0	1 : 1. 5	36	59
12	Cat **2.12a**	toluene	Cs_2CO_3 -1.0	1 : 1. 5	36	57

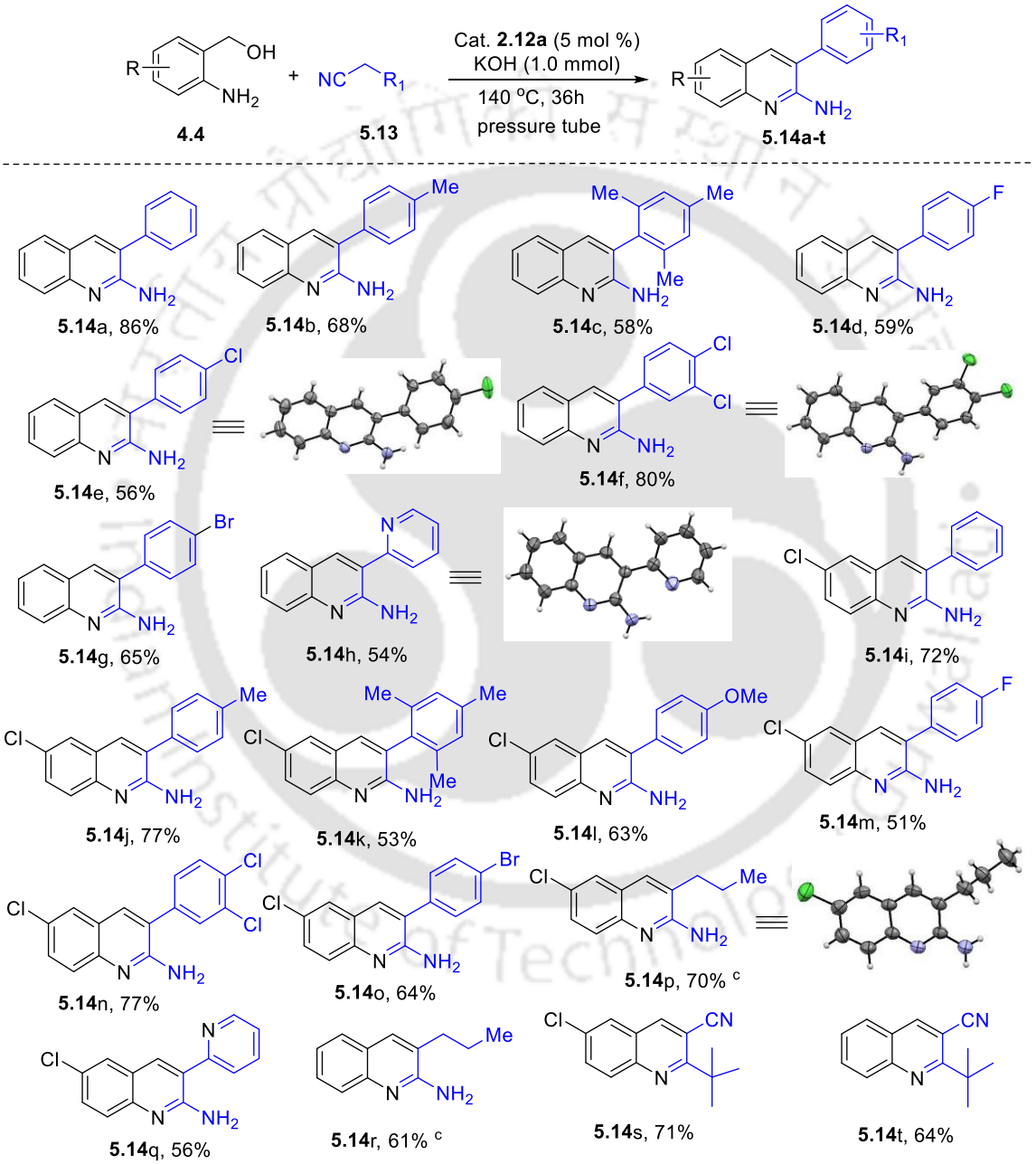
[a] Reaction conditions: 2-aminobenzyl alcohol (1.0 mmol), phenyl acetonitrile (1.2-1.5 mmol), base mmol), cat (5 mol%), toluene (2 mL), pressure tube, 140 °C (oil bath temp), 24-36 h. [b] isolated yield, [c] under argon in open system, [d] 2.5 mol% Cat **2.12a**.

5.5.4. Substrate scope for 2-aminoquinoline:

After having the optimized reaction condition, I wanted to apply this protocol for synthesis of various 2-aminoquinoline derivatives. Benzyl cyanide having both electron-donating and electron-withdrawing groups in the aromatic ring reacted well to give good

yield of the desired 2-aminoquinolines (**Table 5.4**). Not only mono- or di-substituted benzyl cyanide, but also 1,3,5-trisubstituted benzyl cyanide

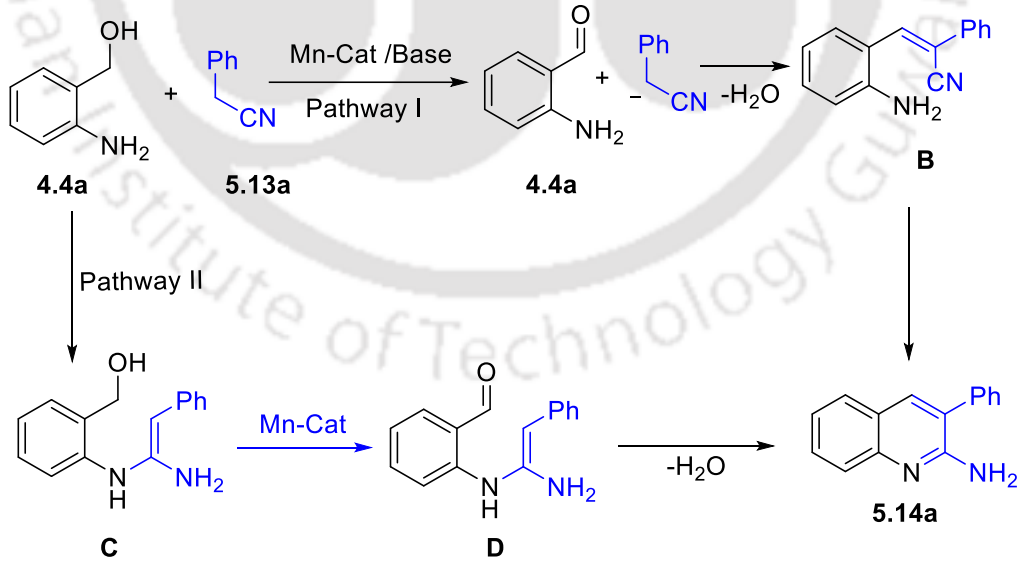
Table 5.4: Synthesis of 2-aminoquinoline from 2-aminobenzylalcohol derivatives and phenyl acetonitrile derivatives[a,b]



[a] Reaction conditions: 2-aminoaryl alcohol (1.0 mmol), nitrile (1.5 mmol), KOH 1.0 mmol, toluene (2ml), cat **2.12a** (5 mol%), 140 °C (oil bath temp), pressure tube, 36 h, [b] isolated yield, [c] 48 h, nitrile (2.0 mmol).

reacted smoothly to give the corresponding product in moderate yield. Heterocyclic cyanide worked successfully under the optimized condition. Interestingly, the reaction with more challenging aliphatic nitrile was found to be sluggish and only 35% yield of **5.14p** was obtained after 36 h, which could be further improved to 70% using longer reaction time (48 h).

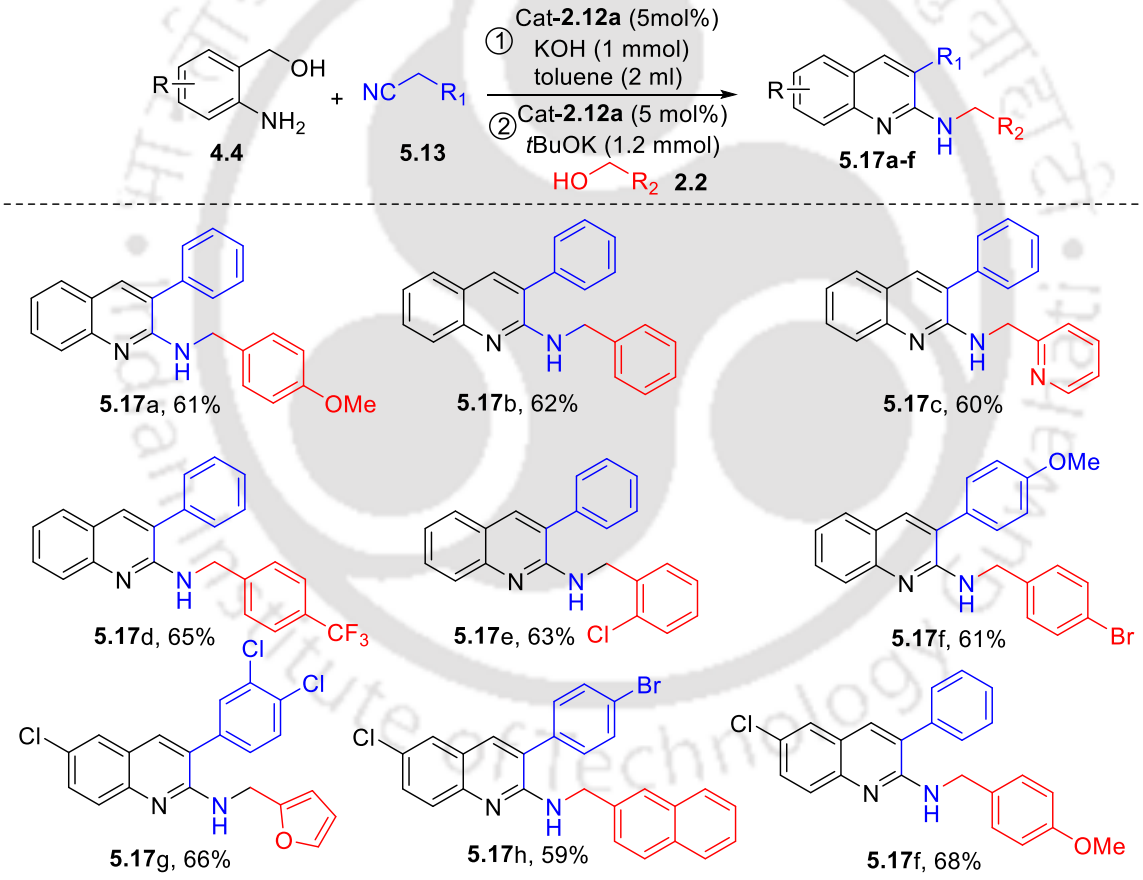
Next, the dehydrogenative coupling of (2-amino-5-chlorophenyl)methanol with pivaloylacetonitrile was studied. There is a possibility of the formation of two different quinoline derivatives: 2-(tert-butyl)quinoline-3-carbonitrile (*via* Friedländer type pathway: nucleophilic addition of NH_2 to C=O) and 3-(tert-butyl)quinoline-2-amine (*via* nucleophilic addition of NH_2 to CN). In this protocol, 2-(tert-butyl)quinoline-3-carbonitrile were obtained in 71% yield. Interesting, no 3-(tert-butyl)quinoline-2-amine was observed, hence it can be concluded that the amine preferred to attack ketone over the nitrile under the reaction condition. Two different pathways for the formation of 2-aminoquinoline is proposed (**Scheme 5.10**). In Pathway **I**, the reaction commences with the dehydrogenation of alcohol and subsequent formation of **B** *via* the condensation at α-carbon of phenyl acetonitrile.



Scheme 5.10. Proposed mechanistic pathways for the formation of 2-aminoquinoline.

Then, the nucleophilic addition of amino group to the cyano functionality followed by the tautomerization lead to the formation of 2-aminoquinoline. In Pathway II, the reaction initiated with the formation of **C**, *via* nucleophilic addition of NH_2 to the CN followed by the tautomerization, which upon dehydrogenation followed by the condensation reaction leads to the formation of **5.14a**. The reaction of benzyl alcohol with phenyl acetonitrile under the optimized reaction condition leads to the formation of 2,3-diphenylacrylonitrile *via* dehydrogenative condensation at *α*-phenyl acetonitrile suggesting that the formation 2-aminoquinoline **B** through path I is more likely.

Table 5.5: Synthesis of 2-alkylaminoquinolines [a,b]



[a] Reaction conditions: 2-aminoaryl alcohol (1.0 mmol), nitrile (1.5 mmol), cat **2.12a** (5 mol%), and KOH (1.0 mmol) in toluene (2 ml) at 140 °C (oil bath temp), pressure tube, for 36 h followed by addition of cat **2.12a** (5 mol%), *t*BuOK (1.2 mmol) and primary alcohol (1.5 mmol), heated for 24 h, [b] isolated yield.

Next, I wanted to investigate the catalytic applicability of the Mn-complexes towards the synthesis of 2-alkylaminoquinolines through sequential dehydrogenative annulation and *N*-alkylation reaction. As the catalyst is also capable of doing *N*-alkylation (Chapter 2) reaction, herein, the one pot synthesis of 2-alkylaminoquinolines through ADC reaction and *N*-alkylation reaction was attempted. Thus, the dehydrogenative annulation between 2-aminobenzyl alcohol and phenyl acetonitrile followed by the *N*-alkylation reaction with benzyl alcohol were examined in presence of cat **2.12a.** Gratifyingly, 61% yield of the desired *N*-(4-methoxybenzyl)-3-phenylquinolin-2-amine was isolated after column chromatography. Next, a wide range of 2-alkylaminoquinolines were synthesized which is summarized in **Table 5.5**. This methodology was equally successful for the substrates possessing electron donating and electron withdrawing substituents in the aryl acetonitrile as well as alcohol moiety. Heteroaromatic alcohols such as 2-pyridinemethanol and furfuryl alcohol were also reacted smoothly to give moderate yields.

5.6. Conclusion:

In conclusion, the first sustainable synthesis of quinazoline and 2-amino quinoline through dehydrogenative annulation of 2-aminobenzyl alcohol with nitriles using well-defined Mn(I) pincer complex is reported. The reaction proceeds *via* dehydrogenation and concomitant formation of C-C and C-N bond with high atom economy. Furthermore, the syntheses of 2-alkylaminoquinolines were achieved through sequential dehydrogenative annulation and *N*-alkylation reaction with alcohols.

5.7. Experimental section:

General Considerations

Unless otherwise mentioned, all chemicals were purchased from common commercial sources and used as received. All solvents were dried by using standard procedure. The preparation of catalyst was carried out under argon atmosphere with freshly distilled dry THF. All catalytic reactions were carried out with air and/or under argon atmosphere using dried glassware and standard syringe/septa techniques. DRX-

400 Varian spectrometer and Bruker Avance III 600 and 400 spectrometers were used to record ^{1}H and ^{13}C NMR spectra using $CDCl_3$ and DMSO-d_6 as solvent and TMS as an internal standard. Chemical shifts (δ) are reported in ppm and spin-spin coupling constant (J) are expressed in Hz, and other data are reported as follows: s = singlet, d = doublet, t = triplet, m = multiplet, q = quartet, and br s = broad singlet. Q-Tof ESI-MS instrument (model HAB 273) was used for recording mass spectra. X-ray crystallographic data were collected using Agilent Super Nova (Single source at offset, Eos) diffractometer. Data refinement and cell reduction were carried out by CrysAlisPro. Structures were solved by direct methods using SHELXS-97 and refined by full-matrix least-squares on F^2 using SHELXL-97. All of the non-H atoms were refined anisotropically. SRL silica gel (100-200 mesh) was used for column chromatography.

A. General experimental procedure for the synthesis of quinazolines:

A mixture of 2-amino benzyl alcohol (0.5 mmol), nitrile (0.75 mmol), *t*BuOK (0.5 mmol) and **2.12a** (0.025 mmol) was stirred in xylene (1 ml) at 140 °C for 30 h in an open system under argon. After cooling, ethyl acetate was added to dilute the mixture and filtered through celite. The filtrate was concentrated under reduced pressure and the residue was purified by silica gel column chromatography using 2%-10 % ethyl acetate in hexane to get pure compound.

B. General experimental procedure for the synthesis of 2-aminoquinolines:

A mixture of 2-amino benzyl alcohol (1.0 mmol), nitrile (1.5 mmol), KOH (1.0 mmol) and catalyst **2.12a** (0.05 mmol) was stirred in toluene (2 ml) at 140 °C for 36 h in pressure tube. After cooling, ethyl acetate was added to dilute the mixture and filtered through celite. The filtrate was concentrated under reduced pressure and the residue was purified by silica gel column chromatography using 10%-50 % ethyl acetate in hexane with 0.5 ml Et_3N to get pure compound.

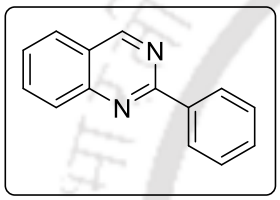
C. General experimental procedure for the synthesis of 2-alkylaminoquinolines:

A mixture of 2-aminobenzyl alcohol (1.0 mmol), nitrile (1.5 mmol), KOH (1.0 mmol) and catalyst **2.12a** (0.05 mmol) was stirred in toluene (2 ml) at 140 °C for 36

h in pressure tube under argon. After cooling, alcohol (1.5 mmol), *t*BuOK (1.2 mmol) and catalyst **2.12a** (0.05 mmol) was added under argon and again stirred for 24 h at 140 °C. After that, ethyl acetate was added to dilute the mixture and filtered through celite. The filtrate was concentrated under reduced pressure and the residue was purified by silica gel column chromatography using 2%-10 % ethyl acetate in hexane to get pure compound.

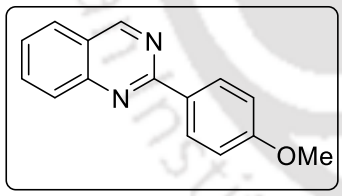
5.8. Characterization data of products:

2-phenylquinazoline(5.2a):[25]



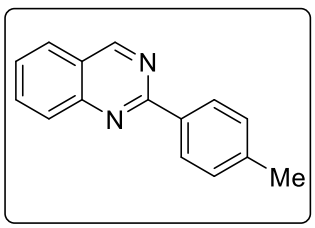
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (89 mg, 86%). 1H NMR (400 MHz, Chloroform-d) δ 9.39 (s, 1H), 8.54 (dd, *J* = 8.0, 1.6 Hz, 2H), 8.01 (d, *J* = 8.9 Hz, 1H), 7.85 - 7.81 (m, 2H), 7.53 (t, *J* = 7.5 Hz, 1H), 7.49 - 7.40 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 161.2, 160.6, 150.9, 138.2, 134.2, 130.7, 128.9 (2C), 128.7, 127.4, 127.3, 123.7.

2-(4-methoxyphenyl)quinazoline(5.2b):[25]



This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (92 mg, 78%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.41 (s, 1H), 8.60 - 8.55 (m, 2H), 8.04 (d, *J* = 8.9 Hz, 1H), 7.92 - 7.83 (m, 2H), 7.59 - 7.52 (m, 1H), 7.07 - 7.02 (m, 2H), 3.90 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.0, 161.0, 160.5, 150.9, 134.1, 130.8, 130.3, 128.5, 127.3, 126.9, 123.4, 114.1, 55.5.

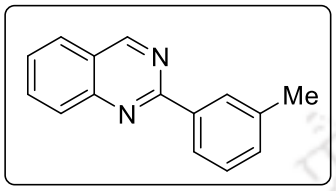
2-(p-tolyl)quinazoline(5.2c):[25]



This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (71 mg, 64%). ^{1}H NMR (600 MHz, Chloroform-*d*) δ 9.43 (s, 1H), 8.52 (d, *J* = 8.1 Hz, 2H), 8.06 (d, *J* = 8.2 Hz, 1H), 7.87 (t,

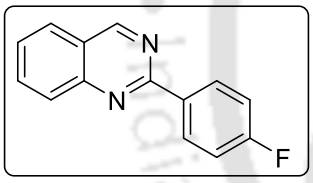
J = 7.7 Hz, 2H), 7.56 (d, *J* = 7.4 Hz, 1H), 7.35 (d, *J* = 8.0 Hz, 2H), 2.44 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 161.2, 160.5, 150.9, 140.9, 135.4, 134.1, 129.5, 128.6 (2C), 127.2, 127.1, 123.6, 21.6.

2-(m-tolyl)quinazoline(5.2d):[25]



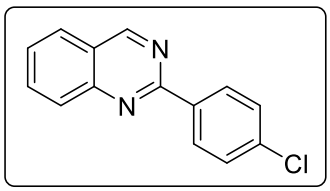
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (63 mg, 57%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.46 (s, 1H), 8.44 - 8.41 (m, 2H), 8.09 (d, *J* = 8.4 Hz, 1H), 7.95 - 7.85 (m, 2H), 7.60 (t, *J* = 7.5 Hz, 1H), 7.44 (t, *J* = 7.6 Hz, 1H), 7.33 (d, *J* = 7.5 Hz, 1H), 2.50 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 161.3, 160.6, 150.9, 138.4, 138.1, 134.2, 131.6, 129.2, 128.7(2C), 127.3, 127.2, 125.9, 123.7, 21.6.

2-(4-fluorophenyl)quinazoline(5.2e):[25]



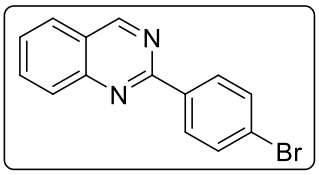
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (43mg 38%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.45 (s, 1H), 8.63 (dd, *J* = 9.0, 5.6 Hz, 2H), 8.07 (d, *J* = 8.4 Hz, 1H), 7.93 (dd, *J* = 7.5, 2.6 Hz, 2H), 7.62 (ddd, *J* = 8.1, 7.0, 1.1 Hz, 1H), 7.23 - 7.19 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 164.8 (d, *J* = 250.3 Hz), 160.7, 160.3, 150.9, 134.4, 134.4, 130.8, 130.8, 128.7, 127.4 (d, *J* = 22.1 Hz), 123.6, 115.7 (d, *J* = 21.6 Hz).

2-(4-chlorophenyl)quinazoline(5.2f):[25]



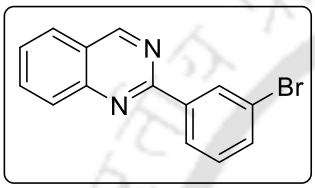
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (87 mg, 72%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.44 (s, 1H), 8.57 (d, *J* = 8.6 Hz, 2H), 8.07 (d, *J* = 8.9 Hz, 1H), 7.91 (t, *J* = 7.7 Hz, 2H), 7.62 (t, *J* = 7.5 Hz, 1H), 7.50 (d, *J* = 8.6 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.7, 160.2, 150.8, 137.0, 136.6, 134.4, 130.0, 129.0, 128.7, 127.6, 127.3, 123.7.

2-(4-bromophenyl)quinazoline(5.2g):[25]



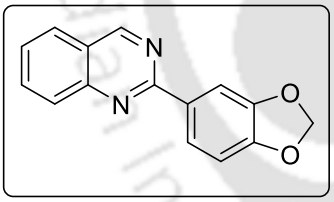
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (106 mg, 74%). ^{1}H NMR (600 MHz, Chloroform-*d*) δ 9.44 (s, 1H), 8.49 (d, *J* = 8.6 Hz, 2H), 8.07 (dd, *J* = 8.4, 1.0 Hz, 1H), 7.95 - 7.86 (m, 2H), 7.66 (m, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 160.6, 160.1, 150.7, 137.0, 134.3, 131.8, 130.2, 128.6, 127.5, 127.2, 125.4, 123.7.

2-(3-bromophenyl)quinazoline(5.2h):[25]



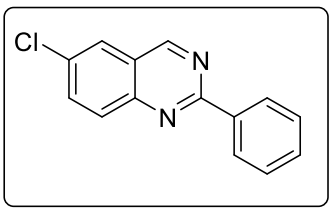
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (102 mg, 72%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.46 (s, 1H), 8.79 - 8.78(m, 1H), 8.55 (dt, *J* = 7.8, 1.1 Hz, 1H), 8.08 (s, 1H), 7.97 - 7.88 (m, 2H), 7.66 - 7.60 (m, 2H), 7.40 (t, *J* = 7.9 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.7, 159.7, 150.8, 140.2, 134.5, 133.6, 131.7, 130.3, 128.8, 127.8, 127.3, 127.2, 123.9, 123.1.

2-(benzo[d][1,3]dioxol-5-yl)quinazoline(5.2i):



This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (78 mg, 62%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.39 (s, 1H), 8.22 (dd, *J* = 8.2, 1.6 Hz, 1H), 8.11 - 810 (m, 1H), 8.02 (d, *J* = 8.9 Hz, 1H), 7.87 (t, *J* = 7.7 Hz, 2H), 7.57 (t, *J* = 7.9 Hz, 1H), 6.95 (d, *J* = 8.2 Hz, 1H), 6.05 (s, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) *δ* 160.6, 160.5, 150.8, 150.0, 148.3, 134.2, 132.6, 128.5, 127.2, 127.0, 123.6, 123.5, 108.8, 108.4, 101.6. HRMS (ESI) calcd for $C_{15}H_{10}N_2O_2$ $[M + H]^+$: 251.0821; found, 251.0825.

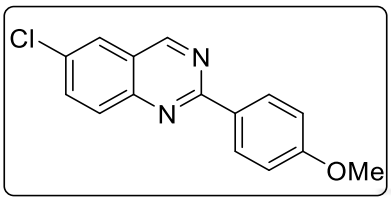
6-chloro-2-phenylquinazoline(5.2j):[25]



This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (79 mg, 66%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.38 (s, 1H), 8.59 (dd, *J* = 7.5, 2.2 Hz, 2H), 8.02 (d, *J* = 9.0 Hz, 1H), 7.89 (s, 1H), 7.82 (dd, *J* = 9.0, 2.3 Hz, 1H), 7.62 –

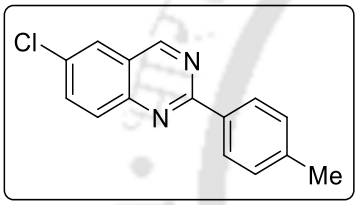
7.46 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 161.4, 159.6, 149.4, 137.7, 135.2, 132.9, 131.0, 130.5, 128.8, 128.7, 125.9, 124.1.

6-chloro-2-(4-methoxyphenyl)quinazoline (5.2k):[24]



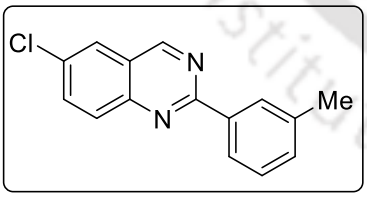
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (88 mg, 65%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.32 (s, 1H), 8.54 (d, *J* = 8.9 Hz, 2H), 7.96 (d, *J* = 9.0 Hz, 1H), 7.85 - 7.84 (m, 1H), 7.78 (dd, *J* = 9.0, 2.3 Hz, 1H), 7.03 (d, *J* = 8.9 Hz, 2H), 3.90 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.1, 161.2, 159.5, 149.5, 135.1, 132.3, 130.4 (2C), 130.3, 125.9, 123.8, 114.1, 55.5.

6-chloro-2-(p-tolyl)quinazoline (5.2l):[24]



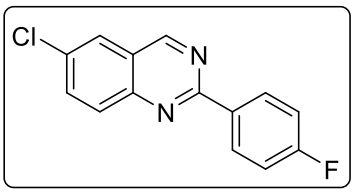
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (82 mg, 65%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.34 (s, 1H), 8.47 (d, *J* = 8.2 Hz, 2H), 7.98 (d, *J* = 9.0 Hz, 1H), 7.85 - 7.84 (m, 1H), 7.79 (dd, *J* = 9.0, 2.3 Hz, 1H), 7.33 (d, *J* = 8.1 Hz, 2H), 2.44 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 161.4, 159.5, 149.4, 141.3, 135.1, 135.0, 132.6, 130.4, 129.6, 128.6, 125.9, 124.0, 21.6.

6-chloro-2-(m-tolyl)quinazoline (5.2m):



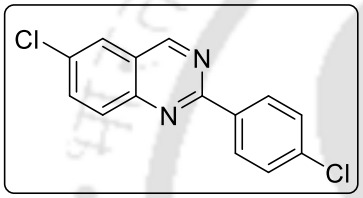
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (89 mg, 70%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.36 (s, 1H), 8.38 (d, *J* = 9.1 Hz, 2H), 8.01 (d, *J* = 9.0 Hz, 1H), 7.87 - 7.86 (m, 1H), 7.80 (dd, *J* = 9.0, 2.3 Hz, 1H), 7.42 (t, *J* = 7.6 Hz, 1H), 7.33 (d, *J* = 7.5 Hz, 1H), 2.48 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 161.5, 159.6, 149.3, 138.5, 137.6, 135.2, 132.8, 131.8, 130.4, 129.2, 128.7, 125.9, 125.9, 124.0, 21.7. HRMS (ESI) calcd for $C_{15}H_{11}N_2Cl$ $[M + H]^+$: 255.0689; found, 255.0688.

6-chloro-2-(4-fluorophenyl)quinazoline (5.2n):[34]



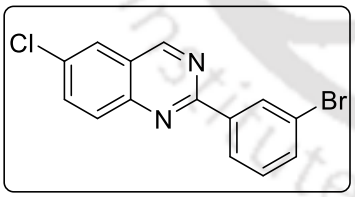
This compound was prepared using general experiential. procedure-**A**. Reaction was completed after 30 h Yellow solid (43 mg, 33%). 1H NMR (400 MHz, Chloroform-*d*) δ 9.39 (s, 1H), 8.68 - 8.56 (m, 2H), 8.02 (d, *J* = 9.0 Hz, 1H), 7.92 (d, *J* = 2.2 Hz, 1H), 7.84 (dd, *J* = 9.0, 2.3 Hz, 1H), 7.21 (t, *J* = 8.7 Hz, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 163.5 (d, *J* = 184.5 Hz), 159.7, 149.4, 135.4, 133.93, 133.0, 130.9, 130.8, 130.4, 126.0, 124.0, 115.8 (d, *J* = 21.5 Hz).

6-chloro-2-(4-chlorophenyl)quinazoline (5.2o):[24]



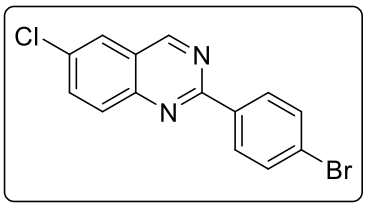
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (89 mg, 65%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.37 (s, 1H), 8.54 (d, *J* = 7.9 Hz, 2H), 8.01 (d, *J* = 8.9 Hz, 1H), 7.90 (s, 1H), 7.83 (d, *J* = 8.9 Hz, 1H), 7.49 (d, *J* = 8.1 Hz, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 160.4, 159.7, 149.3, 137.3, 136.2, 135.4, 133.2, 130.5, 130.0, 129.0, 126.0, 124.1.

2-(3-bromophenyl)-6-chloroquinazoline (5.2p):



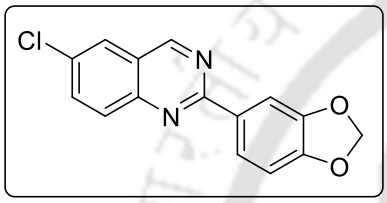
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (100 mg, 63%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.39 (s, 1H), 8.78 - 8.76 (m, 1H), 8.55 - 8.52 (m, 1H), 8.03 (d, *J* = 9.0 Hz, 1H), 7.93 - 7.92 (m, 1H), 7.85 (dd, *J* = 9.0, 2.3 Hz, 1H), 7.64 (ddd, *J* = 7.9, 1.9, 1.0 Hz, 1H), 7.40 (t, *J* = 7.9 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.0, 159.7, 149.3, 139.8, 135.5, 133.9, 133.4, 131.7, 130.6, 130.3, 127.2, 126.0, 124.3, 123.1. HRMS (ESI) calcd for $C_{14}H_8N_2ClBr$ $[M + H]^+$: 318.9638; found, 318.9635.

2-(4-bromophenyl)-6-chloroquinazoline (5.2q):[24]



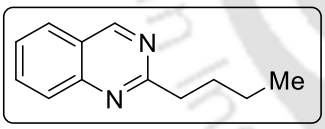
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (110 mg, 69%). ^{1}H NMR (600 MHz, Chloroform-*d*) δ 9.39 (s, 1H), 8.49 (d, *J* = 8.5 Hz, 2H), 8.02 (d, *J* = 8.9 Hz, 1H), 7.92 (d, *J* = 2.0 Hz, 1H), 7.85 (dd, *J* = 9.0, 2.2 Hz, 1H), 7.66 (d, *J* = 8.6 Hz, 2H). ^{13}C NMR (100 MHz, CDCl3) δ 160.5, 159.7, 149.3, 136.7, 135.4, 133.2, 132.0, 130.5, 130.3, 126.0, 125.9, 124.2.

2-(benzo[d][1,3]dioxol-5-yl)-6-chloroquinazoline (5.2r):



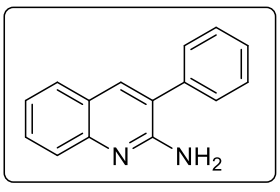
This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (83 mg, 58%). ^{1}H NMR (400 MHz, Chloroform-*d*) δ 9.33 (s, 1H), 8.21 (dd, *J* = 8.2, 1.7 Hz, 1H), 8.09 - 8.08 (m, 1H), 7.97 (d, *J* = 9.0 Hz, 1H), 7.88 - 7.87 (m, 1H), 7.80 (dd, *J* = 9.0, 2.3 Hz, 1H), 6.95 (d, *J* = 8.2 Hz, 1H), 6.06 (s, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 160.9, 159.5, 150.3, 149.4, 148.4, 135.2, 132.5, 132.2, 130.3, 126.0, 123.9, 123.8, 108.8, 108.5, 101.7. HRMS (ESI) calcd for $C_{15}H_9N_2ClO_2$ $[M + H]^+$: 285.0431; found, 285.0438.

2-butylquinazoline (5.2s):[25]



This compound was prepared using general experiential procedure-**A**. Reaction was completed after 30 h. Yellow solid (19 mg, 10%).1H NMR (600 MHz, Chloroform-d) δ 9.32 (s, 1H), 7.95 (d, *J* = 8.3 Hz, 1H), 7.86 (d, *J* = 7.8 Hz, 2H), 7.56 (t, *J* = 7.5 Hz, 1H), 3.11 - 3.08 (m, 2H), 1.87 (q, *J* = 7.7 Hz, 2H), 1.44 (h, *J* = 7.3 Hz, 2H), 0.95 (t, *J* = 7.4 Hz, 3H). 13C NMR (150 MHz, CDCl3) δ 168.0, 160.5, 150.4, 134.1, 127.9, 127.2, 127.0, 123.1, 39.8, 31.3, 22.8, 14.1.

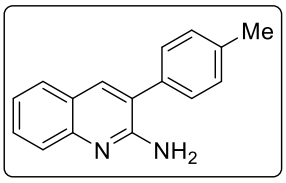
3-phenylquinolin-2-amine (5.14a):[27]



This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (189 mg, 86 %), ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.68 (s, 1H), 7.60 (d, *J* = 8.4 Hz, 1H), 7.55 (dd, *J* = 8.0, 1.7 Hz, 1H),

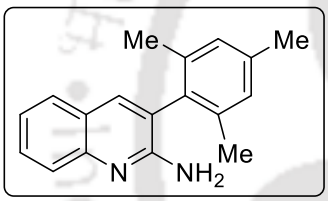
7.48-7.32 (m, 6 H), 7.18 -7.16 (m, 1H), 5.02 (br s, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 155.4, 147.2, 137.7, 137.4, 129.8, 129.3, 129.0, 128.3, 127.6, 125.6, 125.1, 124.3, 122.9.

3-(p-tolyl)quinolin-2-amine (5.14b):



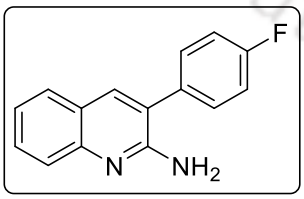
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (159 mg, 68%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.76 (s, 1H), 7.68 (d, *J* = 8.4 Hz, 1H), 7.63 (d, *J* = 8.0 Hz, 1H), 7.59 - 7.52 (m, 2H), 7.41 (d, *J* = 8.0 Hz, 2H), 7.32 - 7.22 (m, 3H), 5.03 (s, 2H), 2.42 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.5, 147.2, 138.2, 137.2, 134.7, 129.9, 129.6, 128.9, 127.6, 125.7, 125.2, 124.4, 122.8, 21.4. HRMS (ESI) calcd for $C_{16}H_{14}N_2$ [M + H]$^+$: 235.1235; found, 235.1239.

3-mesitylquinolin-2-amine (5.14c):



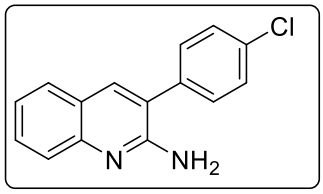
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (152 mg, 58%), ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.63 (d, *J* = 8.4 Hz, 1H), 7.58 - 7.53 (m, 2H), 7.50 (ddd, *J* = 8.4, 7.0, 1.4 Hz, 1H), 7.22 - 7.17 (m, 1H), 6.93 (s, 2H), 4.62 (s, 2H), 2.28 (s, 3H), 1.98 (s, 6H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 155.6, 147.4, 138.1, 137.4, 137.2, 132.7, 129.6, 128.9, 127.5, 125.8, 124.3, 123.7, 122.6, 21.2, 20.3. HRMS (ESI) calcd for $C_{18}H_{18}N_2$ [M + H]$^+$: 263.1548; found, 263.1549.

3-(4-fluorophenyl)quinolin-2-amine (5.14d):



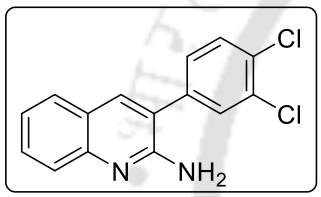
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (140 mg, 59%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.76 (s, 1H), 7.70 - 7.63 (m, 2H), 7.58 (t, *J* = 7.4 Hz, 1H), 7.53 - 7.46 (m, 2H), 7.30 - 7.17 (m, 3H), 4.93 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.8 (d, *J* = 248.0 Hz), 155.2, 147.3, 137.6, 133.6, 133.6, 130.9 (d, *J* = 8.2 Hz), 130.0, 127.6, 125.8, 124.2 (d, *J* = 18.9 Hz), 123.1, 116.3 (d, *J* = 21.4 Hz). HRMS (ESI) calcd for $C_{15}H_{11}N_2F$ [M + H]$^+$: 239.0985; found, 239.0986.

3-(4-chlorophenyl)quinolin-2-amine (5.14e):



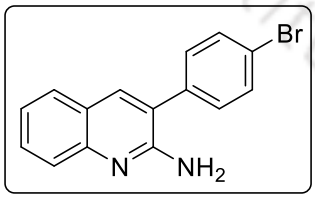
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (143 mg, 56%), ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.68 (s, 1H), 7.60 (d, *J* = 8.4 Hz, 1H), 7.56 (d, *J* = 7.7 Hz, 1H), 7.50 (t, *J* = 8.2 Hz, 1H), 7.39 (s, 4H), 7.20 (t, *J* = 7.8 Hz, 1H), 4.89 (s, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 155.0, 147.4, 137.5, 136.1, 134.4, 130.4, 130.0, 129.5, 127.7, 125.8, 124.2, 123.9, 123.1. HRMS (ESI) calcd for $C_{15}H_{11}N_2Cl$ $[M + H]^+$: 255.0689; found, 255.0688.

3-(3,4-dichlorophenyl)quinolin-2-amine (5.14f):



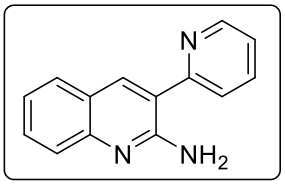
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (231 mg, 80%), ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.76 (s, 1H), 7.67 (d, *J* = 8.4 Hz, 1H), 7.65 - 7.62 (m, 2H), 7.60 - 7.56 (m, 1H), 7.55 (d, *J* = 8.2 Hz, 1H), 7.37 (dd, *J* = 8.2, 2.0 Hz, 1H), 7.30 - 7.26 (m, 1H), 5.05 (s, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 154.7, 147.5, 137.7, 137.7, 133.5, 132.7, 131.2, 131.0, 130.3, 128.4, 127.7, 125.8, 124.0, 123.2, 122.6. HRMS (ESI) calcd for $C_{15}H_{10}N_2Cl_2$ $[M + H]^+$: 289.0299; found, 289.0297.

3-(4-bromophenyl)quinolin-2-amine (5.14g):[27]



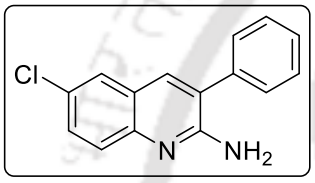
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (194 mg, 65%), ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.77 (s, 1H), 7.69 (d, *J* = 8.4 Hz, 1H), 7.66 - 7.63 (m, 3H), 7.58 (t, *J* = 7.6 Hz, 1H), 7.41 (d, *J* = 8.2 Hz, 2H), 7.28 (t, *J* = 7.4 Hz, 1H), 4.94 (s, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 154.9, 147.4, 137.5, 136.6, 132.5, 130.7, 130.1, 127.7, 125.8, 124.2, 123.9, 123.1, 122.6. HRMS (ESI) calcd for $C_{15}H_{11}N_2Br$ $[M + H]^+$: 299.0184; found, 299.0184.

3-(pyridin-2-yl)quinolin-2-amine (5.14h):



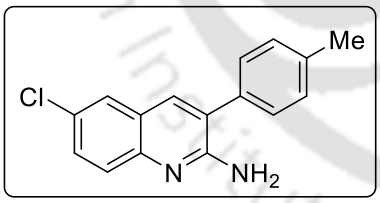
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (119 mg, 54%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.58 - 8.57 (m, 1H), 8.14 (s, 1H), 7.79 - 7.69 (m, 2H), 7.63 - 7.58 (m, 2H), 7.49 (ddd, *J* = 8.4, 6.9, 1.3 Hz, 1H), 7.24 - 7.10 (m, 3H), 6.87 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.0, 156.4, 148.3, 148.0, 137.5, 137.4, 130.6, 128.1, 125.5, 123.8, 122.8, 122.6, 122.4, 120.6. HRMS (ESI) calcd for $C_{14}H_{11}N_3$ $[M + H]^+$: 222.1031; found, 222.1030.

6-chloro-3-phenylquinolin-2-amine (5.14i):



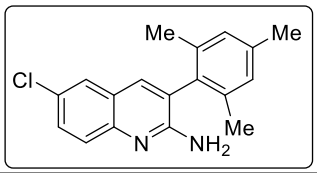
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (183 mg, 72%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.68 (s, 1H), 7.60 (dd, *J* = 5.6, 3.2 Hz, 2H), 7.53 - 7.40 (m, 6H), 5.04 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.5, 145.8, 137.2, 136.3, 130.3, 129.4, 128.9, 128.6, 128.0, 127.3, 126.3, 126.0, 124.9. HRMS (ESI) calcd for $C_{15}H_{11}N_2Cl$ $[M + H]^+$: 255.0689; found, 255.0688.

6-chloro-3-(p-tolyl)quinolin-2-amine (5.14j):



This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (207 mg, 77%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.57 (s, 1H), 7.50 (dd, *J* = 5.7, 3.2 Hz, 2H), 7.39 - 7.37 (m, 1H), 7.31 - 7.29 (m, 2H), 7.22 (d, *J* = 7.8 Hz, 2H), 5.00 (s, 2H), 2.34 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.7, 145.4, 138.6, 136.2, 134.1, 130.2, 130.0, 128.8, 127.9, 127.0, 126.3, 126.1, 124.9, 29.8. HRMS (ESI) calcd for $C_{16}H_{13}N_2Cl$ $[M + H]^+$: 269.0846; found, 269.0841.

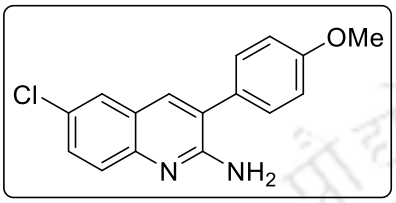
6-chloro-3-mesitylquinolin-2-amine (5.14k):



This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (157 mg, 53%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.64 -

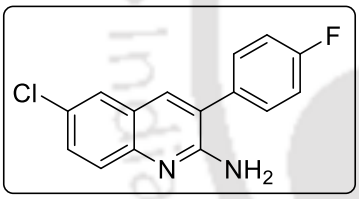
7.58 (m, 2H), 7.55 (s, 1H), 7.50 7.47 (m, 1H), 7.00 (s, 2H), 2.35 (s, 3H), 2.04 (s, 6H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 155.8, 145.9, 138.3, 137.0, 136.3, 132.3, 130.1, 129.0 (2c), 127.7, 127.2, 126.3, 124.8, 124.7, 21.2, 20.2. HRMS (ESI) calcd for $C_{18}H_{17}N_2Cl$ [M + H]$^+$: 297.1159; found, 297.1156.

6-chloro-3-(4-methoxyphenyl)quinolin-2-amine (5.14l):



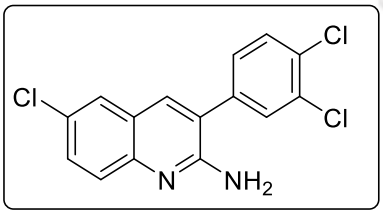
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (179 mg, 63%), ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.65 (s, 1H), 7.62 - 7.57 (m, 2H), 7.47 (dd, *J* = 8.9, 2.3 Hz, 1H), 7.45 - 7.41 (m, 2H), 7.08 - 6.99 (m, 2H), 5.02 (s, 2H), 3.87 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 159.9, 155.8, 145.6, 136.1, 130.2, 129.3, 127.9, 127.2, 126.2, 125.8, 125.0, 114.8, 55.5. HRMS (ESI) calcd for $C_{16}H_{13}N_2ClO$ [M + H]$^+$: 285.0795; found, 285.0792.

6-chloro-3-(4-fluorophenyl)quinolin-2-amine (5.14m):



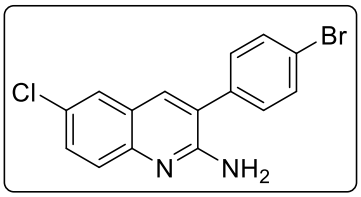
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (139 mg, 51%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.66 (s, 1H), 7.61 - 7.59 (m, 2H), 7.53 - 7.43 (m, 3H), 7.20 (t, *J* = 8.6 Hz, 2H), 4.97 (s, 2H).^{13}C NMR (100 MHz, $CDCl_3$) δ 162.9 (d, *J* = 248.6 Hz), 155.4, 145.8, 136.5, 133.2 (d, *J* = 3.6 Hz), 130.9, 130.8, 130.5, 128.2, 127.4, 126.3, 124.9 (d, *J* = 13.7 Hz), 116.4 (d, *J* = 21.4 Hz). HRMS (ESI) calcd for $C_{15}H_{10}N_2ClF$ [M + H]$^+$: 273.0595; found, 273.0594.

6-chloro-3-(3,4-dichlorophenyl)quinolin-2-amine (5.14n):



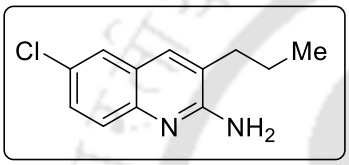
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (249 mg, 77%), ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.67 (s, 1H), 7.62 - 7.55 (m, 4H), 7.50 (dd, *J* = 8.9, 2.2 Hz, 1H), 7.36 (dd, *J* = 8.2, 1.9 Hz, 1H), 5.02 (s, 2H).^{13}C NMR (150 MHz, $CDCl_3$) δ 154.8, 146.0, 137.2, 136.7, 133.6, 133.0, 131.4, 130.9, 130.9, 128.4, 128.3, 127.4, 126.4, 124.6, 123.5. HRMS (ESI) calcd for $C_{15}H_9N_2Cl_3$ [M + H]$^+$: 322.9910; found, 322.9908.

3-(4-bromophenyl)-6-chloroquinolin-2-amine (5.14o):



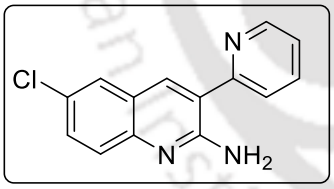
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (213 mg, 64%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.68 - 7.63 (m, 2H), 7.62 - 7.58 (m, 3H), 7.49 (m, 2H), 7.41 - 7.35 (m, 1H), 5.02 (s, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 155.1, 145.9, 136.4, 136.1, 132.6, 130.7, 130.6, 128.2, 127.4, 126.3, 124.8, 122.9. HRMS (ESI) calcd for $C_{15}H_{10}N_2ClBr$ $[M + H]^+$: 332.9794; found, 332.9798.

6-chloro-3-propylquinolin-2-amine (5.14p):



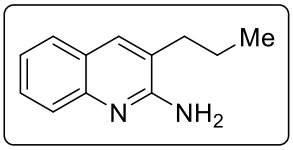
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 48 h. White solid (154 mg, 70%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.59 - 7.50 (m, 3H), 7.44 - 741 (m, 1H), 4.99 (s, 2H), 2.53 (t, *J* = 7.7 Hz, 2H), 1.79 - 1.70 (m, 2H), 1.03 (t, *J* = 7.3 Hz, 3H).^{13}C NMR (150 MHz, $CDCl_3$) δ 156.5, 145.0, 134.6, 129.5, 127.8, 127.1, 125.8, 125.1, 124.6, 33.3, 21.0, 14.1. HRMS (ESI) calcd for $C_{12}H_{13}N_2Cl$ $[M + H]^+$: 221.0846; found, 256.0643.

6-chloro-3-(pyridin-2-yl)quinolin-2-amine (5.14p):



This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (143 mg, 56%), ^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.68 - 8.66 (m, 1H), 8.11 (s, 1H), 7.86 - 7.78 (m, 2H), 7.68 - 7.63 (m, 1H), 7.58 (d, *J* = 8.8 Hz, 1H), 7.49 (dd, *J* = 8.9, 2.4 Hz, 1H), 7.31 (dd, *J* = 7.4, 4.8 Hz, 1H), 6.95 (s, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 156.6, 156.5, 148.3, 146.5, 137.6, 136.2, 131.1, 127.6, 127.1, 126.6, 124.3, 122.9, 122.7, 121.4. HRMS (ESI) calcd for $C_{14}H_{10}N_3Cl$ $[M + H]^+$: 256.0642; found, 256.0641.

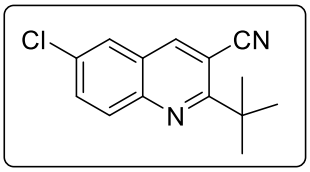
3-propylquinolin-2-amine (5.14r):



This compound was prepared using general experiential procedure-**B**. Reaction was completed after 48 h. White solid (113 mg, 61%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.70 - 7.63 (m, 2H), 7.62 - 7.58 (m, 1H), 7.55 - 7.48 (m, 1H), 7.30 - 7.21 (m, 1H), 4.89 (s, 2H),

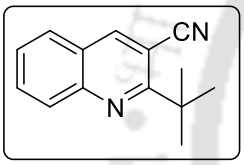
2.60 - 2.53 (m, 2H), 1.81 - 1.72 (h, *J* = 7.4 Hz, 2H), 1.05 (t, *J* = 7.3 Hz, 3H).^{13}C NMR (100 MHz, $CDCl_3$) δ 156.3, 146.5, 135.7, 128.9, 127.1, 125.6, 124.6, 123.6, 122.7, 33.4, 21.2, 14.1. HRMS (ESI) calcd for $C_{12}H_{14}N_2$ $[M + H]^+$: 187.1235; found, 187.1235.

2-(tert-butyl)-6-chloroquinoline-3-carbonitrile (5.14s):



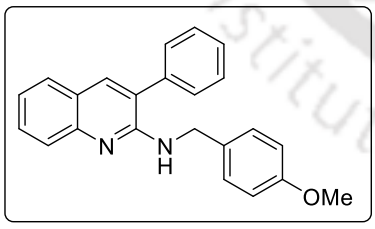
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (174 mg, 71%), ^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.43 (s, 1H), 8.02 (d, *J* = 9.0 Hz, 1H), 7.80 - 7.79 (m, 1H), 7.74 (dd, *J* = 8.9, 2.3 Hz, 1H), 1.62 (s, 9H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 167.4, 145.8, 144.2, 133.5, 133.3, 131.5, 126.0, 125.1, 118.7, 105.8, 39.9, 29.2. HRMS (ESI) calcd for $C_{14}H_{13}N_2Cl$ $[M + H]^+$: 245.0846; found, 245.0845.

2-(tert-butyl)quinoline-3-carbonitrile (5.14t):



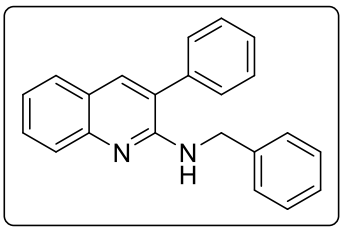
This compound was prepared using general experiential procedure-**B**. Reaction was completed after 36 h. White solid (134 mg, 64%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.51 (s, 1H), 8.08 (d, *J* = 8.4 Hz, 1H), 7.87 - 7.77 (m, 2H), 7.59 (ddd, *J* = 8.1, 7.0, 1.0 Hz, 1H), 1.64 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.9, 147.4, 145.3, 132.4, 129.9, 127.6, 127.4, 124.5, 119.2, 104.7, 39.8, 29.3. HRMS (ESI) calcd for $C_{14}H_{14}N_2$ $[M + H]^+$: 221.1235; found, 221.1235.

***N*-(4-methoxybenzyl)-3-phenylquinolin-2-amine (5.17a):**



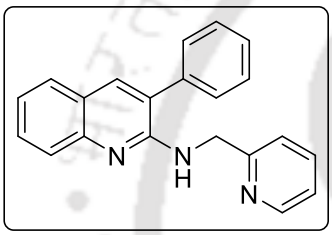
This compound was prepared using general experiential procedure-**C**. Reaction was completed after 60 h. Yellow solid (207 mg, 61%) ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.79 (d, *J* = 8.4 Hz, 1H), 7.69 (s, 1H), 7.62 (d, *J* = 7.9 Hz, 1H), 7.56 (ddd, *J* = 8.4, 7.1, 1.4 Hz, 1H), 7.50 - 7.44 (m, 4H), 7.40 (ddd, *J* = 8.7, 6.1, 3.3 Hz, 1H), 7.30 (d, *J* = 8.6 Hz, 2H), 7.26 - 7.22 (m, 1H), 6.86 -6.84(m, 2H), 5.06 (s, 1H), 4.75 (d, *J* = 5.4 Hz, 2H), 3.79 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 158.8, 154.3, 147.7, 137.6, 136.5, 131.9, 129.4, 129.3, 129.2, 129.2, 128.3, 127.5, 126.3, 125.7, 123.7, 122.3, 114.0, 55.4, 45.1. HRMS (ESI) calcd for $C_{23}H_{20}N_2O$ $[M + H]^+$: 341.1654; found, 341.1654.

_N_-benzyl-3-phenylquinolin-2-amine (5.17b):[35]



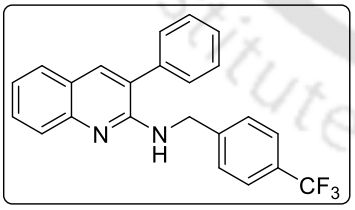
This compound was prepared using general experiential procedure-**C**. Reaction was completed after 60 h. Yellow solid (192 mg, 62%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.82 - 7.71 (m, 1H), 7.67 - 7.65 (m, 1H), 7.60 - 7.58 (m, 1H), 7.55 - 7.51 (m, 1H), 7.46 - 7.43 (m, 4H), 7.41 - 7.32 (m, 3H), 7.32 - 7.26 (m, 2H), 7.25 - 7.18 (m, 2H), 5.10 (s, 1H), 4.81 (d, *J* = 5.2 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.3, 147.7, 140.0, 137.5, 136.5, 129.4, 129.3, 129.2, 128.6, 128.3, 127.8, 127.5, 127.1, 126.4, 125.7, 123.8, 122.4, 45.5.

3-phenyl-_N_-(pyridin-2-ylmethyl)quinolin-2-amine (5.17c):[35]



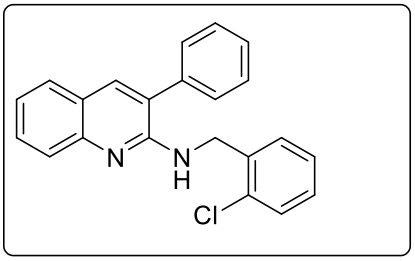
This compound was prepared using general experiential procedure-**C**. Reaction was completed after 60 h. Yellow solid (187 mg, 60%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.79 (s, 1H), 7.70 - 7.64 (m, 2H), 7.58 (dd, *J* = 7.0, 1.4 Hz, 1H), 7.56 - 7.47 (m, 5H), 7.46 -7.43 (m, 1H), 7.32 - 7.27 (m, 1H), 7.17 - 7.10 (m, 1H), 7.07 (d, *J* = 7.0 Hz, 1H), 6.70 (d, *J* = 7.6 Hz, 1H), 4.96 (s, 1H), 4.69 (s, 2H).^{13}C NMR (150 MHz, $CDCl_3$) δ 155.3, 147.2, 146.2, 137.6, 137.4, 129.8, 129.5, 129.3, 129.0, 128.4, 127.6, 125.6, 125.2, 125.0, 124.3, 123.0, 118.2, 116.1, 64.5.

3-phenyl-_N_-(4-(trifluoromethyl)benzyl)quinolin-2-amine (5.17d):



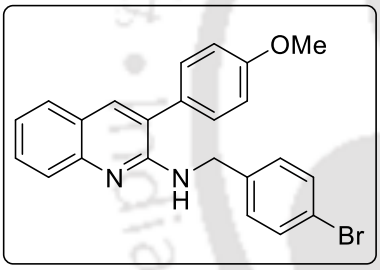
This compound was prepared using general experiential procedure-**C**. Reaction was completed after 60 h. Yellow solid (246 mg, 65%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.74 -7.72 (m, 1H), 7.62 (d, *J* = 6.9 Hz, 1H), 7.54 (t, *J* = 6.9 Hz, 3H), 7.51 - 7.45 (m, 6H), 7.26 - 7.24 (m, 2H), 5.17 (q, *J* = 5.0, 4.4 Hz, 1H), 4.96 - 4.77 (m, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 154.0, 147.5, 144.4, 137.4, 136.7, 129.6, 129.5, 129.4, 129.2, 128.7 (d, *J* = 14.2 Hz), 128.5, 128.0, 127.5, 126.4, 125.6, 125.5 (q, *J* = 3.7 Hz), 123.9, 122.7, 44.9. HRMS (ESI) calcd for $C_{23}H_{17}N_2F_3$ $[M + H]^+$: 379.1422; found, 379.1432.

_N_-(2-chlorobenzyl)-3-phenylquinolin-2-amine (5.17e):



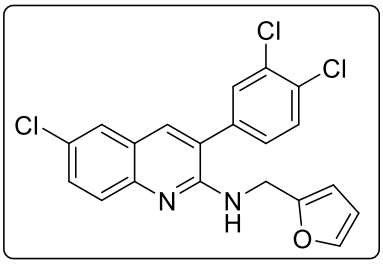
This compound was prepared using general experiential procedure-**C**. Reaction was completed after 60 h. White solid (217 mg, 63%) ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.77 (d, *J* = 8.3 Hz, 1H), 7.69 (s, 1H), 7.60 (d, *J* = 7.7 Hz, 1H), 7.54 (t, *J* = 7.5 Hz, 2H), 7.51 - 7.47 (m, 4H), 7.43 (dq, *J* = 6.4, 3.0 Hz, 1H), 7.37 - 7.31 (m, 1H), 7.23 (t, *J* = 7.8 Hz, 1H), 7.20 - 7.17 (m, 2H), 5.33 (t, *J* = 6.0 Hz, 1H), 4.88 (d, *J* = 6.0 Hz, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 154.0, 147.6, 137.5, 137.3, 136.5, 133.9, 130.6, 129.5, 129.4, 129.4, 129.2, 128.5, 128.4, 127.5, 126.9, 126.4, 125.7, 123.8, 122.4, 43.4. HRMS (ESI) calcd for $C_{22}H_{17}N_2Cl$ $[M + H]^+$: 345.1159; found, 345.1153.

_N_-(4-bromobenzyl)-3-(4-methoxyphenyl)quinolin-2-amine (5.17f):



This compound was prepared using general experiential procedure-**C**. Reaction was completed after 60 h. Yellow solid (256 mg, 61%), ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.78 (d, *J* = 8.4 Hz, 1H), 7.71 (s, 1H), 7.64 (d, *J* = 7.7 Hz, 1H), 7.57 (t, *J* = 7.6 Hz, 1H), 7.46 - 7.42 (m, 4H), 7.28 (d, *J* = 8.4 Hz, 3H), 7.04 (d, *J* = 8.6 Hz, 2H), 5.17 (t, *J* = 5.4 Hz, 1H), 4.79 (d, *J* = 5.7 Hz, 2H), 3.89 (s, 3H).^{13}C NMR (150 MHz, $CDCl_3$) δ 159.7, 154.4, 147.4, 139.2, 136.4, 131.6, 130.3, 129.6, 129.5, 129.3, 127.4, 126.3, 125.3, 123.9, 122.5, 120.9, 114.8, 55.5, 44.9. HRMS (ESI) calcd for $C_{23}H_{19}N_2ClO$ $[M + H]^+$: 419.0759; found, 419.0756.

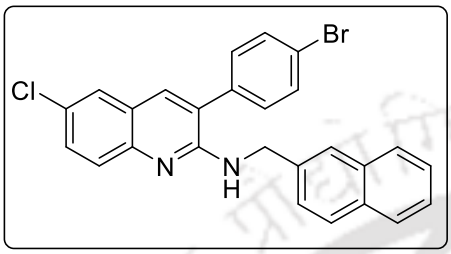
6-chloro-3-(3,4-dichlorophenyl)-_N_-(thiophen-2-ylmethyl)quinolin-2-amine (5.17g):



This compound was prepared using general experiential procedure-**C**. Reaction was completed after 60 h. Yellow solid (266 mg, 66%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.70 (d, *J* = 8.9 Hz, 1H), 7.57 - 7.55 (m, 4H), 7.50 (dd, *J* = 8.9, 2.4 Hz, 1H), 7.35 -7.34 (m, 1H), 7.31 (dd, *J* = 8.2, 2.0 Hz, 1H), 6.32 - 6.26 (m, 2H), 4.97 (t, *J* = 5.4 Hz, 1H), 4.77 (d, *J* =

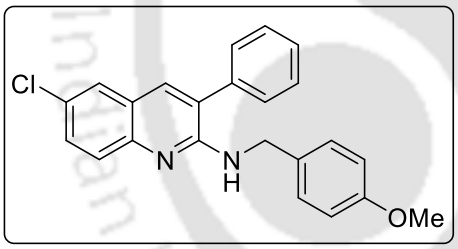
5.3 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.4, 152.4, 146.2, 142.1, 137.0, 135.9, 133.7, 133.0, 131.4, 131.2, 130.5, 128.4, 128.1, 127.9, 126.3, 124.1, 110.5, 107.4, 38.7. HRMS (ESI) calcd for $C_{20}H_{13}N_2OCl_3$ $[M + H]^+$: 403.0172; found, 403.0169.

3-(4-bromophenyl)-6-chloro-*N*-(naphthalen-2-ylmethyl)quinolin-2-amine (5.17h):



This compound was prepared using general experiential procedure-**C**. Reaction was completed after 60 h. White solid (258 mg, 59%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.83 - 7.77 (m, 4H), 7.72 (d, *J* = 8.9 Hz, 1H), 7.64 - 7.55 (m, 4H), 7.53 - 7.42 (m, 4H), 7.38 - 7.31 (m, 2H), 5.10 (t, *J* = 5.4 Hz, 1H), 4.94 (d, *J* = 5.5 Hz, 2H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 154.0, 146.2, 136.9, 135.9, 135.6, 133.5, 132.8, 132.7, 130.8, 130.3, 128.5, 128.0, 127.9, 127.8, 127.6, 126.6, 126.4, 126.3, 126.2, 125.9, 125.3, 124.3, 122.9, 45.8. HRMS (ESI) calcd for $C_{26}H_{18}N_2BrCl$ $[M + H]^+$: 473.0420; found, 473.0425.

6-chloro-*N*-(4-methoxybenzyl)-3-phenylquinolin-2-amine (5.17i):



This compound was prepared using general experiential procedure-**C**. Reaction was completed after 60 h. Yellow solid (254 mg, 68%), ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.71 (d, *J* = 8.9 Hz, 1H), 7.59 (s, 1H), 7.57 - 7.46 (m, 1H), 7.52 - 7.37 (m, 6H), 7.29 (d, *J* = 8.5 Hz, 2H), 6.85 (d, *J* = 8.6 Hz, 2H), 5.10 (t, *J* = 5.1 Hz, 1H), 4.72 (d, *J* = 5.4 Hz, 2H), 3.79 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.9, 154.4, 146.1, 137.1, 135.4, 131.7, 129.9, 129.4, 129.2, 129.1, 128.6, 127.8, 127.3, 126.6, 126.2, 124.4, 114.0, 55.4, 45.1. HRMS (ESI) calcd for $C_{23}H_{19}N_2OCl$ $[M + H]^+$: 375.1265; found, 375.1268.

Crystal data for compound 5.14e, 5.14f, 5.14h, 5.14p:

	Compound **5.14e**	Compound **5.14f**	Compound **5.14h**	Compound **5.14p**
Empirical formula	C15 H11 Cl N2'	'C30 H20 Cl4 N4'	C14 H11 N3	C12 H13 Cl N2'
CCDC	1895880	185882	1895879	1895881
Formula weight	254.71	578.30	221.27	220.69
Temperature, T	293 K	293 K	293 K	293 K
Crystal system	monoclinic	'Triclinic'	monoclinic	monoclinic
Space group	'C 1 2/c 1'	'P-1'	'C 1 2/c 1'	'P 1 21/c 1'
Unit cell dimensions	a= 17.7363(14)Å b=6.0653(5)Å c=23.2152(18) Å α=90° β=101.194(7)° γ=90°	a= 8.9837(6)Å b= 9.2581(6))Å c= 9.6620(7) (18)Å α= 96.983(2)° β= 109.137(2)° γ= 114.774(2)°	A=11.1972(12) Å b=15.0976(13) Å c=13.7789(14) Å α=90.00° β=110.988(12) ° γ=90.00°	A= 9.7193(5)Å b= 5.7932(3)Å c= 19.9458(11)Å α=90.00° β= 97.776(5) ° γ=90.00°
Volume, V (Å^3)	2449.9(3)	657.17(8)	2174.8(4)	1112.74(10)
Z =	8	1	8	4
Density (calculated), Mg·m^{-3}	1.381	1.461	1.352	1.317
Absorption coefficient, μ (mm^{-1}) =	0.293	0.479	0.083	0.310
F(000)	1056.0	296	928.0	464.0
Crystal size, mm^3	0.31 × 0.26 × 0.21	0.31 × 0.25 × 0.19	0.31 × 0.25 × 0.19	0.30 × 0.24 × 0.16
Theta range for data collection	2.34 to 25.00	2.34 to 26.64	2.37 to 24.99	2.75 to 24.98
Index ranges	-14 ≤ h ≤ 20, -3 ≤ k ≤ 7, -27 ≤ l ≤ 24	-10 ≤ h ≤ 10, -11 ≤ k ≤ 11, -11 ≤ l ≤ 11	-13 ≤ h ≤ 12, -17 ≤ k ≤ 17, -16 ≤ l ≤ 14	-11 ≤ h ≤ 10, -6 ≤ k ≤ 6, -10 ≤ l ≤ 23
Reflections	1246	8270	1038	1094

collected				
Independent reflections	2157	2325	1922	1958
Completeness to theta	1.000	1.000	1.000	0.999
Absorption correction	Multi-scan	Multi-scan	Multi-scan	Multi-scan
Max. and min. transmission	1.00000 and 0.48931	1.00000 and 0.71471	1.00000 and 0.71482	1.00000 and 0.97521
Refinement method	'SHELXL-97(Sheldrick, 1997)'	'SHELXL-97 (Sheldrick, 1997)'	'SHELXL-97 (Sheldrick, 1997)'	'SHELXL-97 (Sheldrick, 1997)'
Data / restraints / parameters	2157 /0/ 163	2325/0/180	1922/ 0/ 154	1958/0/137
Goodness-of-fit on F^2	1.078	1.076	1.071	1.083
Final R indices [I>2sigma(I)]	R1 = 0.0473, wR2 = 0.1069	R1 = 0.0342, wR2 = 0.1250	R1=0.0676 wR2 = 0.1899	R1=0.0499 wR2 = 0.0984
R indices (all data)	R1 = 0.0708, wR2 = 0.1176	R1 = 0.0393 wR2 = 0.1350	R1=0.1000 wR2 = 0.2236	R1= 0.0844 wR2 = 0.1231
Extinction coefficient	0.293	0.479	0.081	0.310
Largest diff. peak and hole	0.222and -0.254 e·Å^{-3}	0.193 and -0.350 e·Å^{-3}	0.218 and -0.279 e·Å^{-3}	0.229 and -0.214 e·Å^{-3}

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5.10. Selected NMR spectra of products:

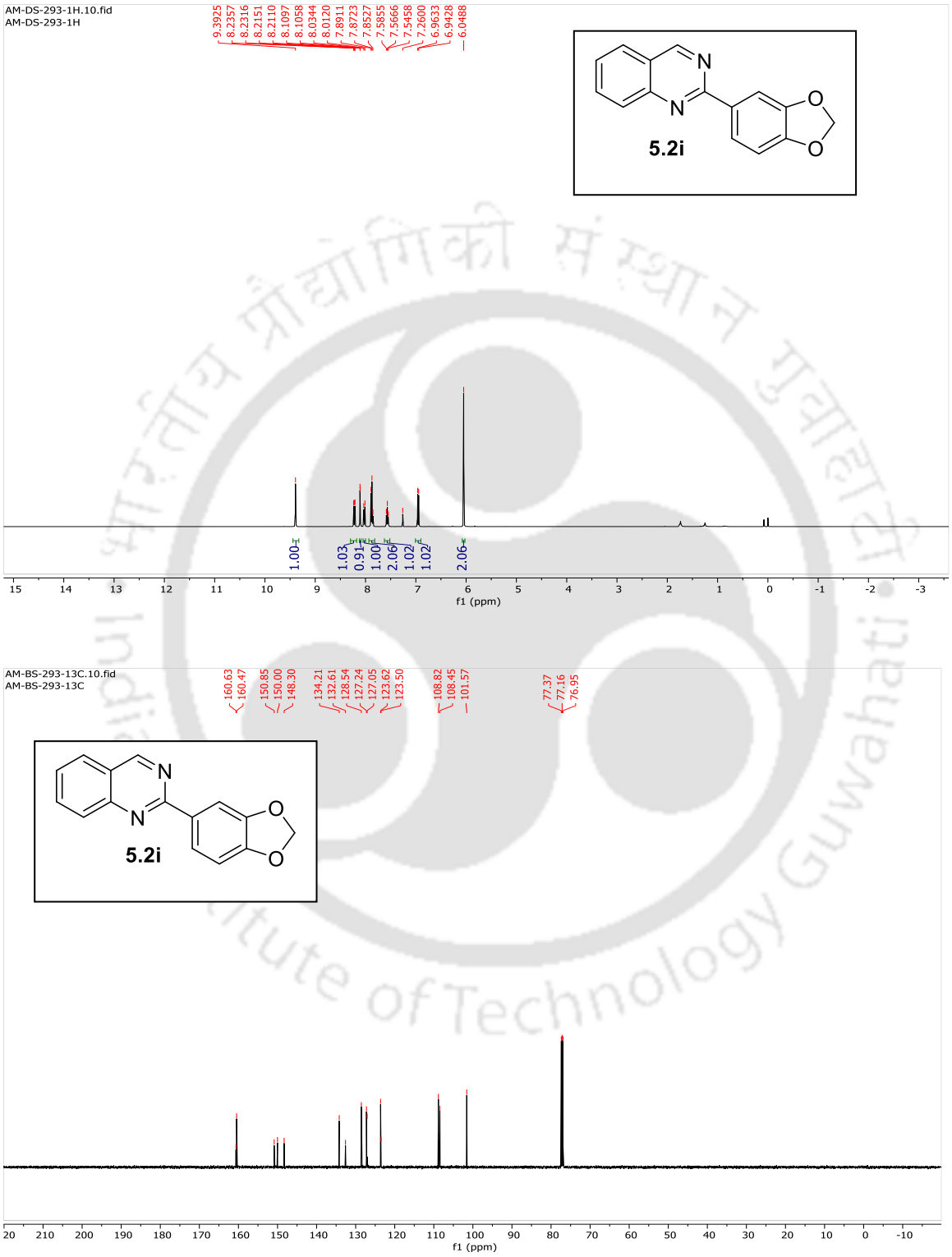

Figure 5.2: ^{1}H and ^{13}C NMR of compound **5.2i**.

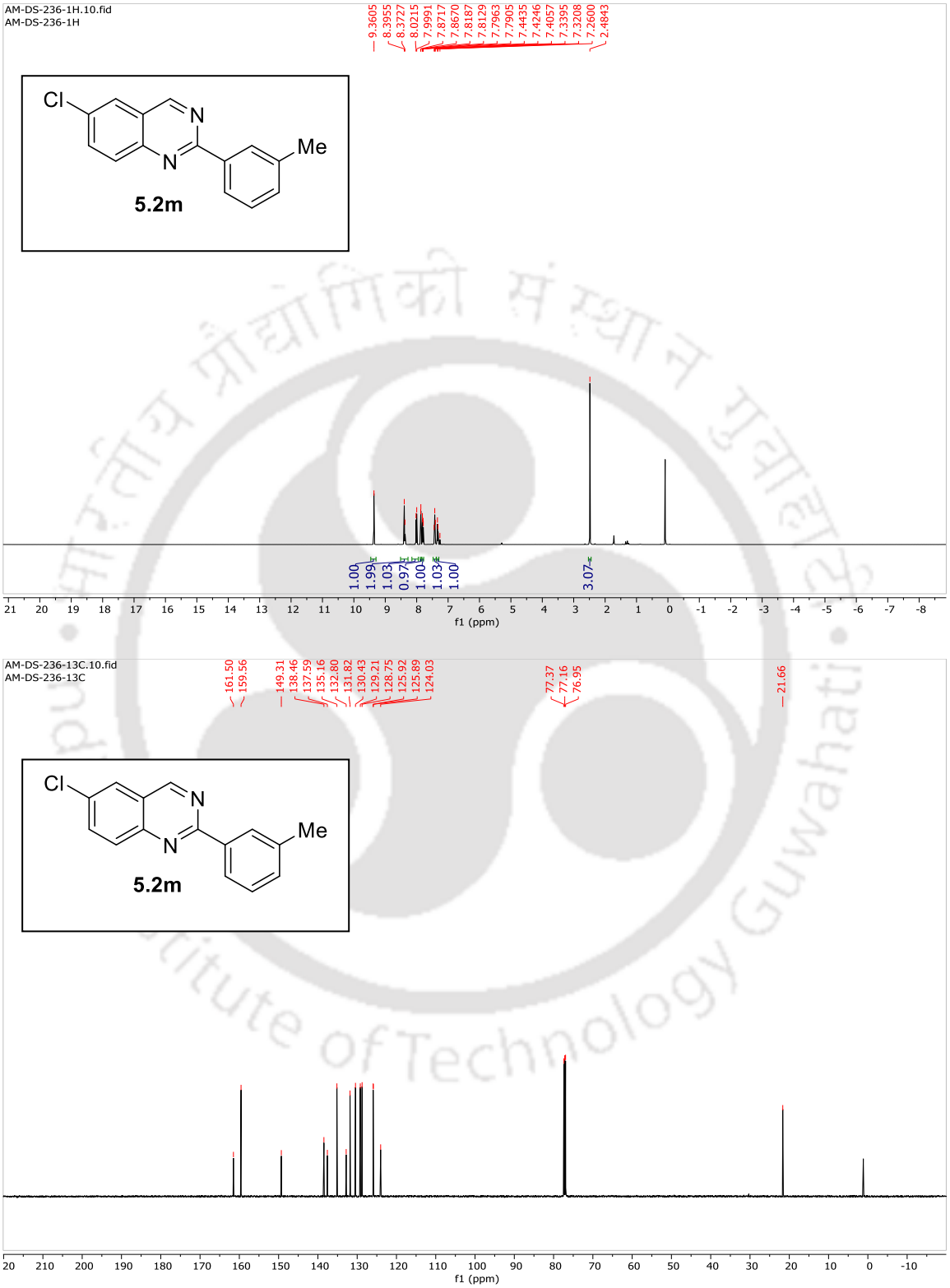

Figure 5.3: ^{1}H and ^{13}C NMR of compound **5.2m**.

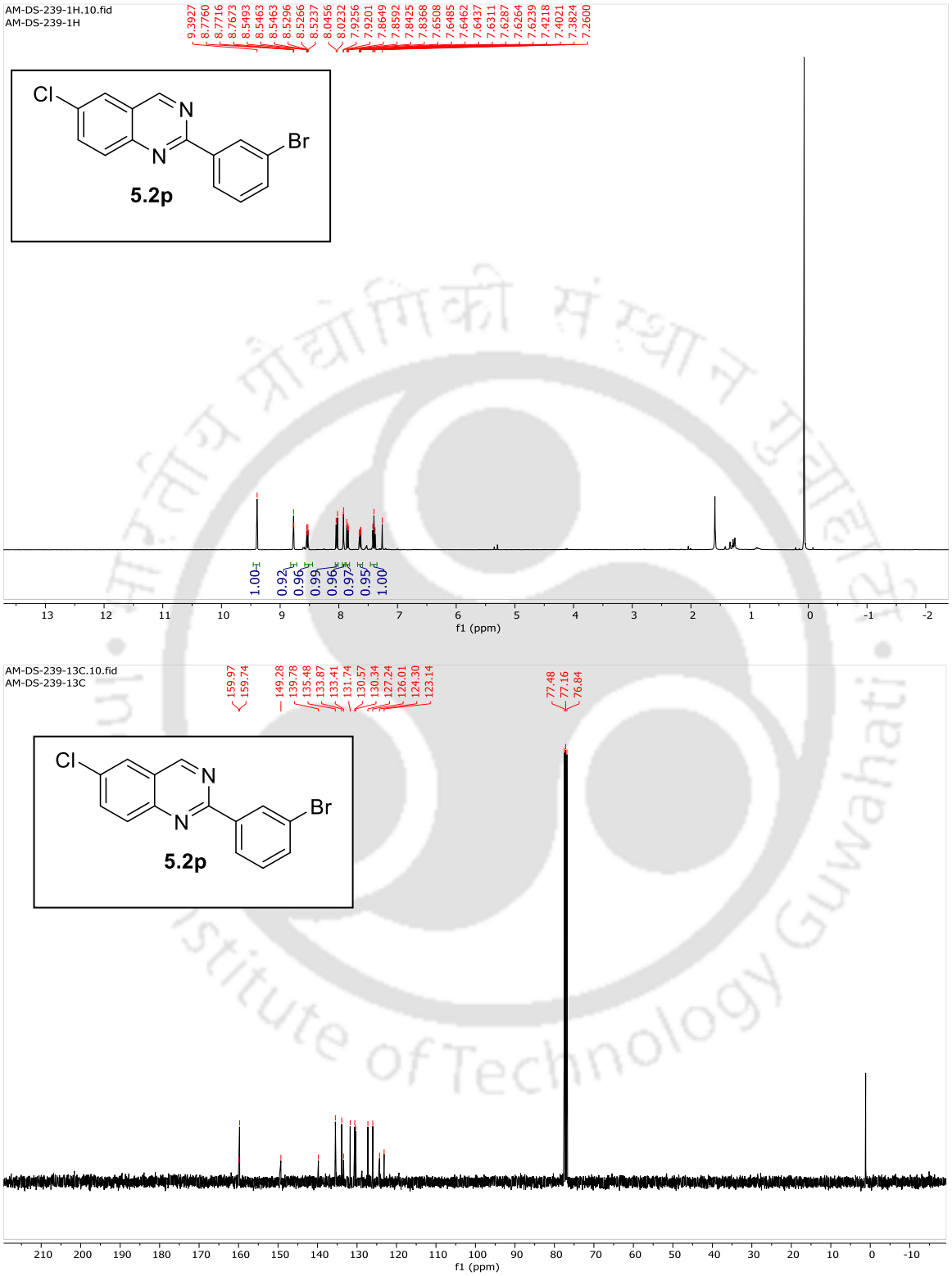

Figure 5.3: ^{1}H and ^{13}C NMR of compound **5.2p**.

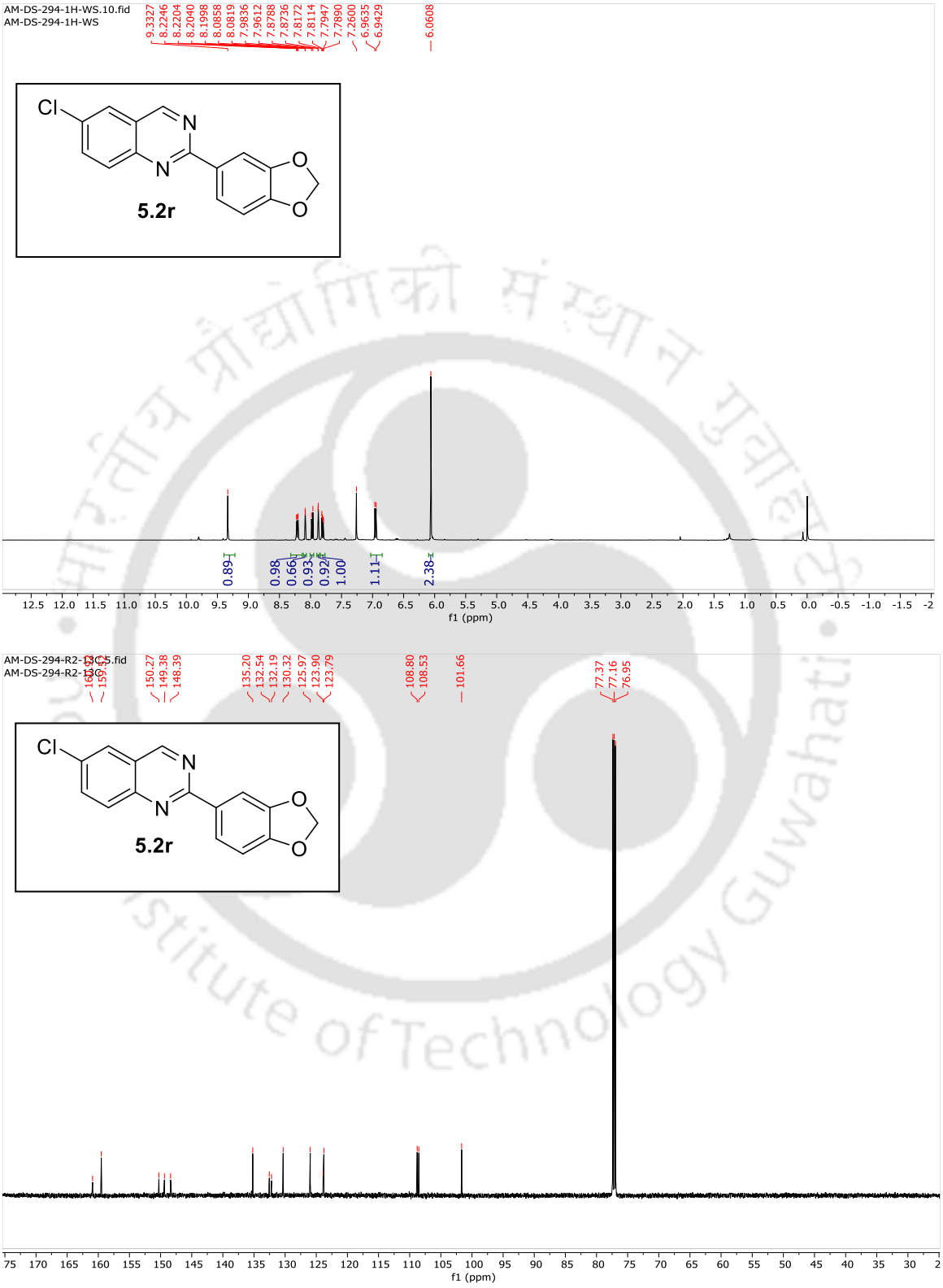

Figure 5.4: ^{1}H and ^{13}C NMR of compound **5.2r**.

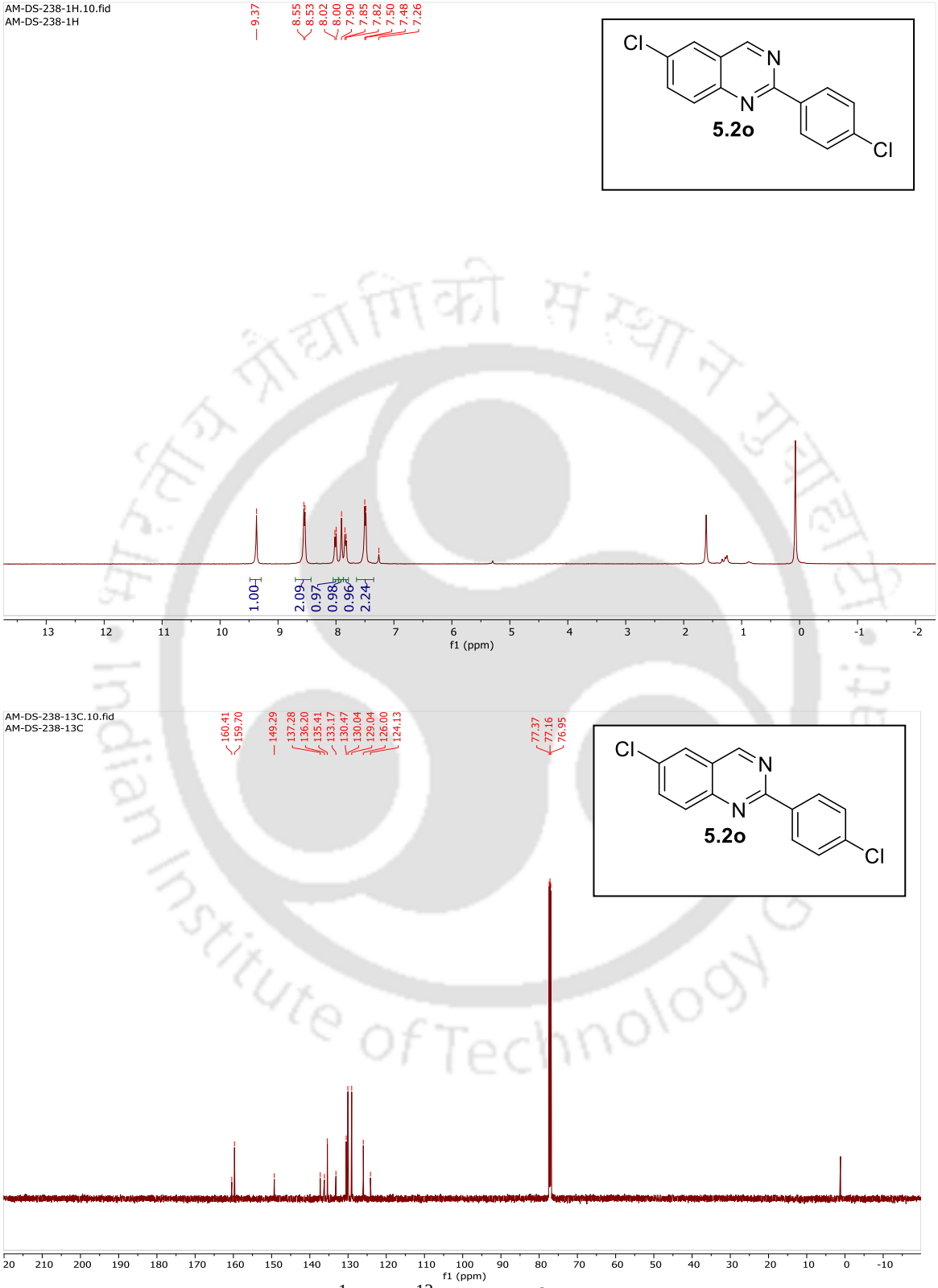

Figure 5.5: ^{1}H and ^{13}C NMR of compound **5.2r**.

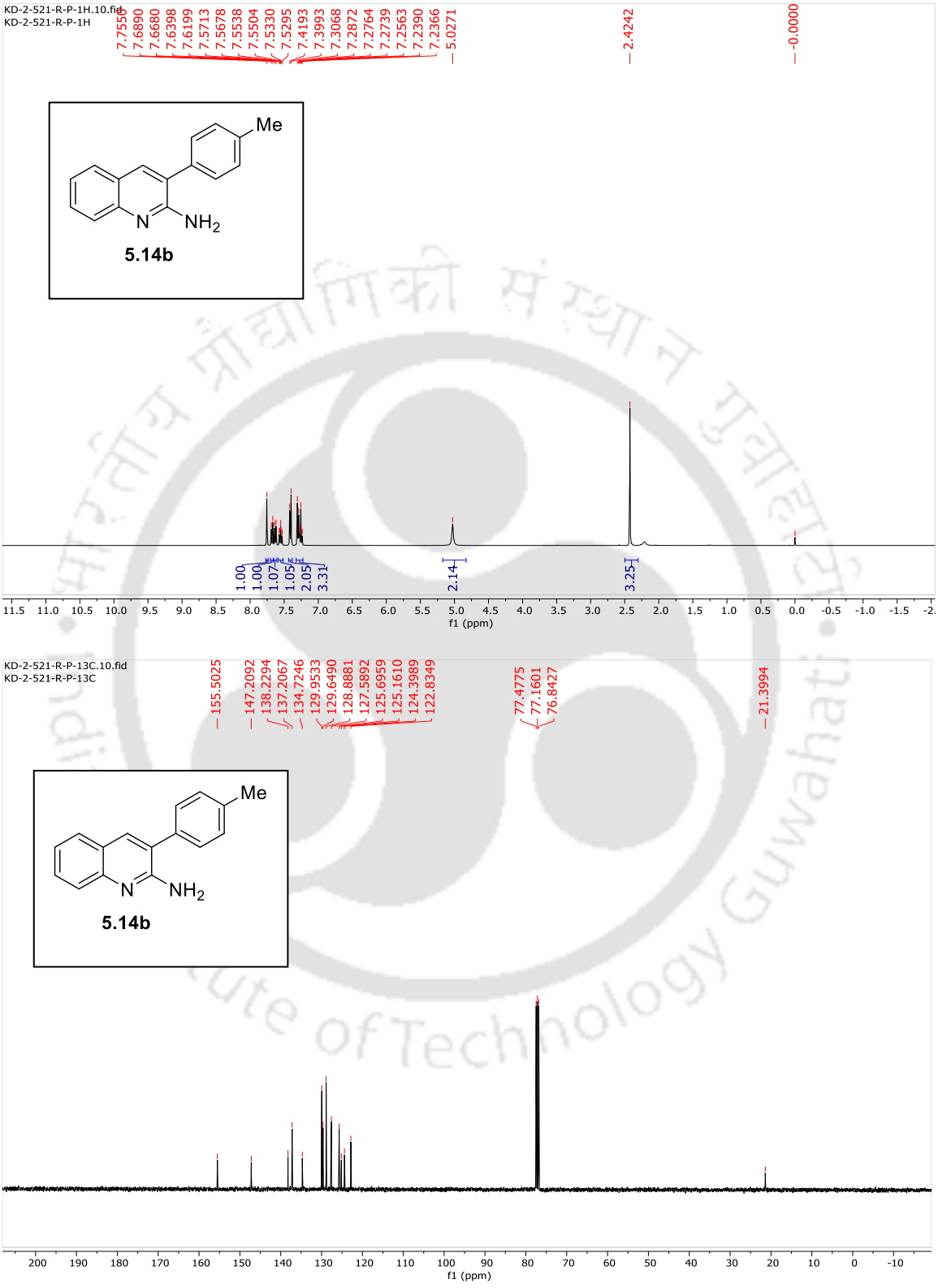

Figure 5.6: ^{1}H and ^{13}C NMR of compound **5.14b**.

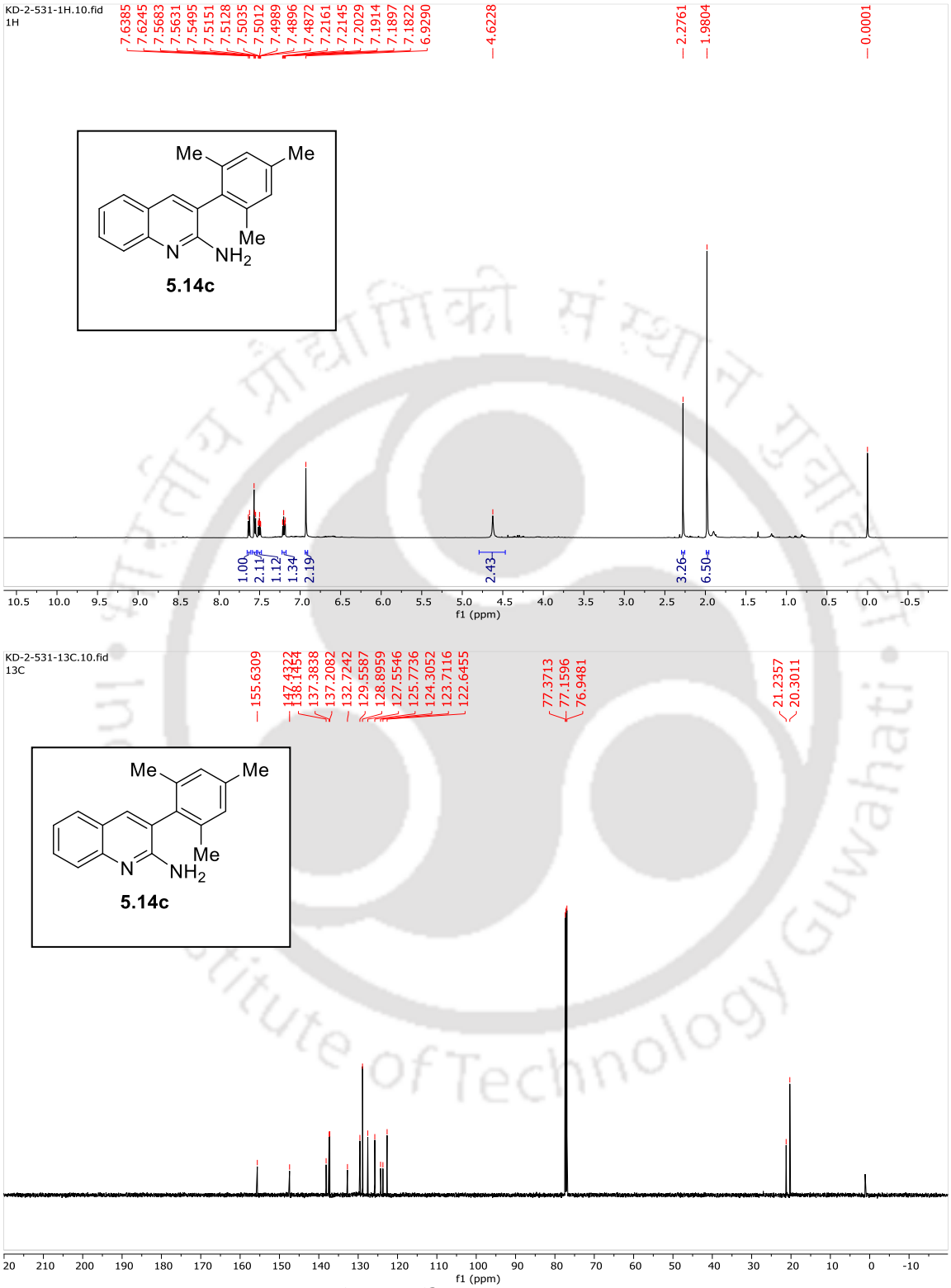

Figure 5.7: ^{1}H and ^{13}C NMR of compound **5.14c**.

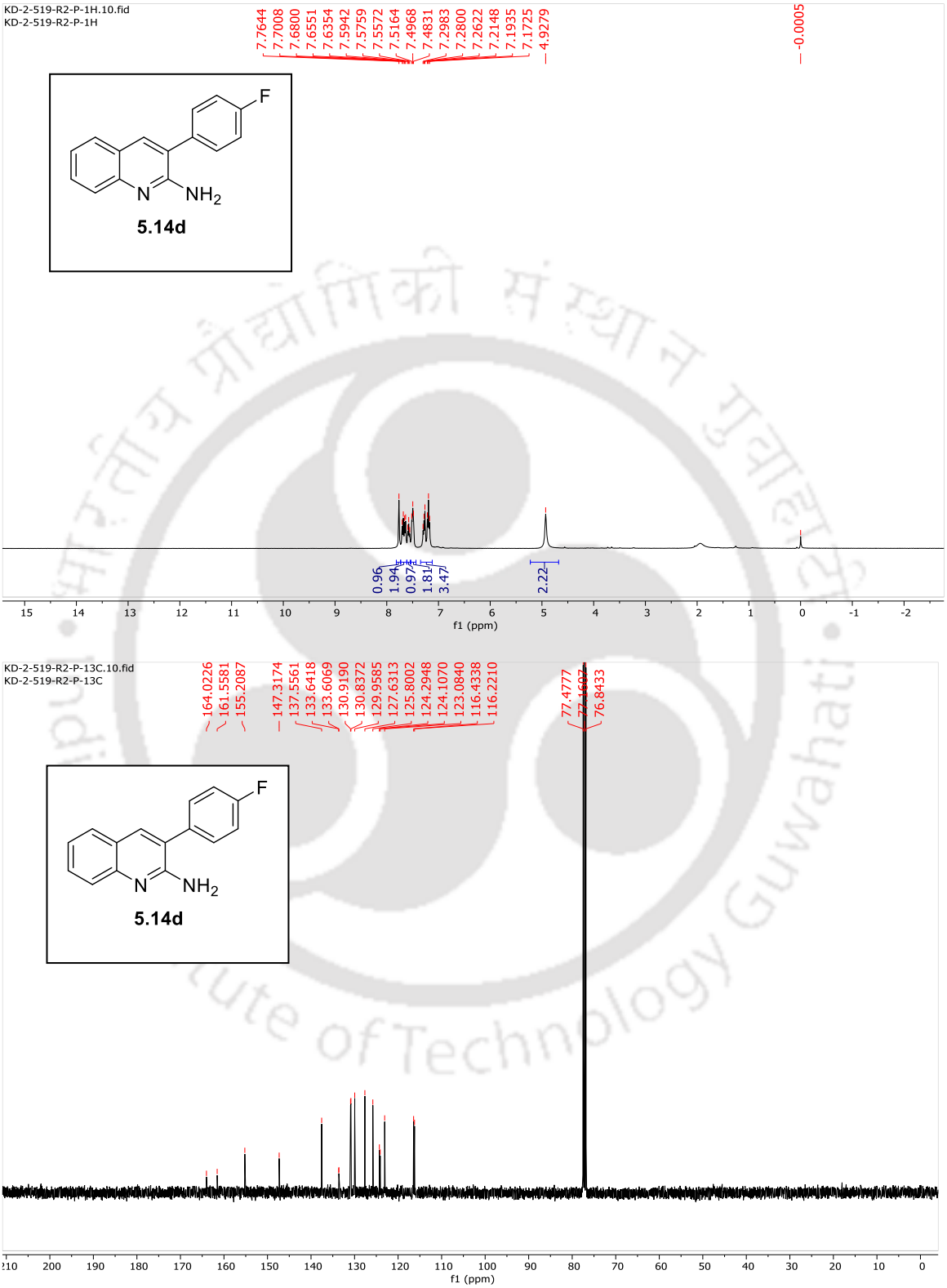

Figure 5.8: ^{1}H and ^{13}C NMR of compound **5.14d**.

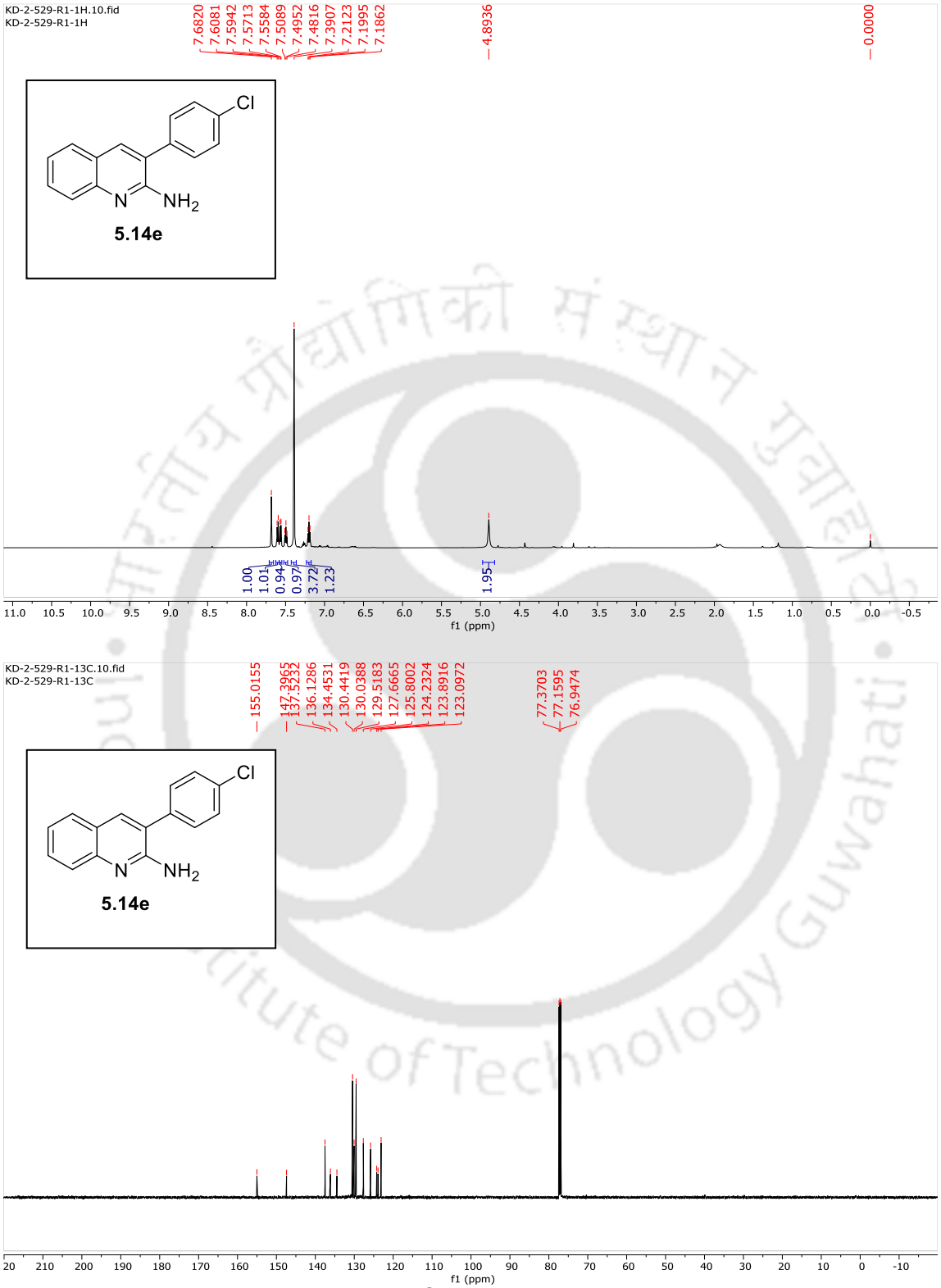

Figure 5.9: ^{1}H and ^{13}C NMR of compound **5.14e**.

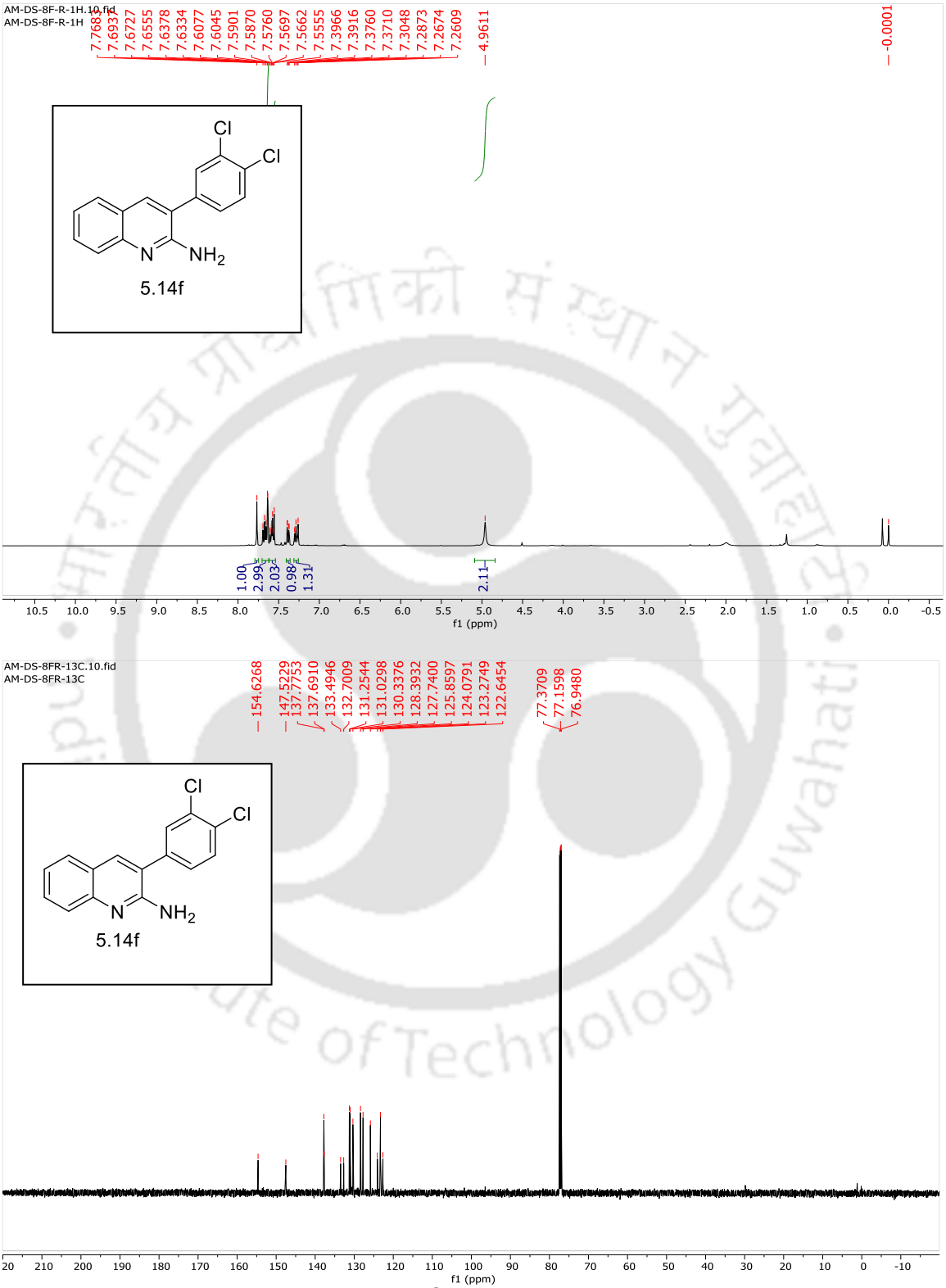

Figure 5.10: ^{1}H and ^{13}C NMR of compound **5.14f**.

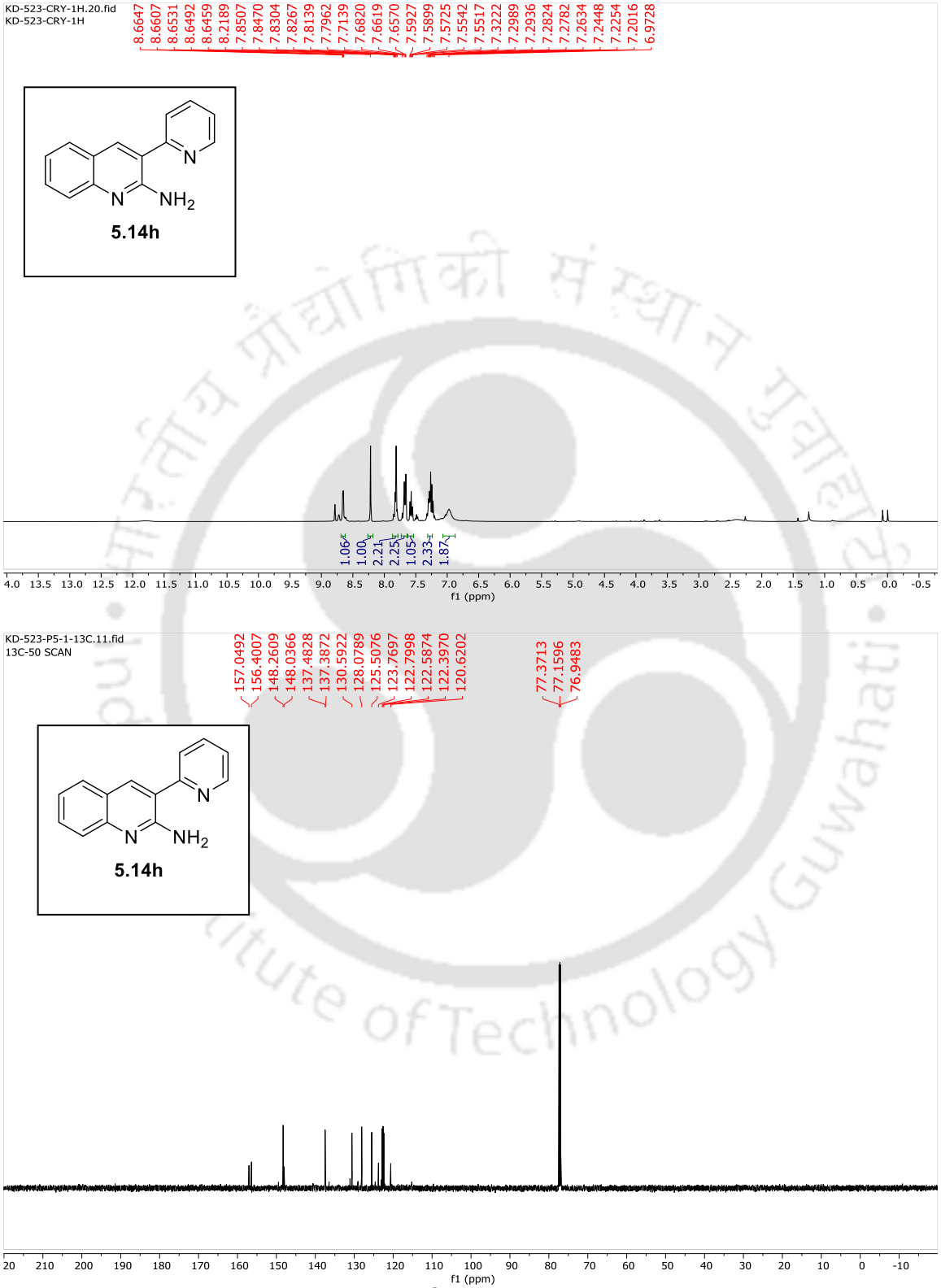

Figure 5.11: ^{1}H and ^{13}C NMR of compound **5.14h**.

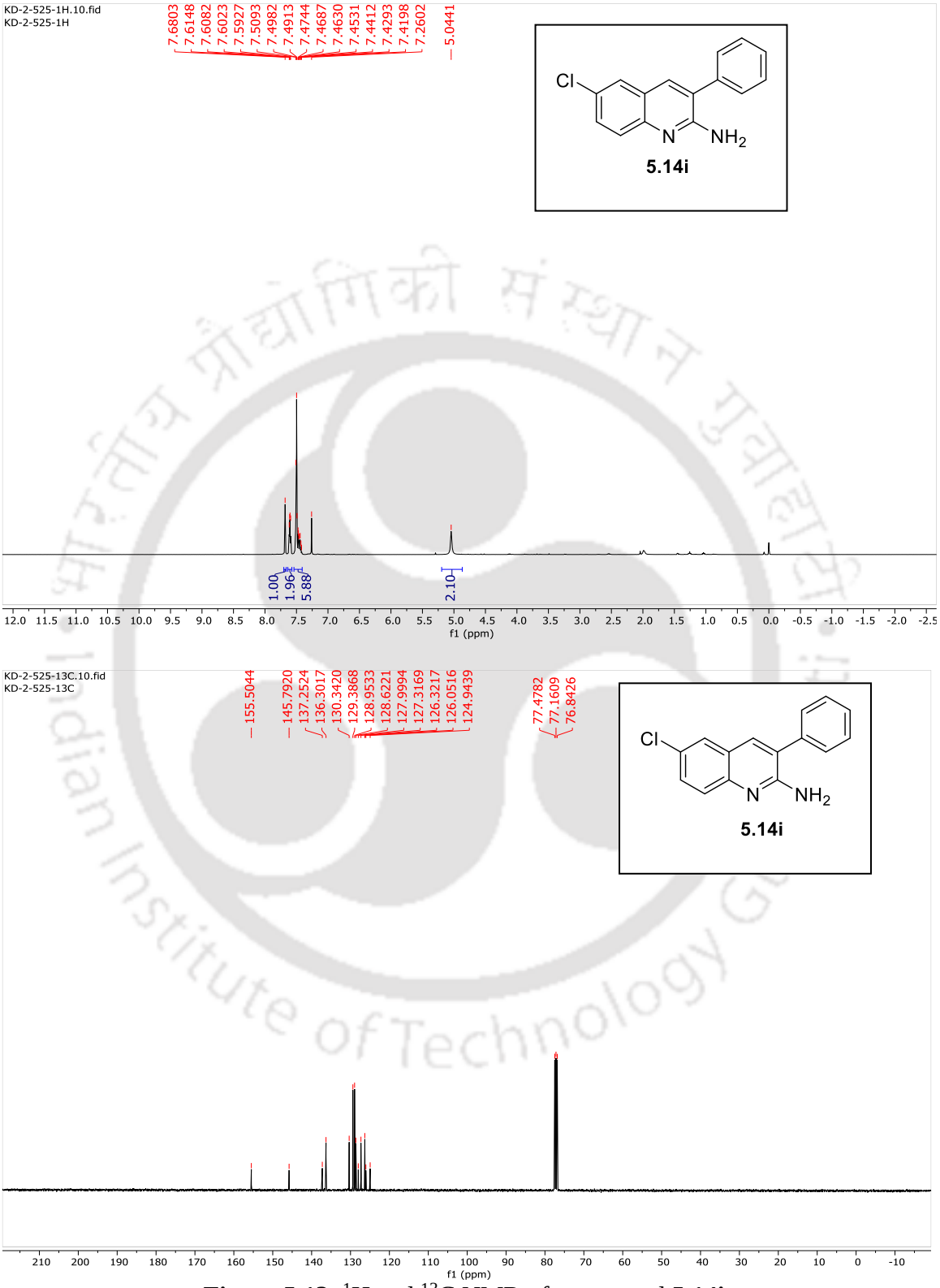

Figure 5.12: ^{1}H and ^{13}C NMR of compound **5.14i**.

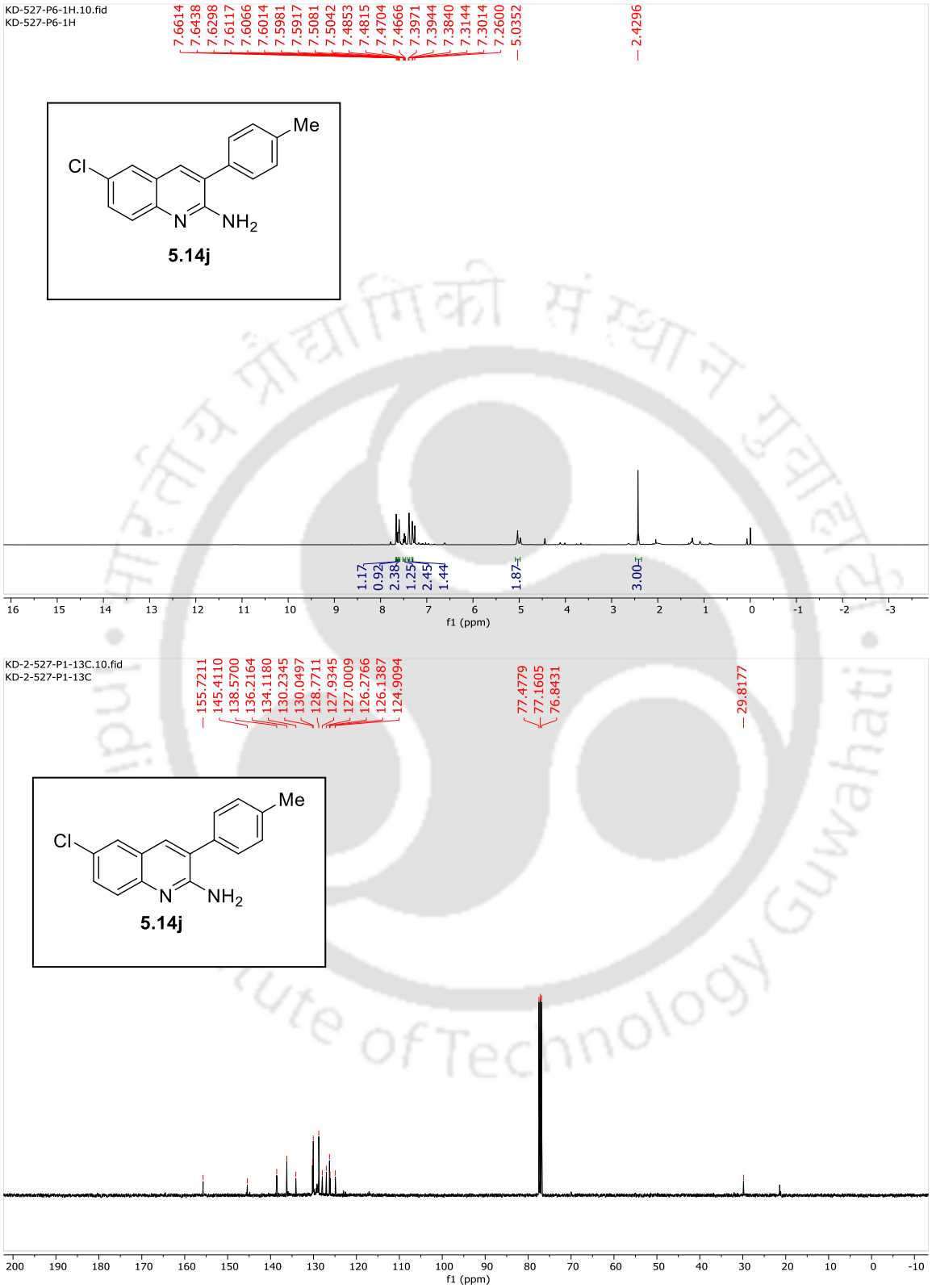

Figure 5.13: ^{1}H and ^{13}C NMR of compound **5.14j**.

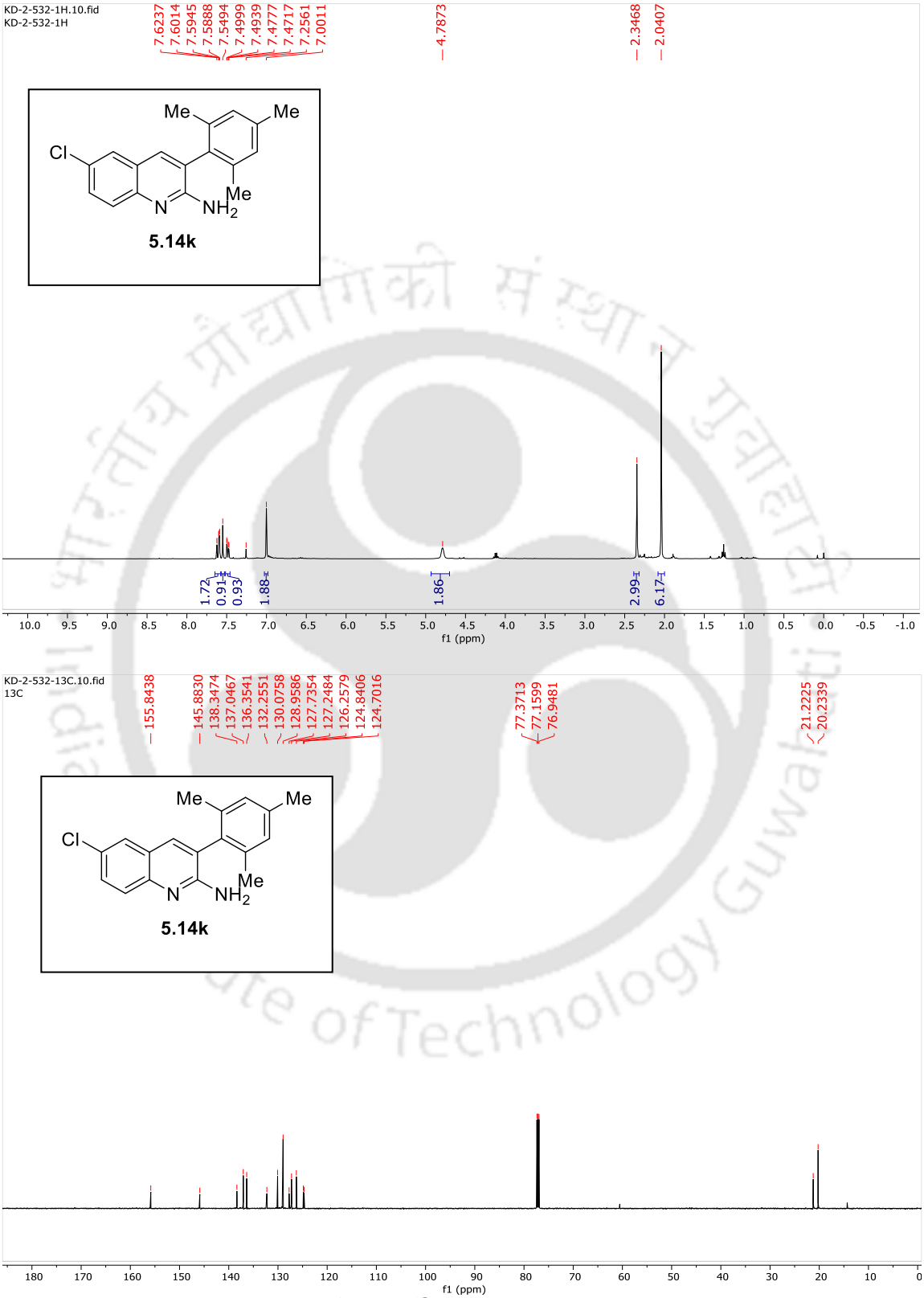

Figure 5.14: ^{1}H and ^{13}C NMR of compound **5.14k**.

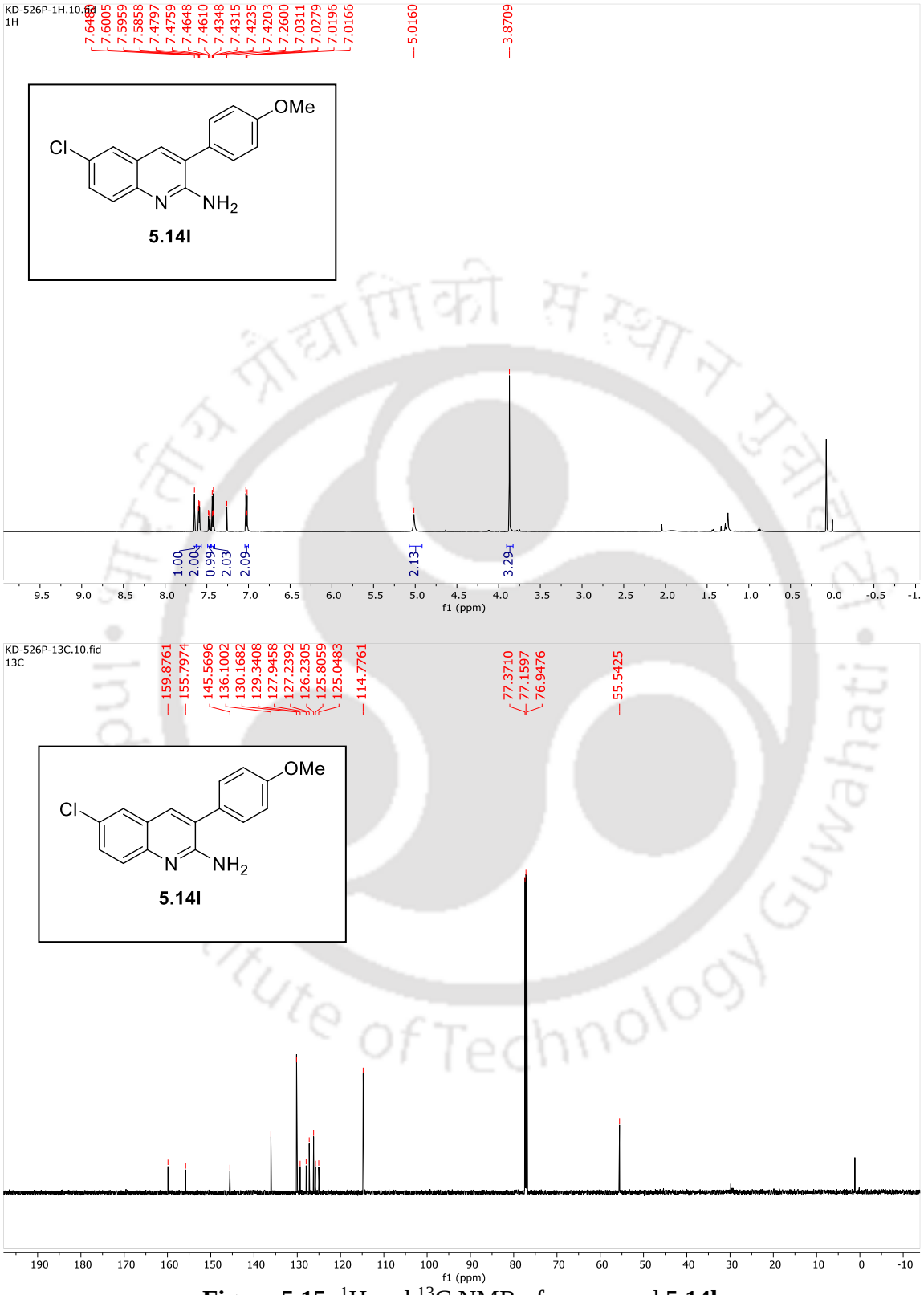

Figure 5.15: ^{1}H and ^{13}C NMR of compound **5.14l**.

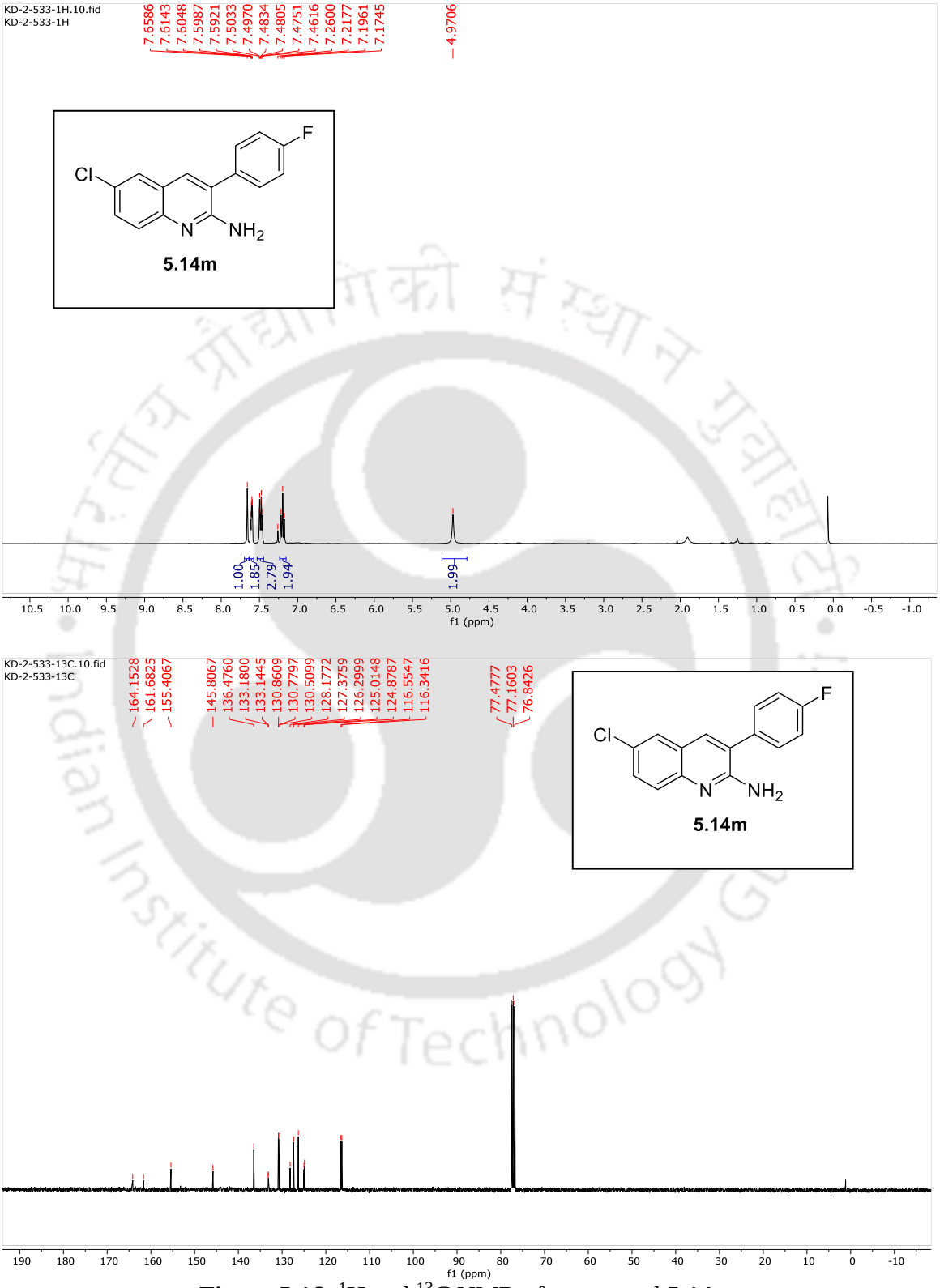

Figure 5.16: ^{1}H and ^{13}C NMR of compound **5.14m**.

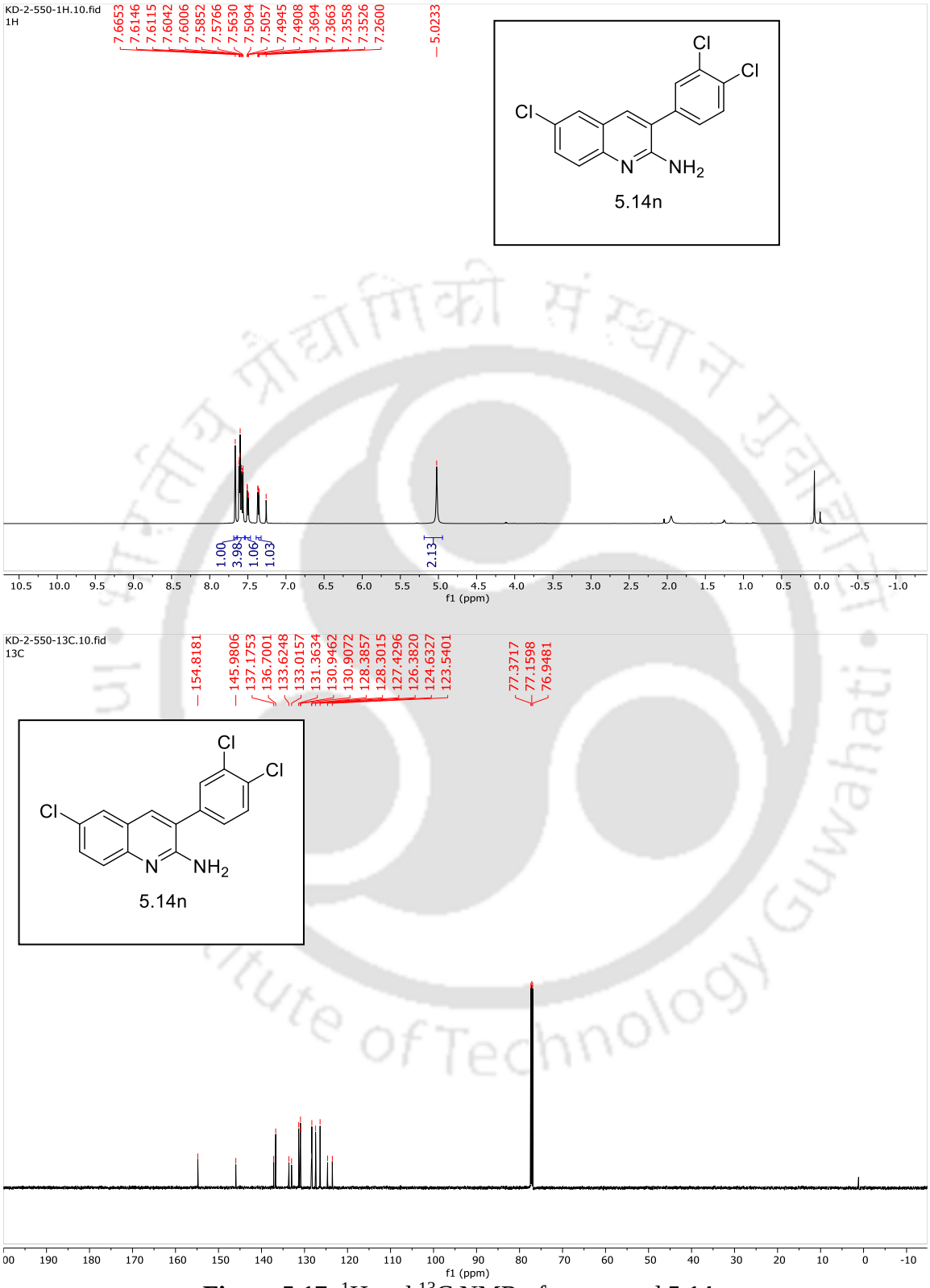

Figure 5.17: ^{1}H and ^{13}C NMR of compound **5.14n**.

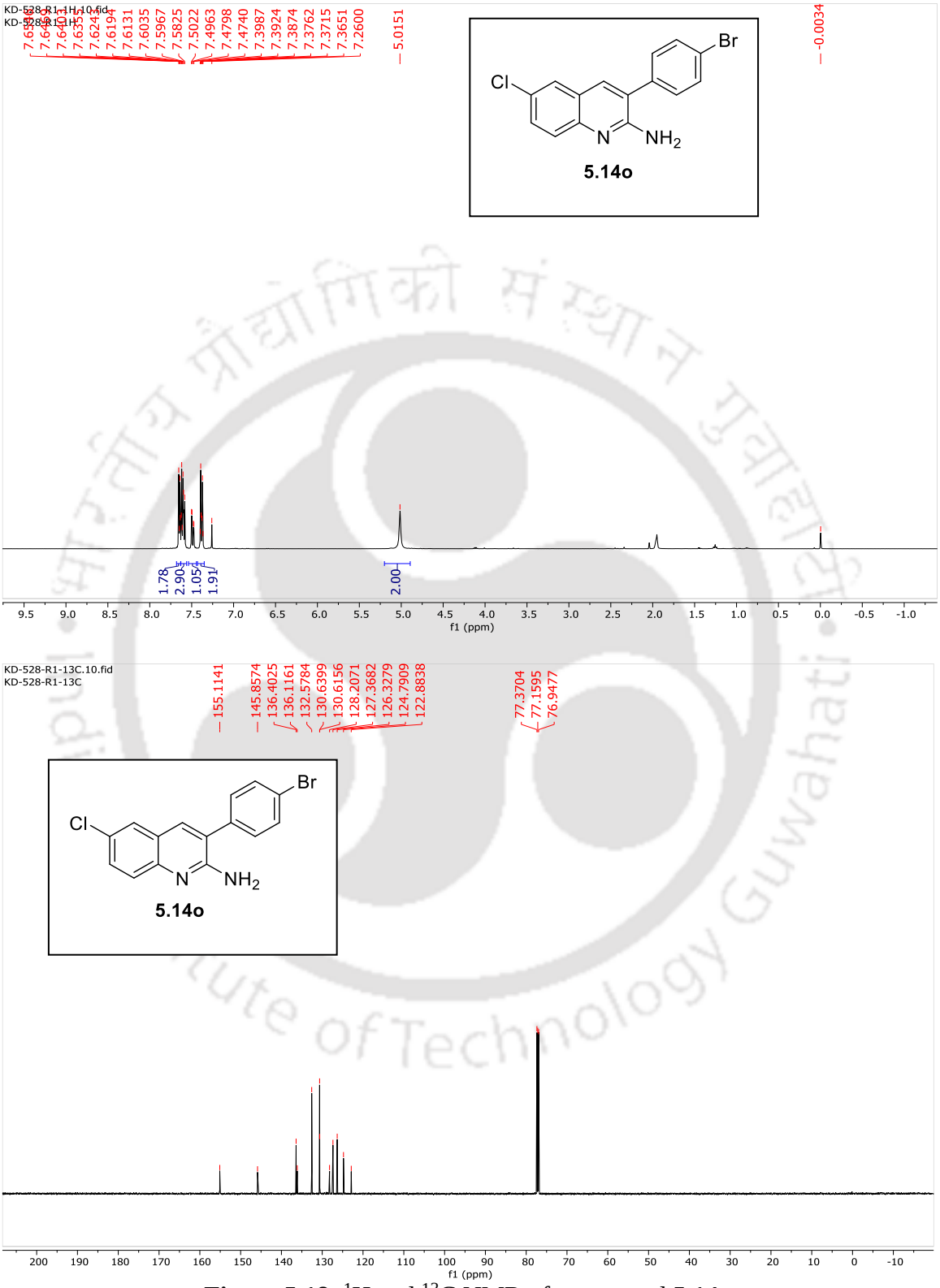

Figure 5.18: ^{1}H and ^{13}C NMR of compound **5.14o**.

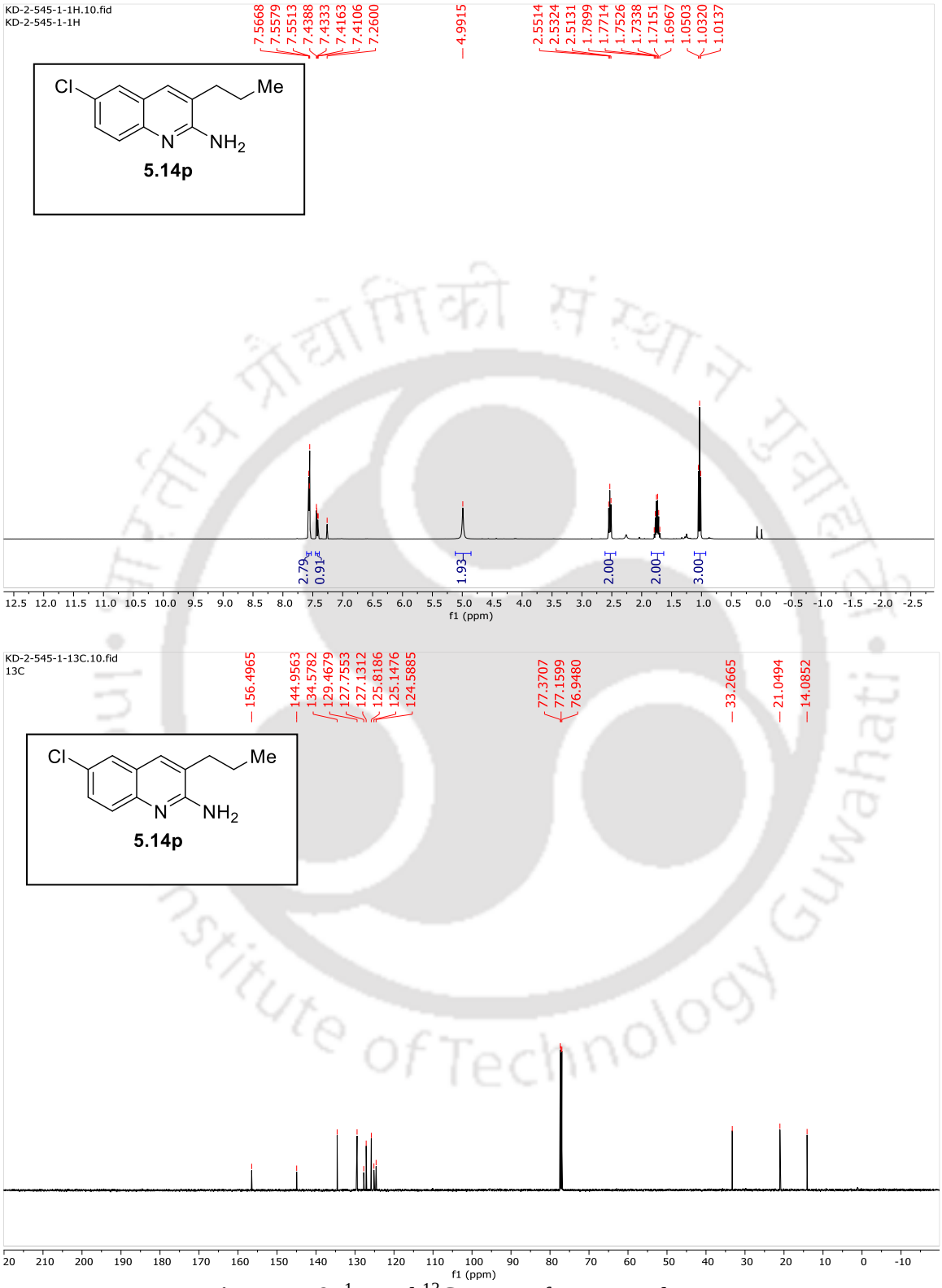

Figure 5.19: ^{1}H and ^{13}C NMR of compound **5.14p**.

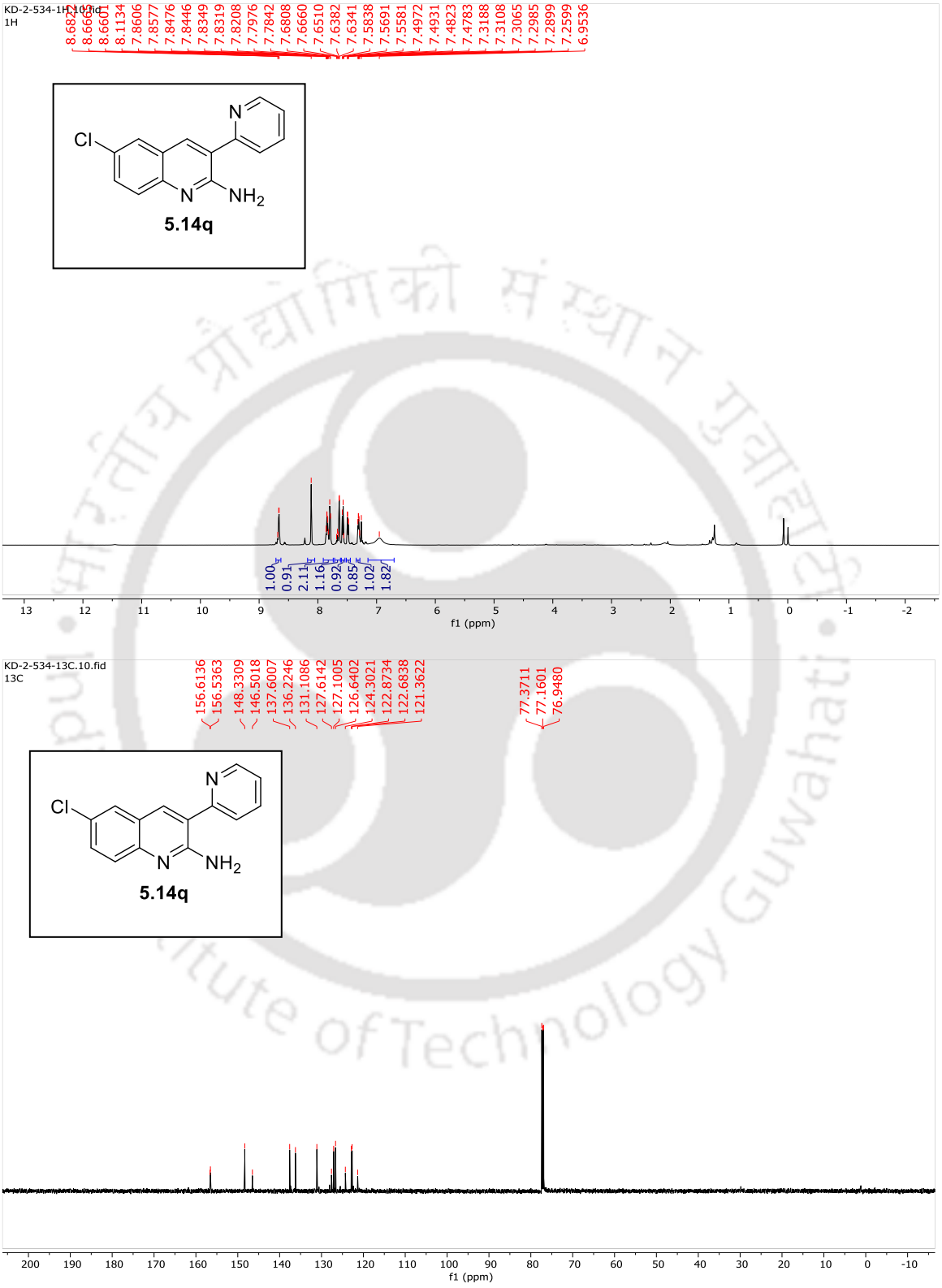

Figure 5.20: ^{1}H and ^{13}C NMR of compound **5.14q**.

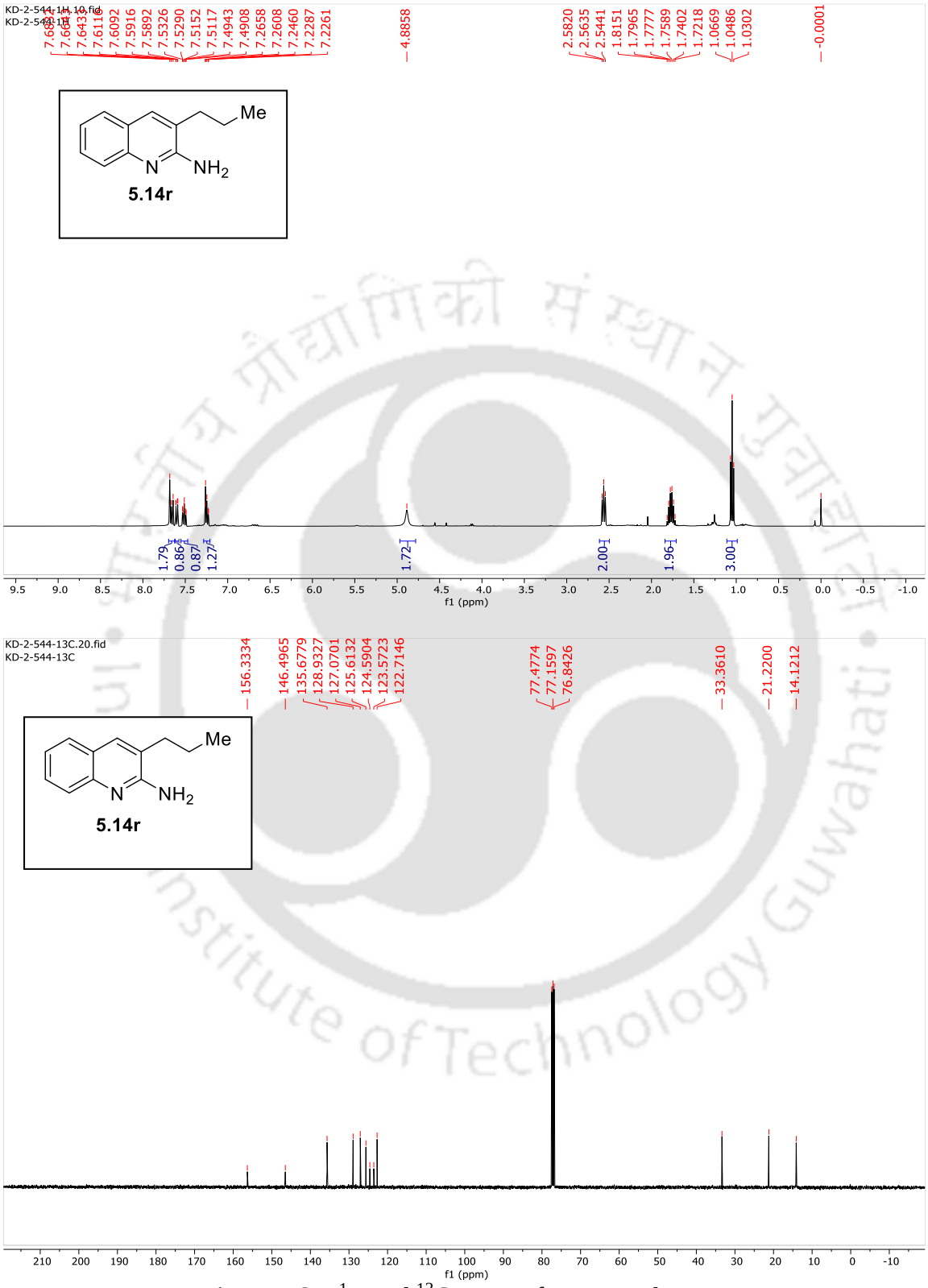

Figure 5.21: ^{1}H and ^{13}C NMR of compound **5.14r**.

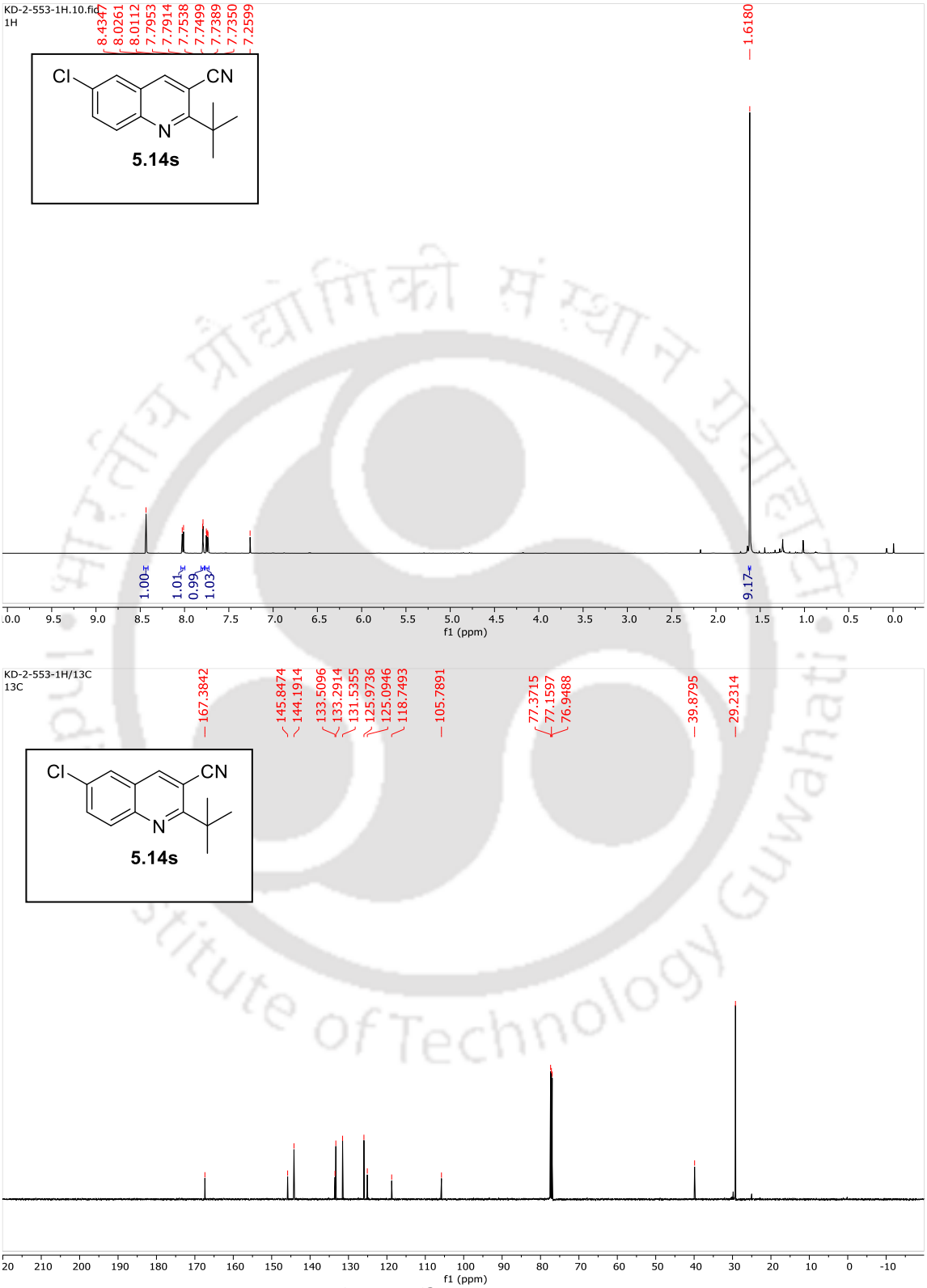

Figure 5.22: ^{1}H and ^{13}C NMR of compound **5.14s**.

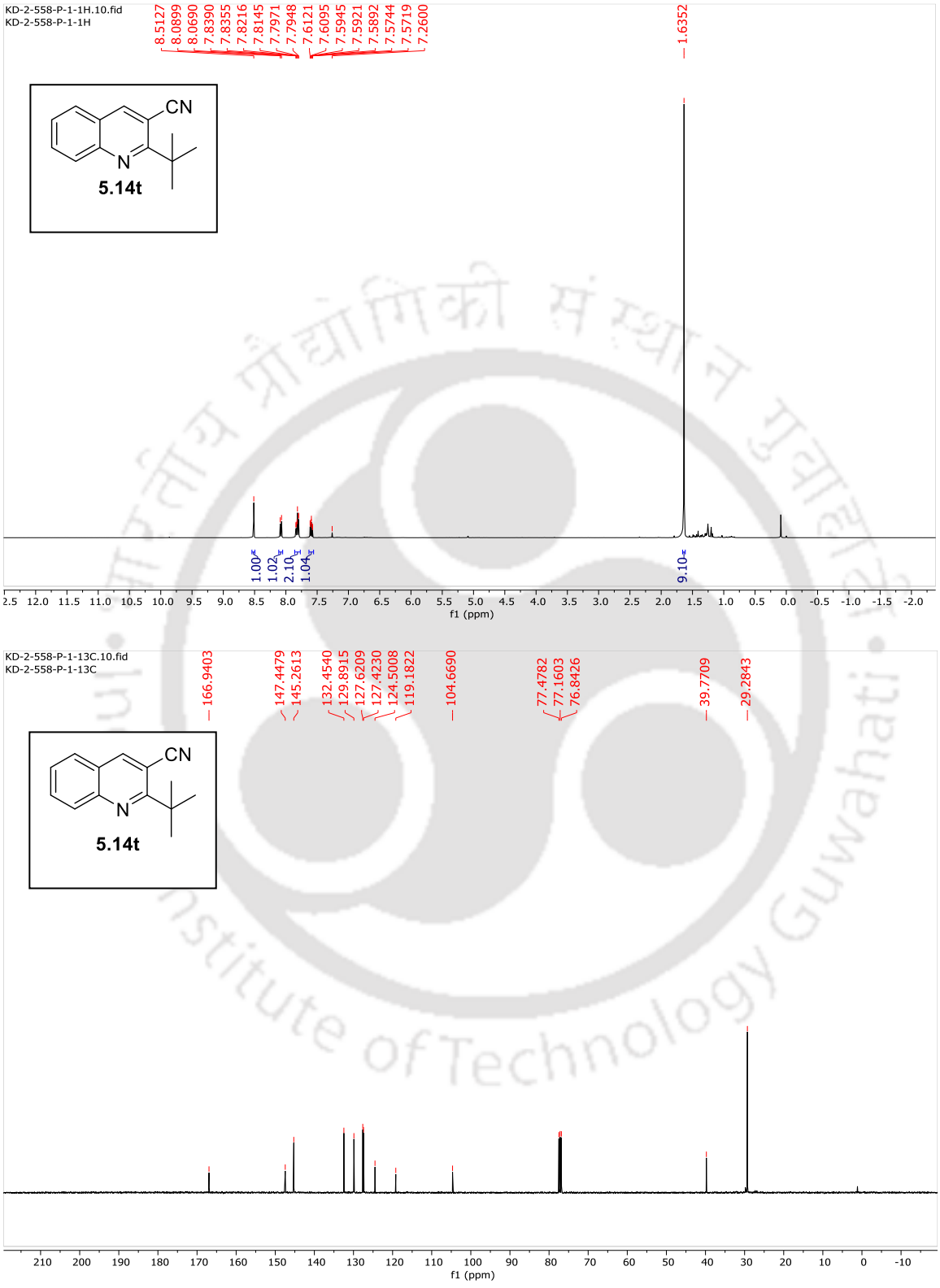

Figure 5.23: ^{1}H and ^{13}C NMR of compound **5.14t**.

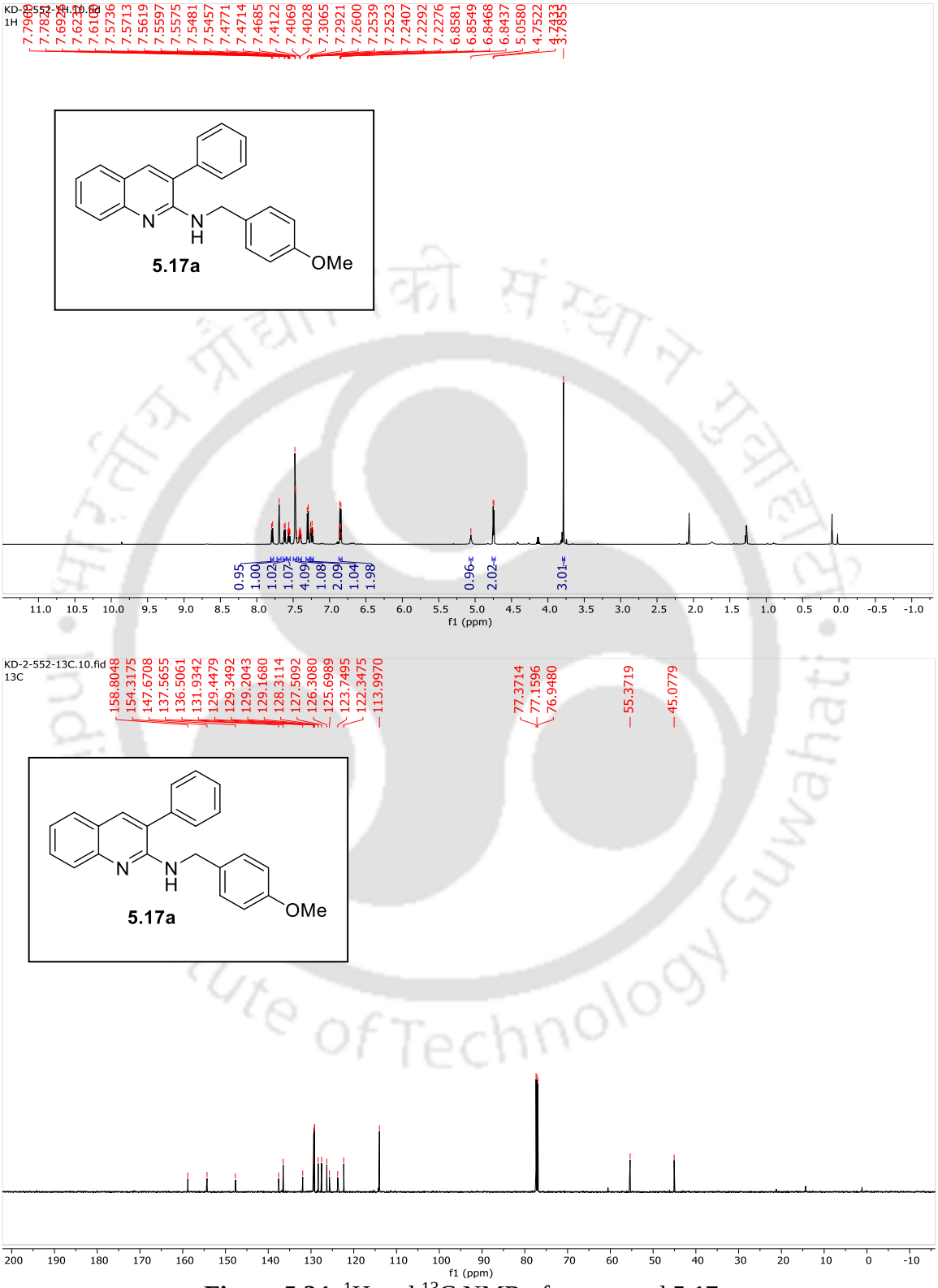

Figure 5.24: ^{1}H and ^{13}C NMR of compound **5.17a**.

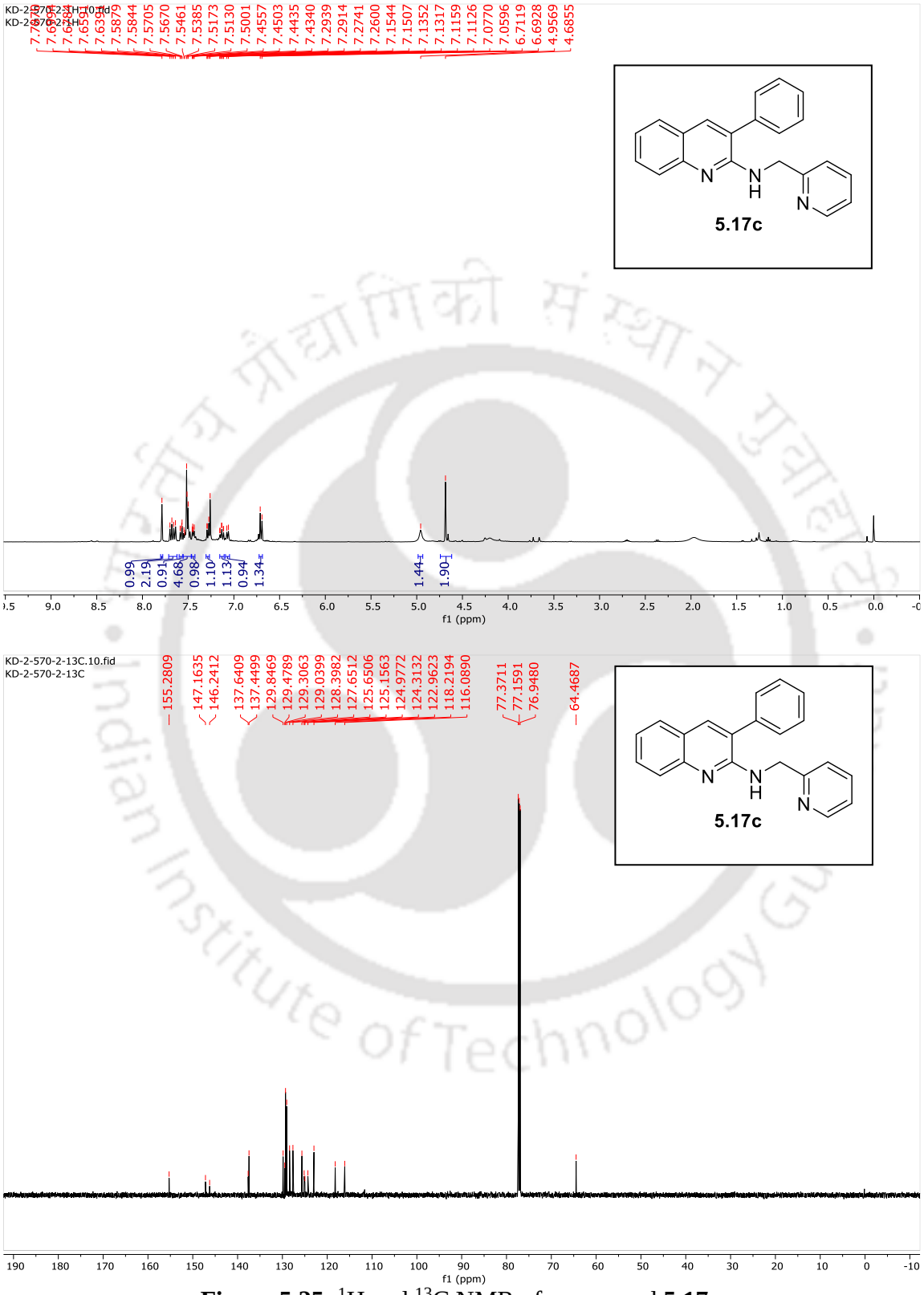

Figure 5.25: ^{1}H and ^{13}C NMR of compound **5.17c**.

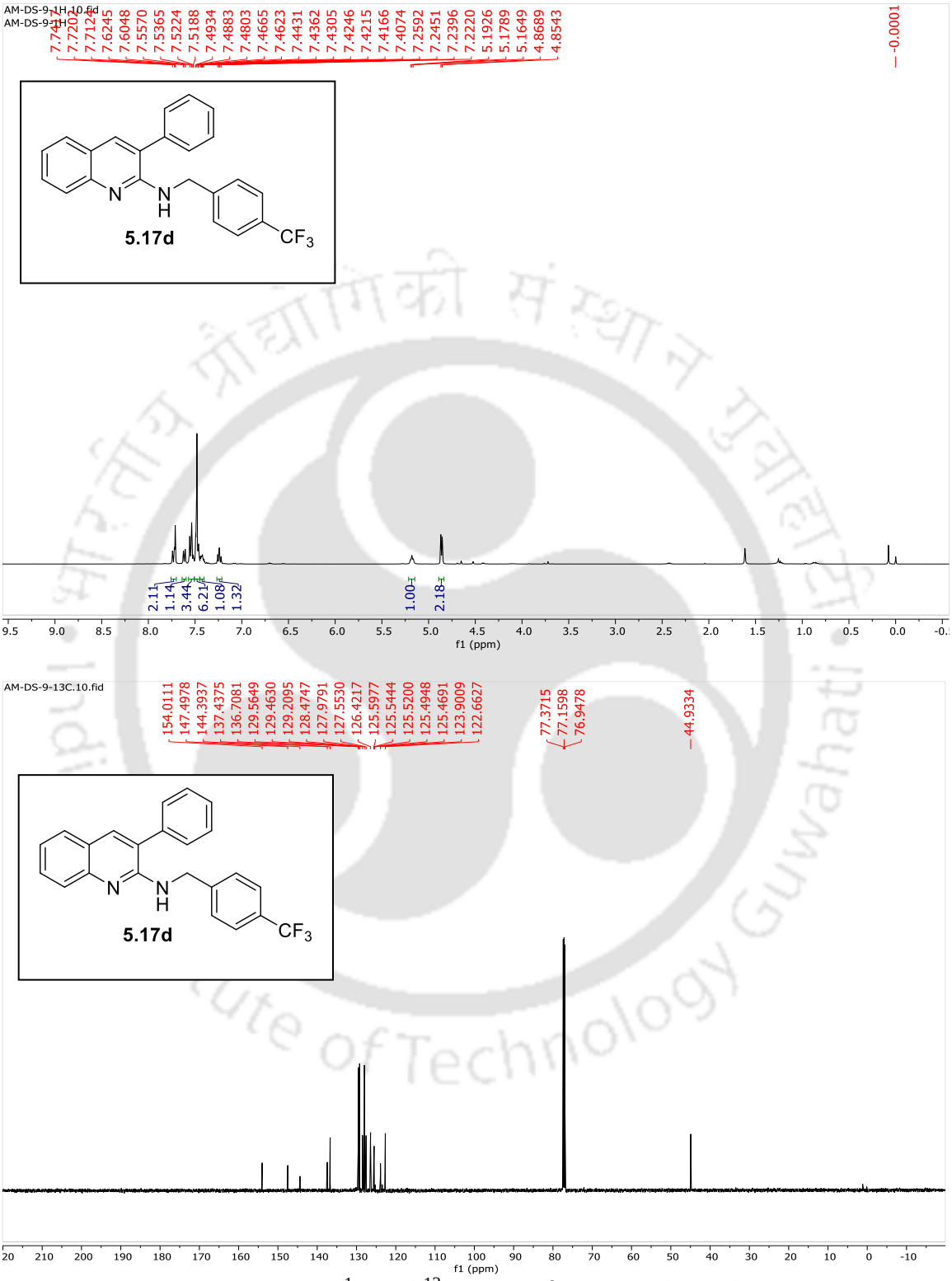

Figure 5.26: ^{1}H and ^{13}C NMR of compound **5.17d**.

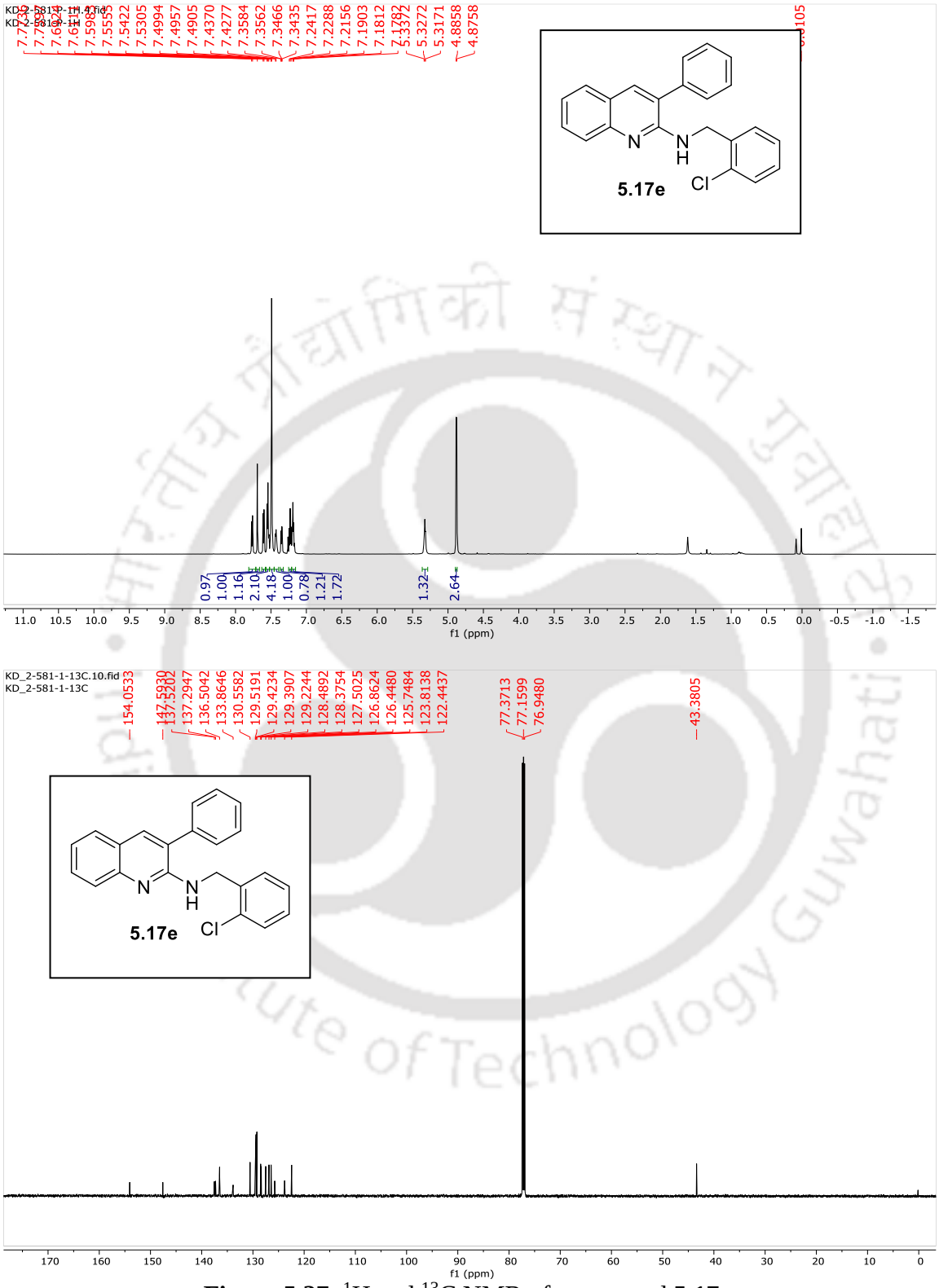

Figure 5.27: ^{1}H and ^{13}C NMR of compound **5.17e**.

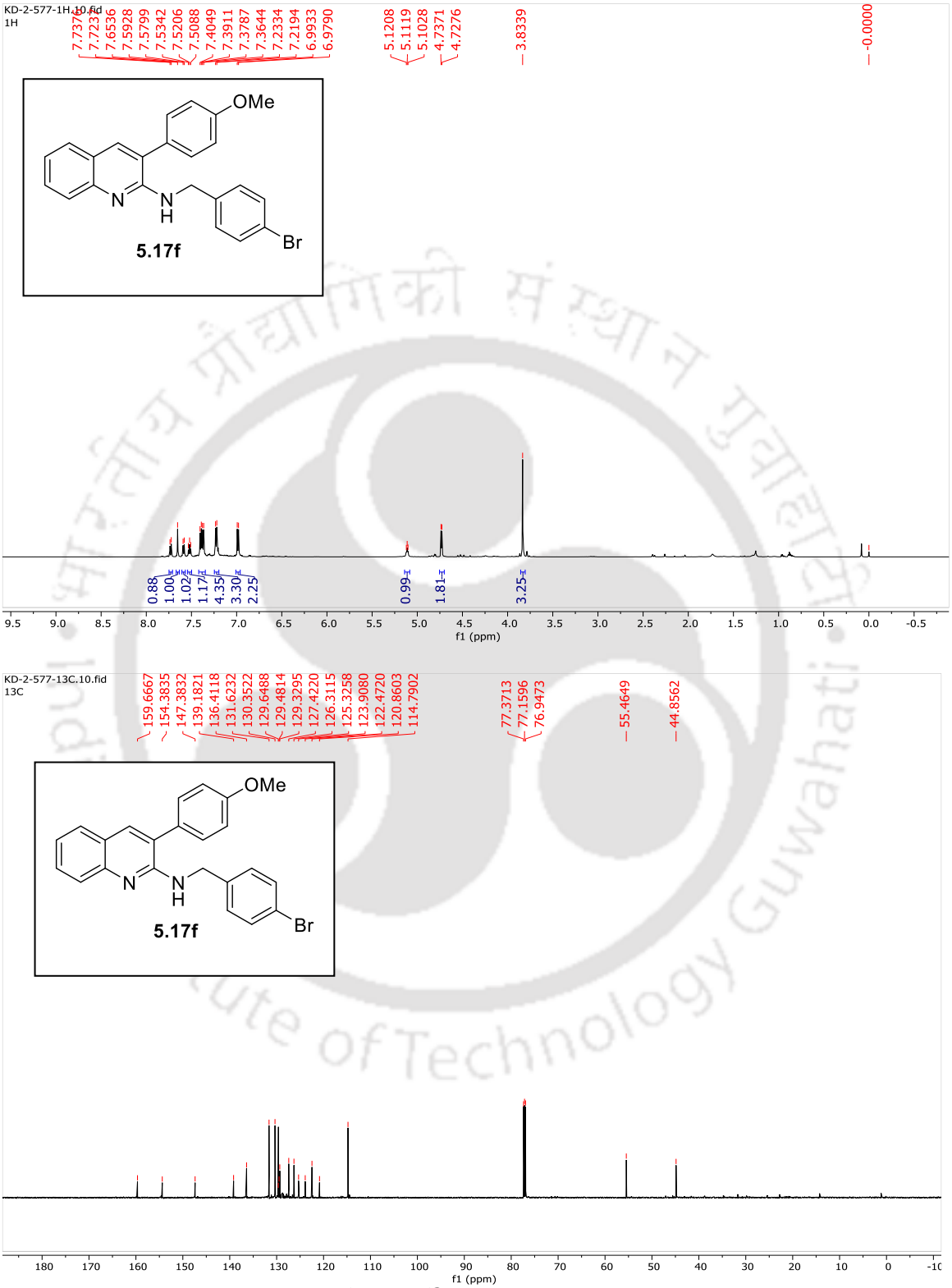

Figure 5.28: ^{1}H and ^{13}C NMR of compound **5.17f**.

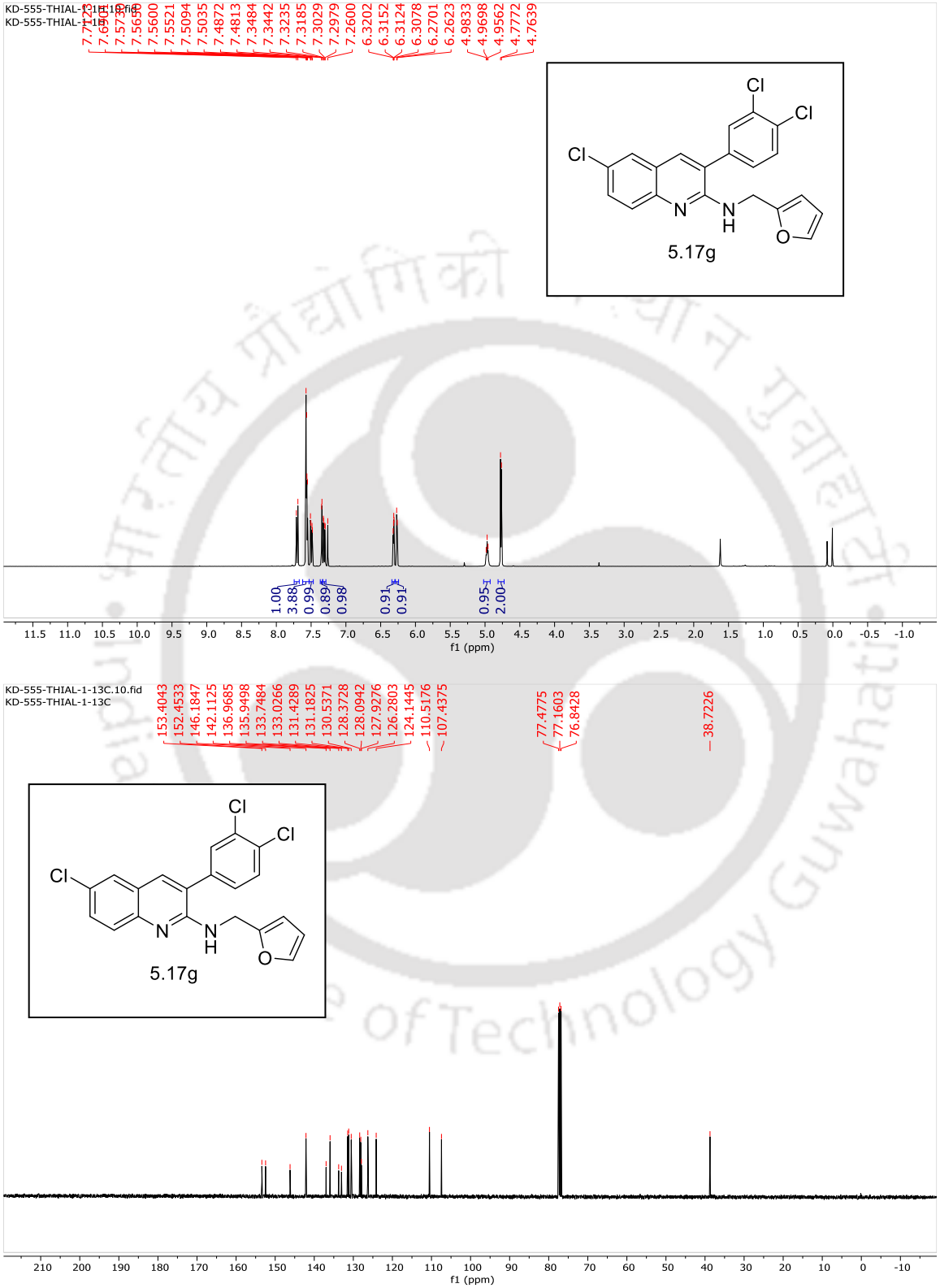

Figure 5.29: ^{1}H and ^{13}C NMR of compound **5.17g**.

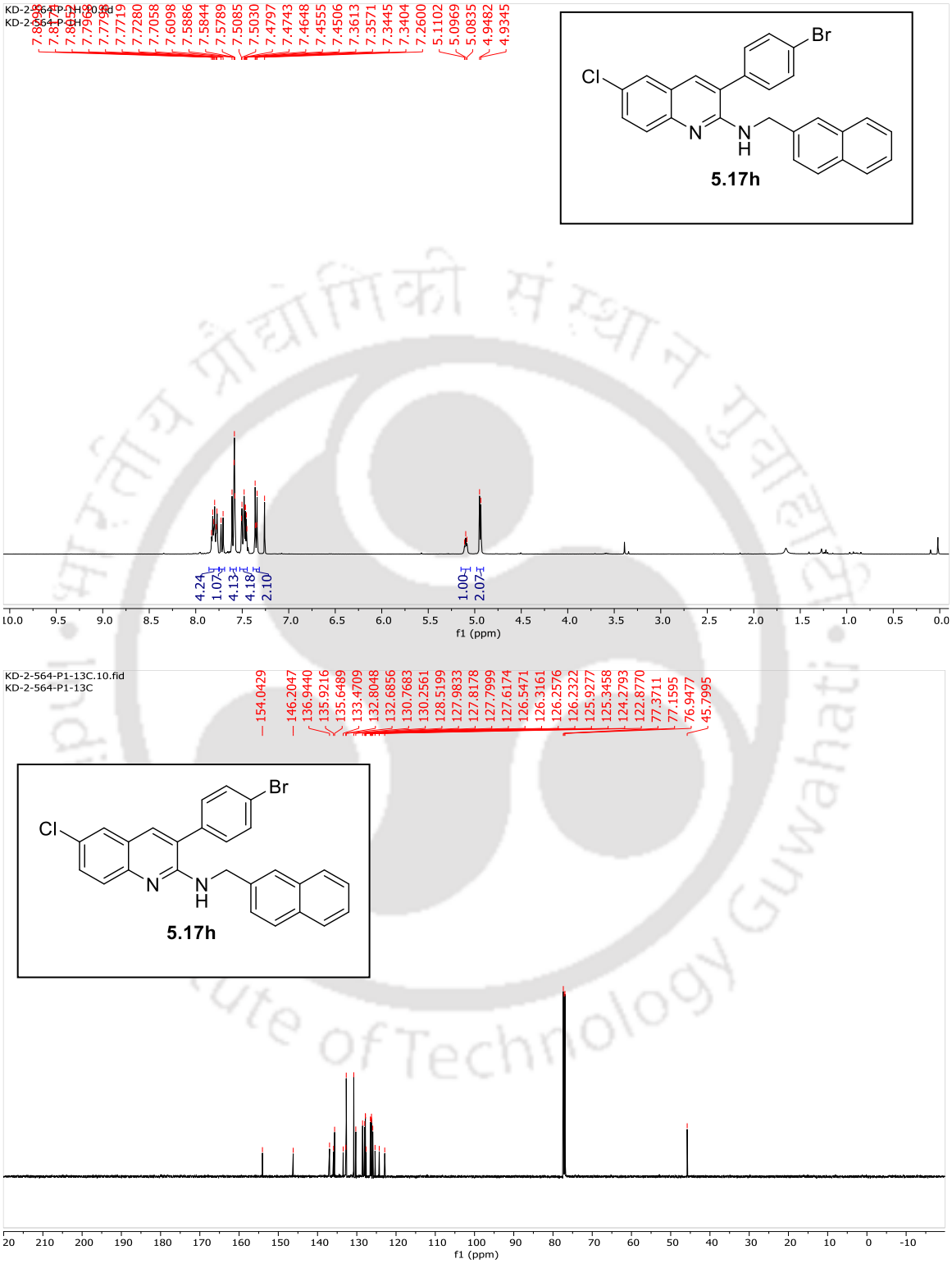

Figure 5.30: ^{1}H and ^{13}C NMR of compound **5.17h**.

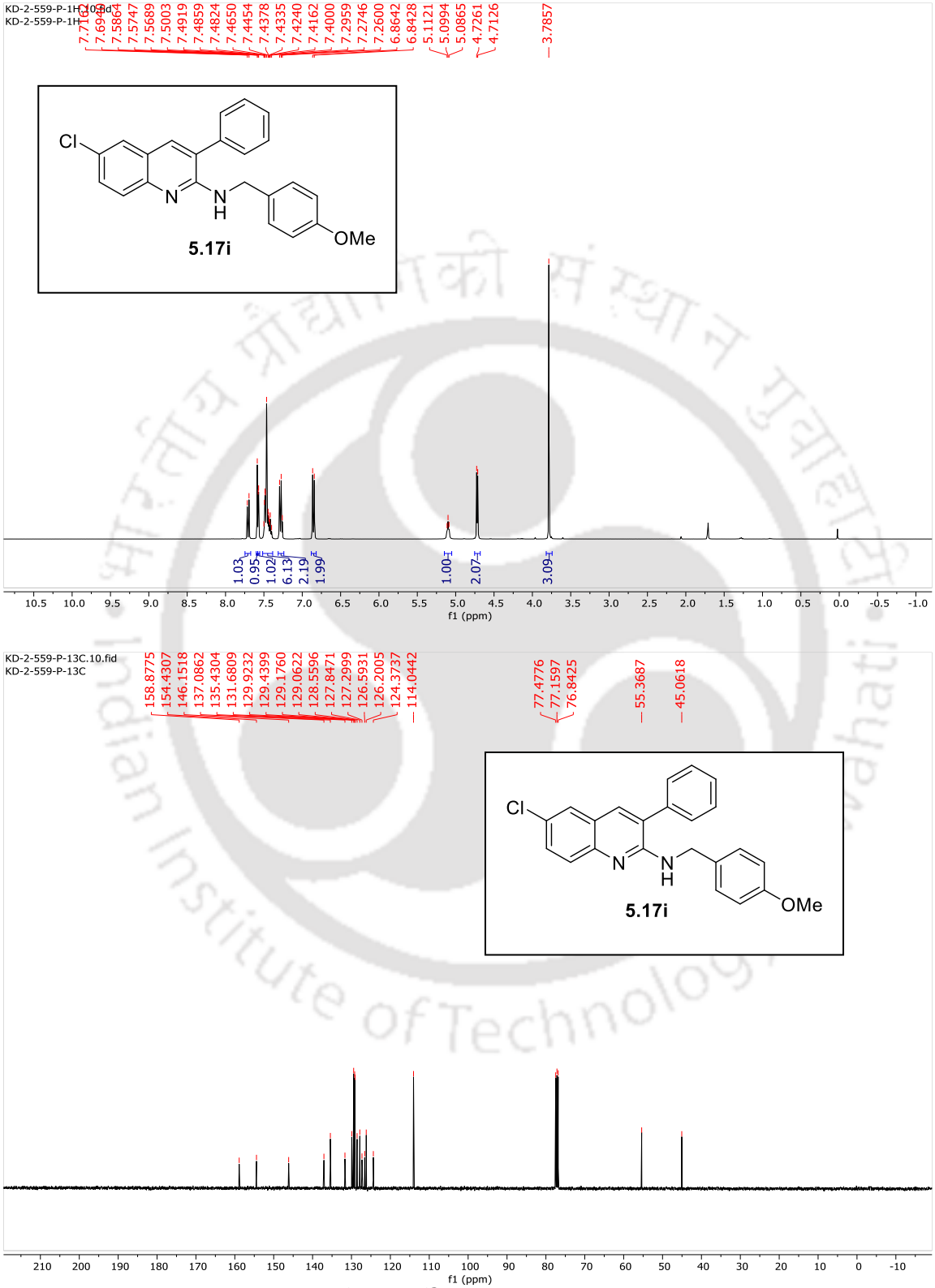

Figure 5.31: ^{1}H and ^{13}C NMR of compound **5.17i**.

List of Publications

1. *Selective Synthesis of 2-Substituted and 1,2-Disubstituted Benzimidazoles Directly from Aromatic Diamines and Alcohols Catalyzed by Molecularly Defined Nonphosphine Manganese(I),* ***Kalicharan Das****, Avijit Mondal, and Dipankar Srimani*, J. Org. Chem.,* ***2018,*** *83,* ***9553-9560.***

2. *Phosphine free Mn-complex catalysed dehydrogenative C–C and C–heteroatom bond formation: a sustainable approach to synthesize quinoxaline, pyrazine, benzothiazole and quinoline derivatives,* ***Kalicharan Das****, Avijit Mondal, and Dipankar Srimani*, Chem. Commun.,* ***2018****, 54, 10582-10585.*

3. *Phosphine-free well-defined Mn(I) complex catalyzed synthesis of secondary, tertiary amine and Imine via hydrogen-autotransfer or acceptorless dehydrogenative coupling of amine and alcohol,* ***Kalicharan Das****, Avijit Mondal, Debjyoti Pal and Dipankar Srimani*, Organometallics* ***2019****, 38, 1815-1825.*

4. *Well-defined Phosphine-free Mn(I) complex catalyzed synthesis of quinozoline, 2-aminoquinoline, and N-substituted 2-aminoquinoline,* ***Kalicharan Das****, Avijit Mondal, Debjyoti Pal and Dipankar Srimani*, Org. Lett.* ***2019****, 21, 3223-3227.*

5. *Acceptorless Dehydrogenative Construction of C=N and C=C bond through Catalytic Aza-Wittig and Wittig Reaction in the Presence of Air-stable Ruthenium Pincer Complex, Nandita Biswas,* ***Kalicharan Das****, Bitan Sardar and Dipankar Srimani*, Dalton Trans.,* ***2019****, 48, 6501-6512.*

List of Presentations

1. **UGC Sponsored One Day Seminar on International year of chemistry: Impact of Chemistry on Our Lives** 25th March 2011, Siksha-Bhavana, Visva-Bharati, Santiniketan. Poster presentation with entitled "***Paracetamol***."

2. **Frontier in Chemical Science** (FICS 2018) from 6-8th December 2018, Department of Chemistry, IIT Guwahati. ***Oral Presentation*** with entitled "***Synthesis of Heterocycles via Acceptorless Dehydrogenative Coupling Catalysed by Well Defined Phosphine free Manganese (I) Complex***."

3. **24th CRSI National Symposium in Chemistry**. Poster presentation with entitled "***Synthesis of Heterocycles Catalysed by Well Defined Phosphine free Manganese (I) Complex via Acceptorless Dehydrogenative Coupling***."

4. Research Conclave-2019. Poster presentation with entitled "**The Sustainable Synthesis of Perimidines, Quinazolines, 2-aminoquinolines and 2-alkylaminoquinolines via Acceptorless Dehydrogenative Coupling by Phosphine free Mn(I) Complexes**."