Designing Bifunctional Mn(I) and Mn(II)-Complexes to Control Selectivity in De(hydrogenative) Transformations

By

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Dedicated

To

My Parents

&

Teachers

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STATEMENT

I, hereby declared that the work comprised in this thesis entitled "***Designing Bifunctional Mn(I) and Mn(II)-Complexes to Control Selectivity in De(hydrogenative) Transformations***" 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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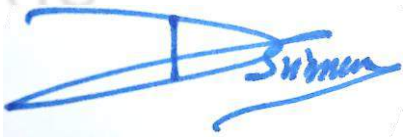
CERTIFICATE

This is to certify that the work incorporated in the thesis entitled "***Designing Bifunctional Mn(I) and Mn(II)-Complexes to Control Selectivity in De(hydrogenative) Transformations***" which is being submitted to the Indian Institute of Technology Guwahati for the award of Doctor of Philosophy in Chemistry by **Mr. Avijit Mondal** (Roll No: **176122001**) 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

June, 2024

~Acknowledgements~

Research is passion and Ph.D. is the start of it, a long journey; an experience that takes you through the untraversed path, the green lush meadows, and the island of Cyclopes to conquer the final goal fixed in mind. Once you achieve the target and turn back, you realize that all your efforts and the pain were worth going through. The small successes & the serendipitous discoveries, the frustrating failures & unexpected crystallizations, the imparted chemical wisdom & the laboratory camaraderie; are all important parts of this beautiful voyage. But one can't succeed in this journey without the guidance and support of the research supervisor, friends, and well-wishers. I am taking this opportunity to express my deepest gratitude to everyone who has helped and supported me throughout my research journey.

I would like to express my sincere gratitude and thanks to my thesis supervisor, my Guru Prof. (Dr) Dipankar Srimani, for his excellent guidance, constant motivation, constructive suggestions, timely help, and continuous support during my Ph.D. journey. I am grateful to him for the freedom I was given in thinking and designing my work. I show my respect to him for teaching me many laboratory skills, techniques, and many aspects of chemistry. I aspired to his hardworking, knowledge, and teaching enthusiasm towards chemistry. I am fortunate to have him as a supervisor who has always inspired me to think beyond the established concepts in research, which instilled the confidence in me to further illuminate my research interest.

I would like to take this opportunity to express my sincere thanks to my doctoral committee members Committee: Prof. Subhas Chandra Pan (Chairperson), Prof. Debapratim Das, Dr. Kalyan Raidongia for their fruitful discussion and valuable insight throughout my studies which helped me a lot to develop my fundamental knowledge and thoughts to pursue research. My sincere thanks to HoD, the Department of Chemistry, and CIF for their support and for providing infrastructure facilities in the institute. I am also thankful to all other faculty members of the Department of Chemistry.

I also thank researchers from IITG, Prof. Anil Kumar Saikia, Prof. Gopal Das, Prof. Chandan Mukherjee, Prof. Subhas Chandra Pan, for their informative and exciting courses they taught me as a part of the course work in the IITG.

I am grateful to our Departmental Staffs Dr. Babulal Das, Mr. Imdadul Islam, and Mr. Aniruddha Gogoi, Mr. Diganta Kumar Hira, Mr. Michael Deka for their various analytical support and assistance related to my research work. I indelibly acknowledge the direct as well as indirect help from teaching as well as non-teaching, administrative, housekeeping, and security staff of our institute. I am grateful to IITG for providing the infrastructure for my research work. Financial support from IITG is gratefully acknowledged.

I would offer my sincere thanks to my former labmates Dr. Ramen Jamatia, Dr. Kalicharan Das, Dr. Nandita Biswas, Dr. T. S. Manikandan, Dr. Bitan Sardar and present lab members Dr. Sundarraman Balaji, Debjyoti Pal, Rahul Sharma, Mithu Roy, Arup Samanta, Kailash Mohar, Hirak Jyoti Phukan, Rajashri Sarmah, Itu Mallick. They make them absolutely free whenever I need help from them. I am also thankful to the M.Sc and summer interns students who worked with me, Mr. Suman Maji, Mr. Mohananda Samanta, Mr. Bishal Dutta, Mr. Bikram Pal, Mr. Saurabh Kumar, Miss. Chandrika Ghosh, Mr. Samiran Kar, Mr. Pranjal Borah, Miss. Purti Patel, Mr. Tushar Khairwal, and Mr. Kaushik Soni for their enthusiastic interactions which strengthened my understanding of fundamental concepts. I thank you all for your cooperation and help as well as for maintaining an excellent working atmosphere in the lab which made me a better researcher and a better person.

A special thanks to my School, graduate, and postgraduate teacher and Miss. Keya Roy, Mr. Prabir Sarkar, Mr. Rajat Samanta, Dr. Tridib Tripathy, Prof. Braja Gopal Bag, Prof. Ajay Kumar Misra, Prof. Sudipta Dalai, Prof. Subal Chandra Manna, Dr. Sumita Roy, and Dr. Maidul Hossain.

I want to express my gratitude to my all childhood and school friends. My appreciation and gratefulness to my college friends, Retwik, Surojit, Gobinda, Robindra, Nilanjona,

Arindam, Arkadip, Dyuti, Souditri, Lina, Subrata, Biswasjit, Arijit, Suman da, Saikat, Ajoyda,……..for their kind help and encouragement towards the success of my life.

I thank my all the PhD colleagues and IITG friends Retwik, Sudip, Subhamoy, Ases, Sourav, Subhasis, Depanjon, Santa, Rituporna, Abhay, Sandeep, Pegu……for their helped, beautiful discussion and the fun I have shared in last few years. I would also like to thank my all seniors specially Dr. Prasenjit Sarkar and juniors who helped during my work and for making a friendly environment.

I would also thankful for my hostel mates Retwik, Subrata, Bikram, Hiru, Bijoy, Arijit da, Arup, Aniket, Maloy, Srijon, Polok, Roop..... for sharing their fun experiences during breakfast, lunch and dinner time.

Sincerely,

Avijit Mondal

~Contents~

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 "**Designing Bifunctional Mn(I) and Mn(II)-Complexes to Control Selectivity in De(hydrogenative) Transformations"** have been divided into six chapters. The first chapter contains a comprehensive outline of literature study related to control de(hydrogenative) transformations and multicomponent approaches and the last five chapters were based on results achieved from the experimental works performed during the entire course of PhD programme.

Chapter 1: Evolution of Transition Metal Catalysis in Control De(hydrogenative) Transformations and Multicomponent Reactions

This chapter provides a comprehensive overview of the development of control de(hydrogenative) transformations and de(hydrogenative) multicomponent reactions (MCRs) catalysed by transition metals, with lignocellulose biomass-derived alcohols serving as a key coupling partner.

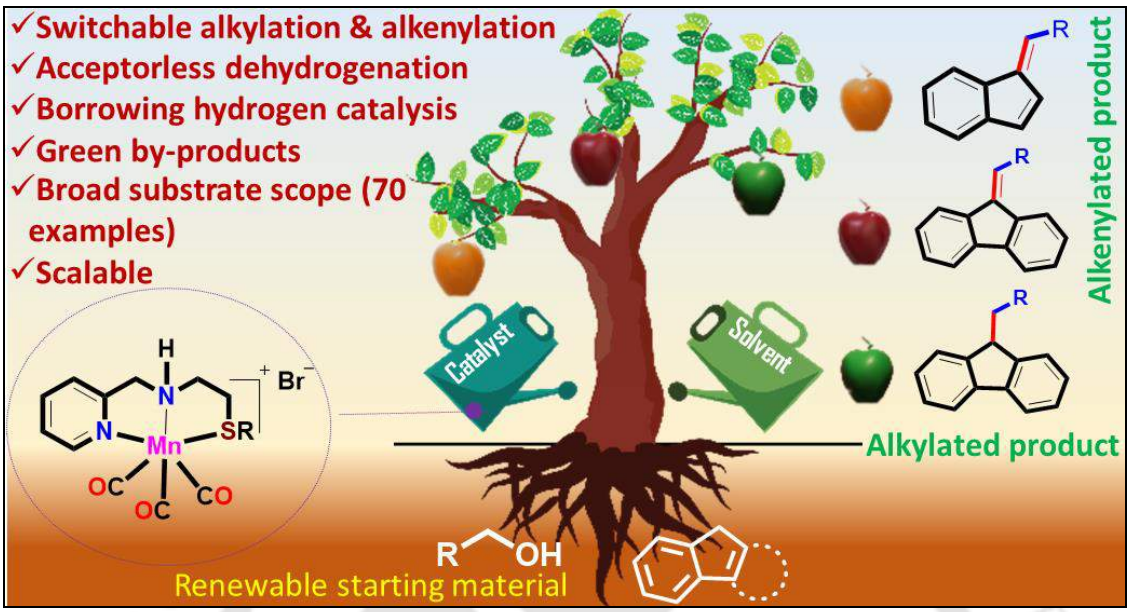
Aim of the Thesis:

The present thesis focuses on the design and synthesis of various phosphine-free bifunctional Mn (I) and Mn(II) complexes. These complexes are well characterized using various spectroscopic and spectrometric tools. Furthermore, by comprehending the bond activation mechanisms of the developed complexes during de(hydrogenative) reactions, these are applied to construct useful molecular building blocks.

Chapter 2: NNS-Mn(I) Catalysed Switchable C-Alkylation/Alkenylation of Fluorenes and Indene with Alcohols

Controlling the de(hydrogenative) reactions to furnish selectively different products from the same set of reactants is a challenging task. The development of a catalyst which can perform both the task under suitable reaction conditions would be more interesting and challenging. This chapter highlights the well defined NNS-Mn(I) catalysed switchable C-alkylation and alkenylation of fluorene/indenes using alcohol as an alkylating agent by controlling the acceptorless dehydrogenation (AD) and borrowing hydrogen (BH) strategy. This catalytic protocol showcased its broad substrate scope by effectively transforming a diverse range of alcohols, encompassing aromatic, heteroaromatic, and aliphatic compounds, with impressive yields. Various control, competitive and kinetic experiments were executed in order to

understand the reaction insight, which showed that olefinated fluorene is a key intermediate to afford the alkylated fluorene.



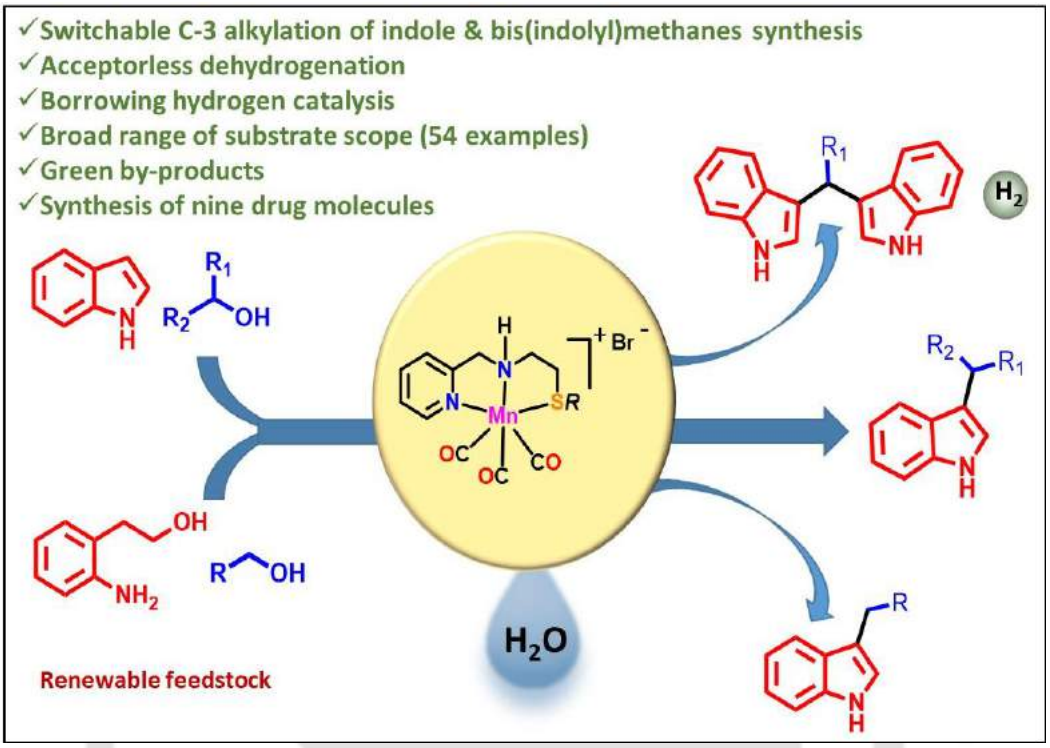
Scheme 1. A schematic demonstration of the research work covered in chapter **2**.

Publication: **A. Mondal,** R. Sharma, D. Pal, D. Srimani* *Chem. Commun.* **2021**, *57,* 10363-10366.

Chapter 3: Well-defined NNS-Mn(I) Complex Catalysed Selective Synthesis of C-3 Alkylated Indoles and Bisindolylmethanes from Same Set of Starting Materials

This chapter describes a new catalytic protocol for the selective functionalization of indoles at C-3 position. Simply by tuning the experimental reaction conditions, both C-3 alkylated indoles and Bis(indolyl)methanes were synthesized using single phosphine free NNS-Mn(I) complex from the same set of alcohols and indoles. This highly efficient catalytic protocol enables the synthesis of a diverse range of substrates, including nine structurally significant drug molecules such as Arsindoline A, Turbomycin B, Antileukemic, Orphan nuclear receptor, and others. The concurrent synthesis and functionalization of indoles in a one-pot fashion directly from 2-amino aryl ethanol and alcohols were also executed. A comprehensive mechanistic analysis was carried out to understand the intricacies of the reaction and its reactivity patterns. The presence of free N-H proton of indole is found to be necessary for increasing the nucleophilicity at C-3 position for condensation with in situ formed carbonyl compounds and nucleophilic attack to intermediate vinylogous imine. On the other hand, the Mn-catalyst plays a pivotal role in the dehydrogenation

of alcohol to aldehyde, which serves as a crucial intermediate and also assists the subsequent condensation step with indoles.



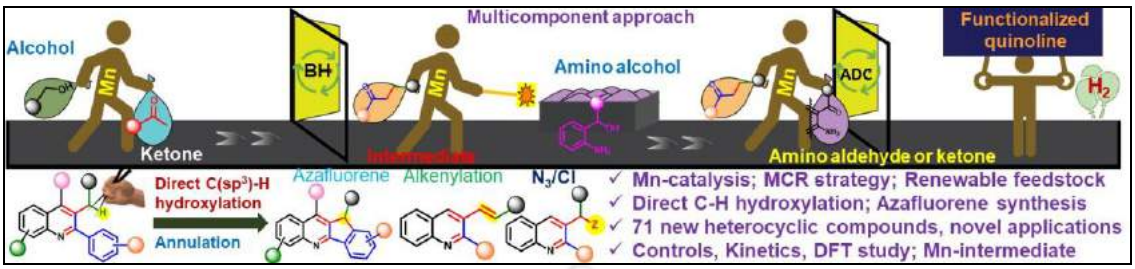
Scheme 2. A schematic demonstration of the research work covered in chapter **3**.

Publication: **A. Mondal,** R. Sharma, B. Dutta, D. Pal, D. Srimani* *J. Org. Chem.* **2022**, *87*, *6*, 3989–4000.

Chapter 4: Mn(I) Complex Catalysed Multicomponent Approach for Poly-substituted Quinolines Synthesis: A Strategic Route to Quinoline Based Azafluorenes via Direct C(sp^3)-H Bond Hydroxylation

The development of a sustainable multi-catalytic methodology comprising two or more mechanistically challenging divergent catalytic processes by employing a single catalyst has been noteworthy in contemporary science for complex molecular diversity. In this chapter we highlight NNN-Mn(I) catalysed a new sequential de(hydrogenative) multicomponent reaction approach (MCR) to synthesize poly functionalized quinoline derivatives. Functionalized quinolines have widespread applications in biological, materials sciences and fine chemical research. This current protocol covers a broad range of substrate scope, including various challenging primary and secondary alcohols, providing genres of highly functionalized complex

quinoline motifs. Furthermore, an unprecedented direct C(sp^3)-H bond hydroxylation of the product provides a new scope to construct medicinally relevant novel azafluorene derivatives.



Scheme 3. A schematic demonstration of the research work covered in chapter **4**.

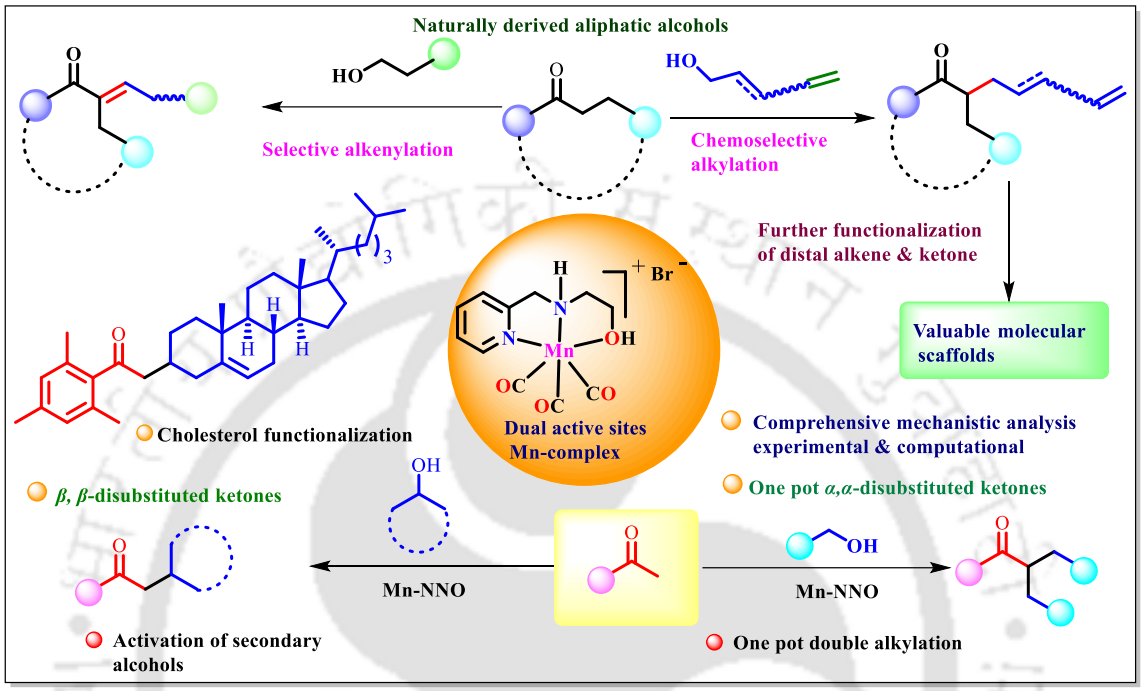
We investigated a series of control, kinetics, Mn-amido complex characterization, hydride trapping experiments and DFT studies to comprehend the detailed reaction route and the catalyst function in the MCR sequence.

Publication*:* **A. Mondal,** D. Pal, H. J. Phukan, M. Roy, S. Kumar, S. Purkayastha, A. K. Guha,* D. Srimani* *ChemSusChem*, **2024**, e202301138.

Chapter 5: Engineering of a Sterically Less Hindered Bifunctional Mn(I) Complex for Chemoselective C(sp^3)-C(sp^3) Bond Formation and its Strategic Applications

The BH-mediated functionalization of branched ketones does not necessarily depend on the dehydrogenation enthalpy of alcohol to convert its corresponding electrophilic equivalent, the reactivity of the generated electrophiles also plays a crucial role. For instance, even though the dehydrogenation enthalpy of methanol to formaldehyde is quite high compared to other aliphatic alcohols, BH-mediated alkylation of bulky α-branched carbonyl compounds is mostly reported to methylation. The tinny size and highly reactive nature of formaldehyde favors the formation of aldol-adduct whereas steric hindrance renders the unstable intermediate aldol adduct and promotes the retro-aldol process for bulky electrophiles. Thus, alkylation of bulky α-branched ketones with long chain aliphatic alcohols require more stringent conditions and/or a large excess of alcohol, which often creates selectivity issue by reducing the keto-group of the branch ketone. In this chapter, these issues were addressed by designing a highly active catalyst with a sterically less hindered metal-ligand cooperative site which can easily accommodate bulky unstable β-hydroxy ketone and bulky α, β-unsaturated ketone. The developed catalytic protocol smoothly activated a library of branched ketones and aliphatic saturated and unsaturated alcohols and chemo selectively delivered α, α-disubstituted ketones in good to excellent yields. The synthetic diversity of distally unsaturated ketone was also highlighted. Various functional groups as well

as carbocycles and heterocycles are installed at distal positions of ketone. Furthermore, this catalytic methodology is also suitable for one-pot tandem double functionalization of various ketones using aromatic primary alcohols. Moreover, modified catalytic conditions also found to be suitable for activating secondary alcohols to synthesize *β, β*-disubstituted ketone derivatives.



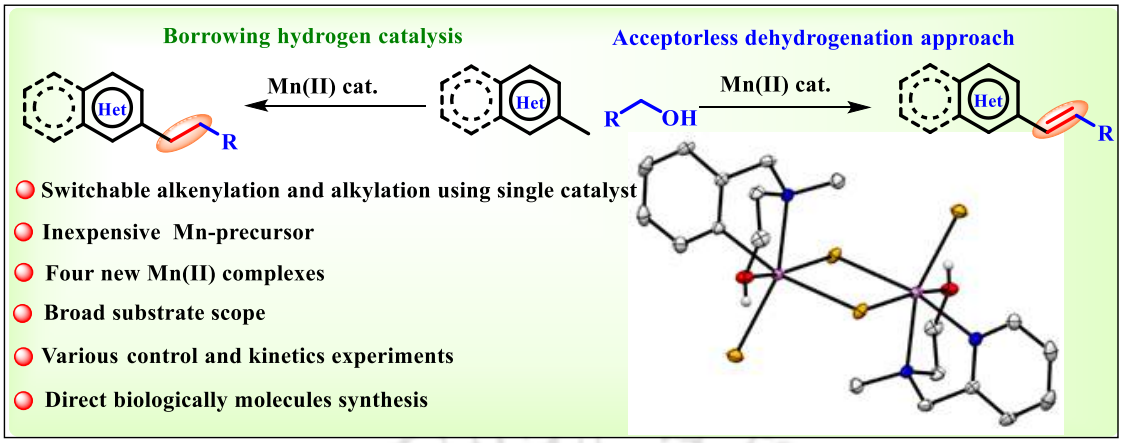
Scheme 4. A schematic demonstration of the research work covered in chapter **5**.

Notably, naturally derived cholesterol molecule is also functionalized under our protocol. To shed light on catalytic insights various control, kinetics, and theoretical calculation were investigated.

Publication: Manuscript under preparation.

Chapter 6: Well-defined Mn(II)-Complex Catalysed Switchable De(hydrogenative) C(sp^3)-H Functionalization of Methyl Heteroarenes: A Sustainable Approach for Diversification of Heterocyclic Motifs

Catalytic activities of Mn(I) complexes derived from expensive $MnBr(CO)_5$ salt have been explored in various de(hydrogenative) transformations. However, the reactivity and selectivity of inexpensive high- spin Mn(II) complexes are uncommon. Herein, we have synthesized four new Mn(II) complexes and explored switchable alkenylation and alkylation of methyl heteroarenes employing a single Mn(II) catalyst.



Scheme 5. A schematic demonstration of the research work covered in chapter **6**.

The developed protocol selectively furnishes a series of functionalized *E*-heteroarenes and C-alkylated heteroarenes with good to excellent yields. Several medicinally and synthetically useful compounds are successfully synthesized using our developed protocol. Various control and kinetic experiments were executed to shed light on the mechanism, which reveals that α-C-H bond breaking of alcohol is the slowest step.

Publication: **A. Mondal,** H. J. Phukan, D. Pal, S. Kumar, M. Roy, D. Srimani* *Chem. Eur. J.* **2024**, *30*, e2023033.

CHAPTER 1

Evolution of Transition Metal Catalysis in Control De(hydrogenative) Transformations and Multicomponent Reactions

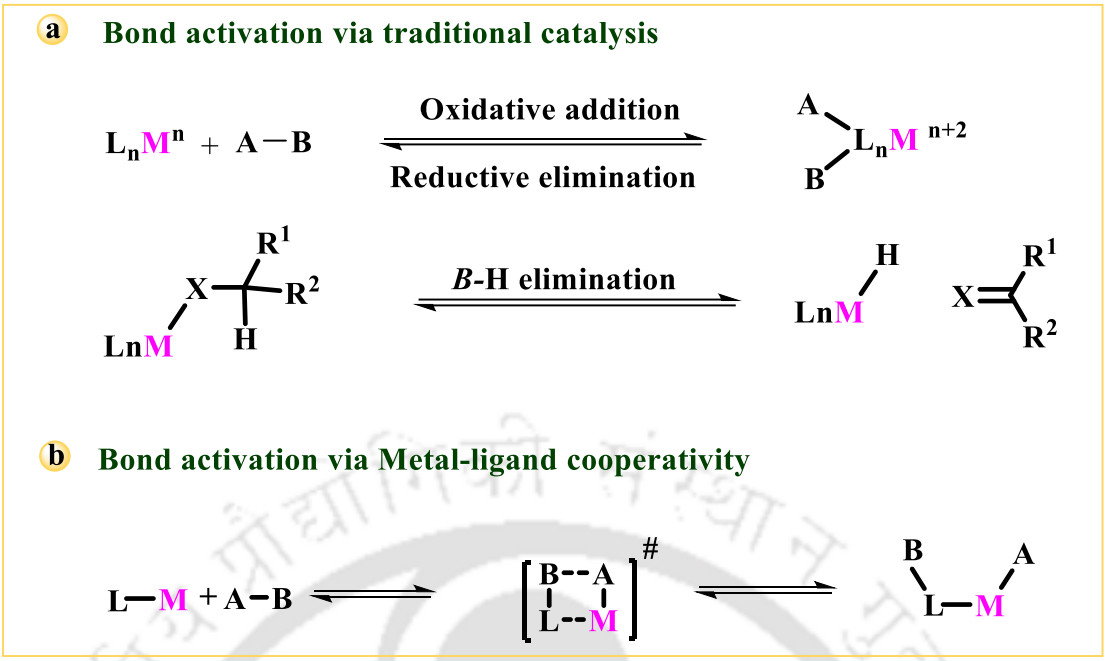
1.1. Introduction:

Catalysis, regarded as the heart of contemporary science, has altered the paradigm of constructing complex molecular architecture with high selectivity and efficiency. For long decades, catalysis has had a significant impact on science and technology due to the quick development of novel synthetic techniques that are labour, cost, time, and yields effective as well as greener. The legacy of catalysis in synthetic organic chemistry has mostly been promoted by organo-catalysis and transition-metal catalysis. Since 2001, these two areas of catalysis have been honored with Nobel Prizes for their contributions to society and science [2001 (William S. Knowles, Rayoji Noyori: for stereoselective hydrogenation and K. Barry Sharpless: for stereoselective oxidation), 2005 (Yves Chauvin, Robert H. Richard R. Schrock: for olefin metathesis), 2010 (Richard F. Heck, Ei-ichi Negishi, and Akira Suzuki: for regarding cross-coupling reactions by palladium catalysts) and 2021 (Benjamin List and David W.C. MacMillan: regarding asymmetric organo-catalysis)].

It is practically impossible to assess which form of catalysis (metal or organo) is superior due to their different reactivity profiles, yet, transition-metal catalysis has long been regarded as a potent pillar of catalysis and has generally dominated the field of organic synthesis. Transition metals can undergo novel and unusual transformations because of their capacity to switch between several oxidation states while building complexes with the reagents in a catalytic cycle. In addition, several parameters, such as the steric and electronic nature of metal-coordinated ligands and counter ions, can be used to fine-tune the reactivity and selectivity of these metal complexes in accordance with the requirements of the catalytic process. Thus, these methods are in general highly proficient and hold remarkable potential for the evolution of novel synthetic approaches to access manifold array of molecular architectures from renewable feedstock with high regio-, chemo-, and stereoselectivity.

1.2. Metal Ligand Cooperation:

Due to the capacity of transition metals to take part in a variety of reactions like oxidative addition, reductive elimination, and β-hydride elimination, the utilization of transition metal catalysts expands the range of reactivity of organic molecules. In traditional transition metal catalysis reactions occurs at metal centre only, ligand act as a spectator.[1]

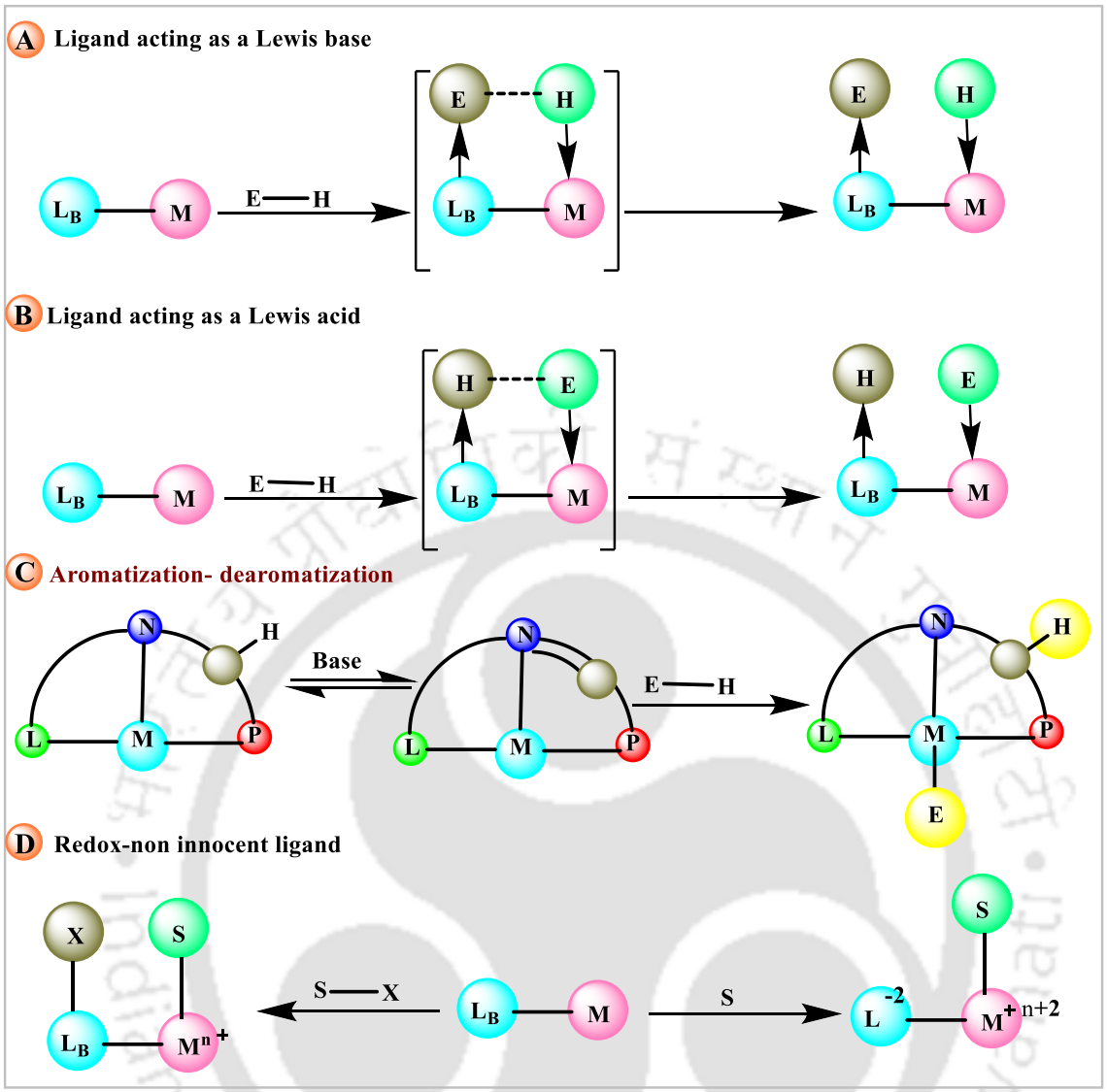


Scheme 1.1. a) Traditional bond activation process; b) Bond activation process via metal-ligand cooperation.

However, in contrast to conventional techniques, bond activation in biological systems is made possible by a precisely calibrated ligand environment that cooperates with the metal to participate in the process. After the discovery of this type of bond activation mechanism, organometallic chemists were interested in mimicking this concept for designing of ligand and transition metal complex, which lead to the evolution of metal-ligand cooperative catalysis. Basically in metal-ligand cooperation–(I) metal as well as ligand actively participate in bond activation process via synergic fashion; (II) During the bond activation process both metal and ligand chemically adjusted simultaneously; (III) The first coordination sphere of ligand was changed in the course of the process.

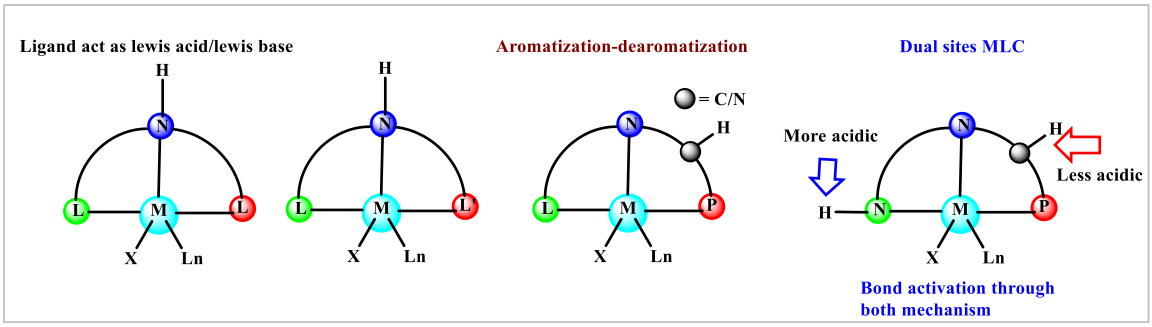
1.3. Design principle of bifunctional ligands and catalysts:

The MLC can be operated in a variety of ways for various forms of bond activation in the catalytic cycle: (I) a pendant or metal-bound ligand may function as a Lewis base, cleave the bond E–H of substrate in cooperation with a metal centre (Scheme **1.2A**); (II) similarly, a pendant or metal-bound ligand may aid (Scheme **1.2B**) as a Lewis acid to cooperatively cleave a substrate bond by accepting electrons from a substrate donor while the metal acts as a Lewis base; (III) a redox non-innocent ligand can function as a radical source or an electron reservoir to conserve the metal oxidation state during a catalytic process that allows it to directly contribute in bond activation (Scheme **1.2D**).[2]



Scheme 1.2. Different way to metal-ligand cooperativity.

In homogeneous catalysis, the conception of auxiliary ligands to fine-tune and enhance the geometrical and electronic characteristics of transition metal complexes is a potent tool that has aided chemists' discovery of novel reaction pathways and enhanced modern protocols. The pioneer researcher Noyori's breakthrough discovery of asymmetric ketone hydrogenations using diamine-ruthenium complex via protonation and deprotonation of acidic N-H proton of ligand opens new directions in the field of bifunctional catalysis. In general, the core of tridentate ligands consists of two side arms containing diverse donating atoms such as phosphorus, sulfur, nitrogen or carbon, and the center often consists of an amine or heterocyclic moiety with a nitrogen donor atom. Moreover, side arms of heterocyclic moieties also have redox-active sites which smoothly assist metal-ligand cooperation. The selection of ligand categories is strategically tailored to different MLC approaches, enabling the resulting complexes to participate in the activation of inert chemical bonds.



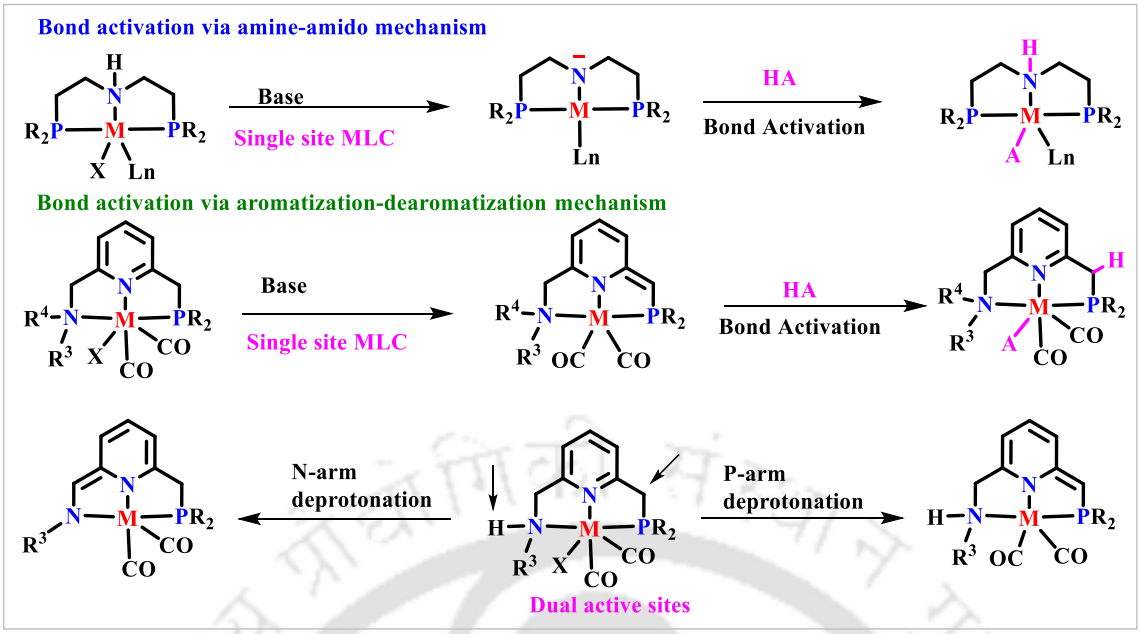
Scheme 1.3. General representation of different modes of bifunctional catalysts.

Metal-ligand cooperative catalysts are also known as **bifunctional catalysts**. Metal ligand bifunctional catalysis has been applied in various organic reaction such as dehydrogenation, hydrogenation, energy storage and liquid organic carrier etc. In **1950** pioneer group Fujiwara was first introduced cooperative palladium catalyst for stilbene synthesis.[3] Then, Shvo's catalyst (**Ru-2**) was developed for the hydrogenation of ketones via outer sphere mechanism. Noyori catalysts are broadly used as a cooperative catalyst in academia as well as industry for asymmetric hydrogenation and transfer hydrogenation reactions.[4]

Scheme 1.4. Pioneer example of bifunctional Ru-catalysts for hydrogenation of ketones.

1.4. Working mechanism of different types of bifunctional catalysts:

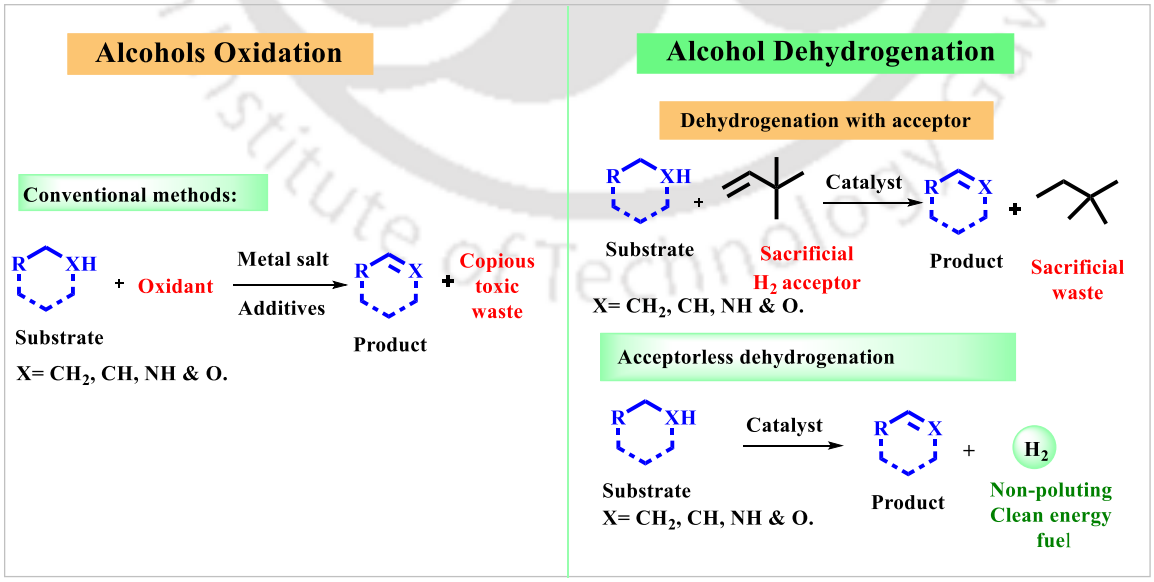
Bifunctional transition metal precatalysts are generally activated under basic condition.[5a] In presence of base more acidic amine (N-H) proton or methylene (-CH_2-) proton is deprotonated and formed active amido or dearomatized complex in situ which subsequently activate diverse range of substrate like alcohols, amines, nitriles, esters, amides, alkane, alkenes, dihydrogen, boranes and silanes etc and formed substrate coordinated metal complex.[5b, 5c]



Scheme 1.5. Bond activation strategies of bifunctional catalysts.

1.4.1. Background of acceptorless dehydrogenation: A sustainable approach:

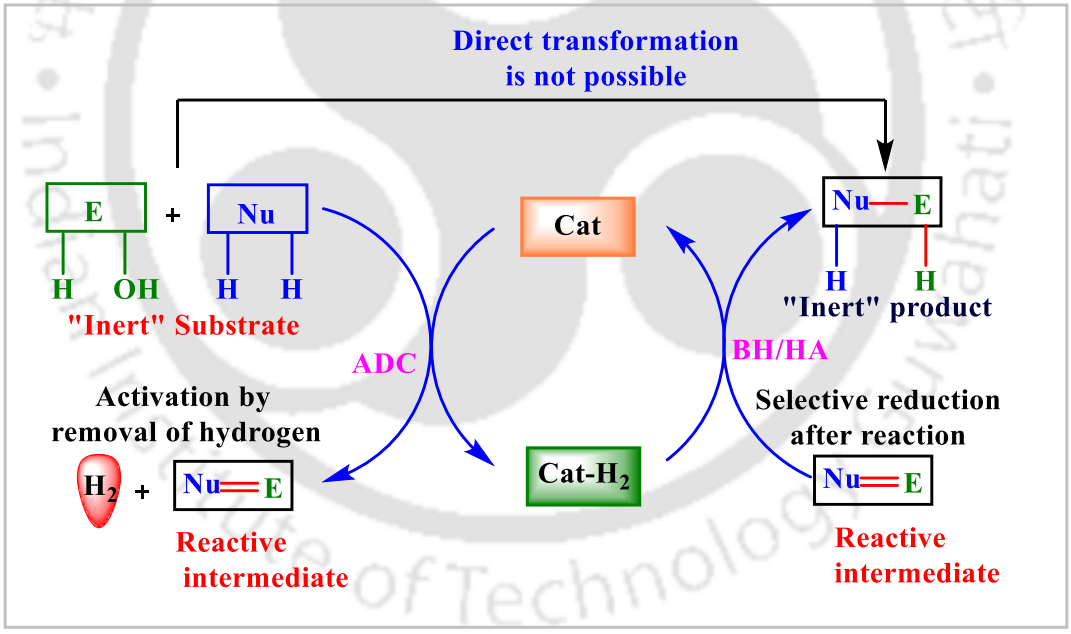
Most of the cases, removing hydrogen atoms from adjoining atomic centres of a hydrogen rich organic compounds is a thermodynamically unfavourable technique. Thus, in order to dehydrogenate such hydrogen rich organic compounds, stoichiometric or excess molar concentrations of strong oxidants, such as mineral acids, oxygen, metal oxides, peroxides, iodates, dichromate or sacrificial hydrogen acceptors, are frequently needed, resulting in the generation of wasteful by-products.[6]



Scheme 1.6. Evolution of acceptorless dehydrogenation strategy.

Conversely, acceptorless de(hydrogenative) coupling (ADC) reaction is a well-known attractive sustainable method since that does not require the substrate to be prefunctionalized, an external oxidant or sacrificial hydrogen acceptors. Thus, catalytic acceptorless dehydrogenation (AD) is a fast and sustainable process for the development of commercial valuable chemicals.

The ADC and BH (Borrowing Hydrogen) commences with mainly transition metal mediated activation of inert substrate, which converted to reactive intermediate. The reactive intermediate subsequently reacted with in situ activate nucleophile and formed an unsaturated species with liberation of water. The resulting unsaturated intermediate can be reduced by in situ formed metal hydride [Cat-H_2] formed at first step to regenerate active catalytic species and deliver the final product of the reaction. The process of transferring the borrowed hydrogen to unsaturated species is known as the Borrowing Hydrogen (BH) or Hydrogen Auto-Transfer (HA) strategy. In 2004 Williams et al.[7] was first coined the term "borrowing hydrogen", although many examples of this strategy were demonstrated earlier decades. These methods (acceptorless dehydrogenation and borrowing hydrogen) are most frequently applied to utilize alcohols as alkylating agents in various C–N and C–C bond-forming procedures.

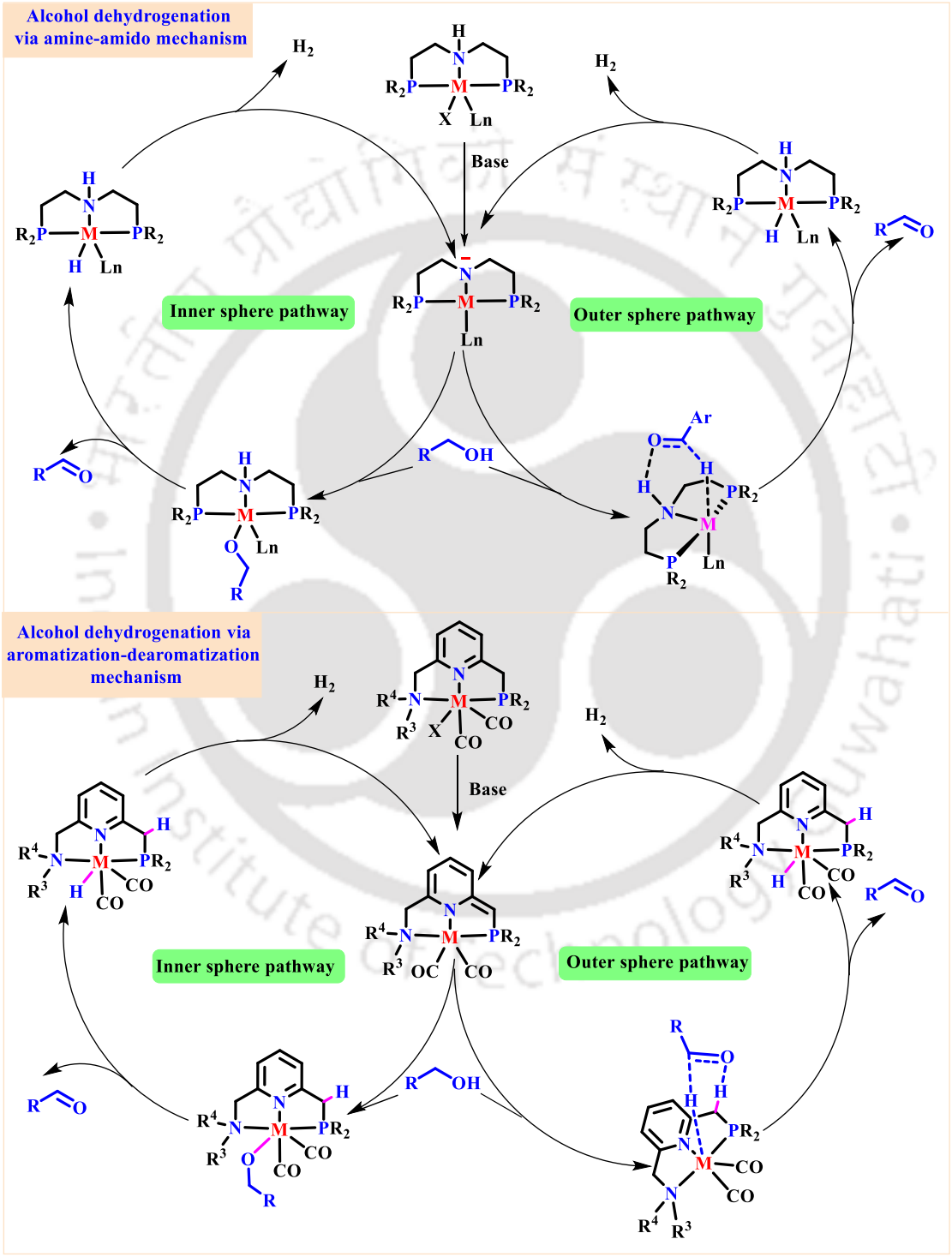


Scheme 1.7. General representation of ADC and BH process.

1.4.2. Alcohol dehydrogenation via metal-ligand bifunctional mechanism:

A survey report disclosed that only 13% of renewable resources are used to make various commodity chemicals of the 20.8 million tons of carbon feedstock's and the majority of organic chemicals are coming from crude oil (76%), natural gas (10%), or coal (1%), respectively. However, with the high demands of large volumes of commodity chemicals and environmental sustainability for the fulfilment of daily requirements and future development, the replacement of

such exponentially depleting fossil fuel derived crude oil and other raw materials is highly desirable and also develop a carbon-neutral paths using lignocellulose derived-feedstock abundant chemicals such as alcohol. Activation of such alcohols into its reactive electrophilic synthons to construct chemical bonds with diverse nucleophiles via de(hydrogenative) process is one of the most dynamic and sustainable technologies in the area of catalysis.

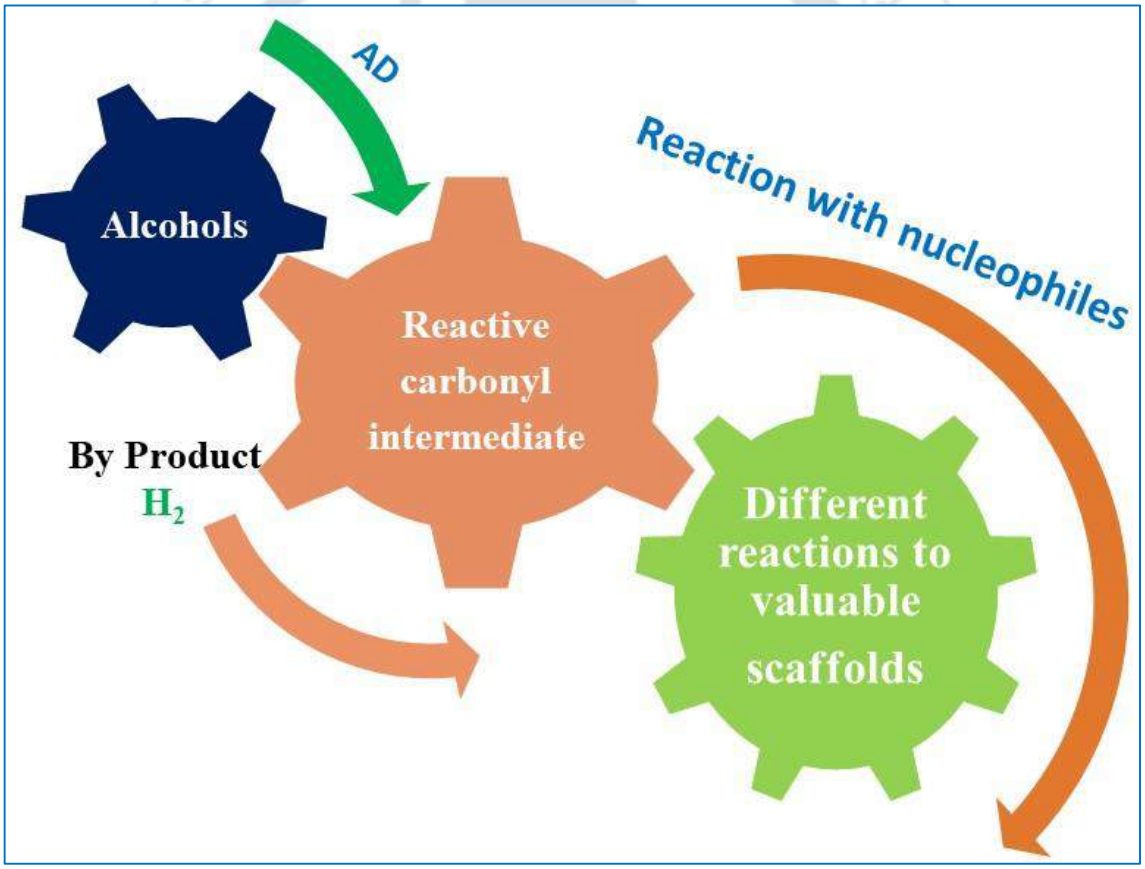


Scheme 1.8. Alcohols activation through-a) amine-amido mechanism; b) aromatization-dearomatization mechanism.

Strategically, alcohols can be activated by transition metal catalysts via the inner sphere or outer sphere mechanism. In this methodology, at first, a metal catalyst borrows the adjacent hydrogen from the alcohol molecules via *β*-hydride elimination. It generates carbonyl compounds in situ, which in the presence of nucleophile, subsequently undergo an aldol or Knoevenagel type of condensation reaction and form an unsaturated molecule. Depending on the experimental parameters and catalysts, the reaction is ended up with the saturation of double bond via the borrowing of hydrogen catalysis.[8]

1.5. Synthetic diversity of alcohols through ADC and BH:

From the beginning of the 20th century, ADC and BH technology have been predominantly dominated in the area of homogeneous catalysis and also heterogeneous catalysis to formulate a multitude of key organic scaffolds via C-C and C-heteroatom bond construction.[1,9]



Scheme 1.9. Synthetic applications of alcohols de(hydrogenative) coupling reaction.

1.6. Construction of different valuable products from same set of starting materials via control de(hydrogenative) pathway:

It is certainly difficult and fascinating to learn how to synthesise a single product by suppressing other potential side-products or all potential products selectively by adjusting the reaction parameters from the same set of starting material by designing new efficient catalysts.

1.7. The state of art of alcohol dehydrogenation to key products:

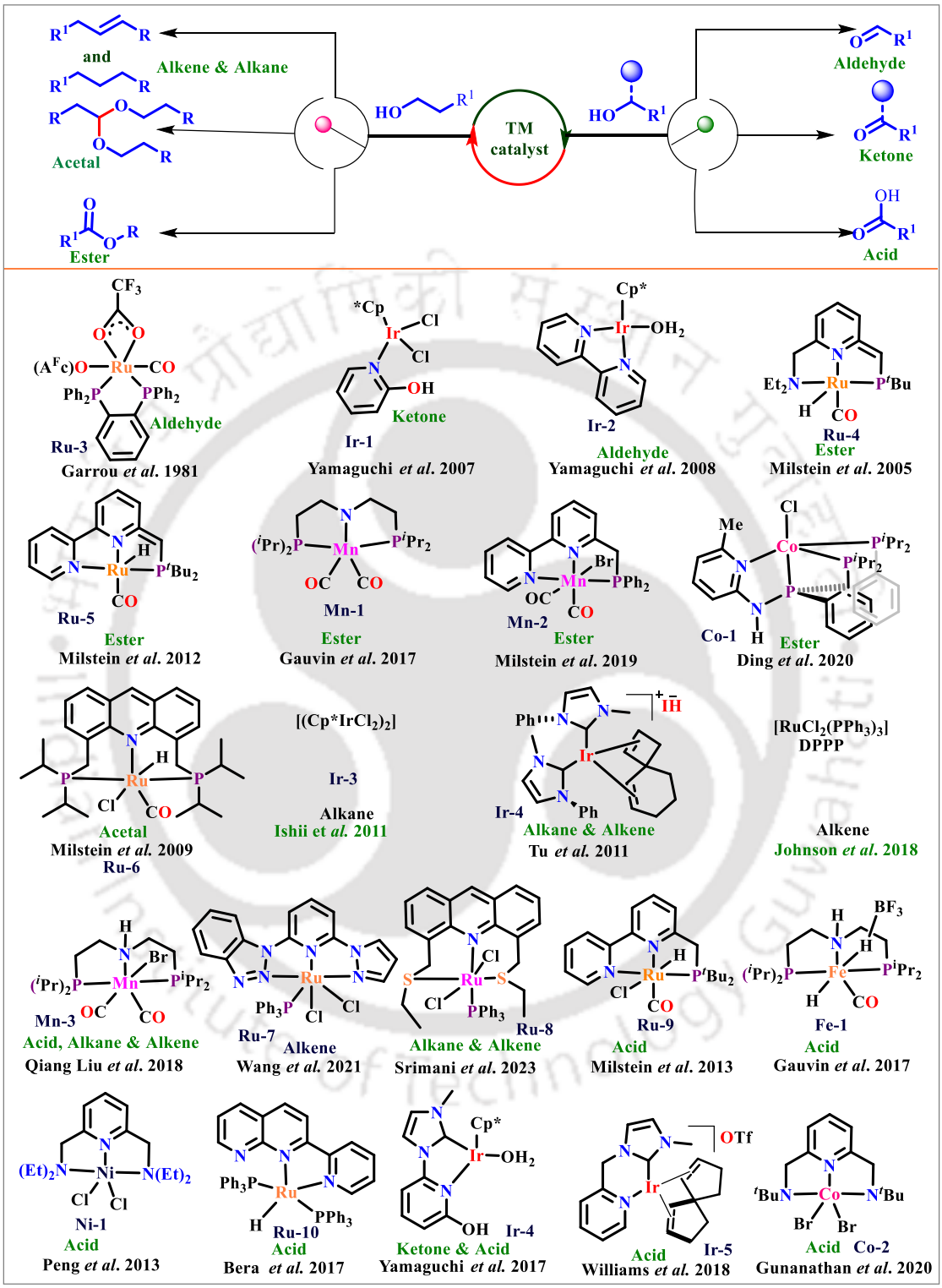
1.7.1. Dehydrogenation of alcohols to aldehydes and ketones:

The transformation of alcohols to corresponding carbonyl compounds through dehydrogenation is one of the most important method in organic chemistry. Diverse range of anaerobic/aerobic catalytic protocols have been investigated for alcohol dehydrogenation via metal-ligand cooperation approach. Precious transition metals[10] like Rh, Ir, Pd and Ru have been well researched by many pioneer researchers in the evolution of numerous catalytic systems. But due to the high cost, toxic nature, and rare availability of noble metal catalysts, the scientific community has recently discovered abundant base metal-derived catalysts that showed comparable reactivity to alcohol dehydrogenation.[11]

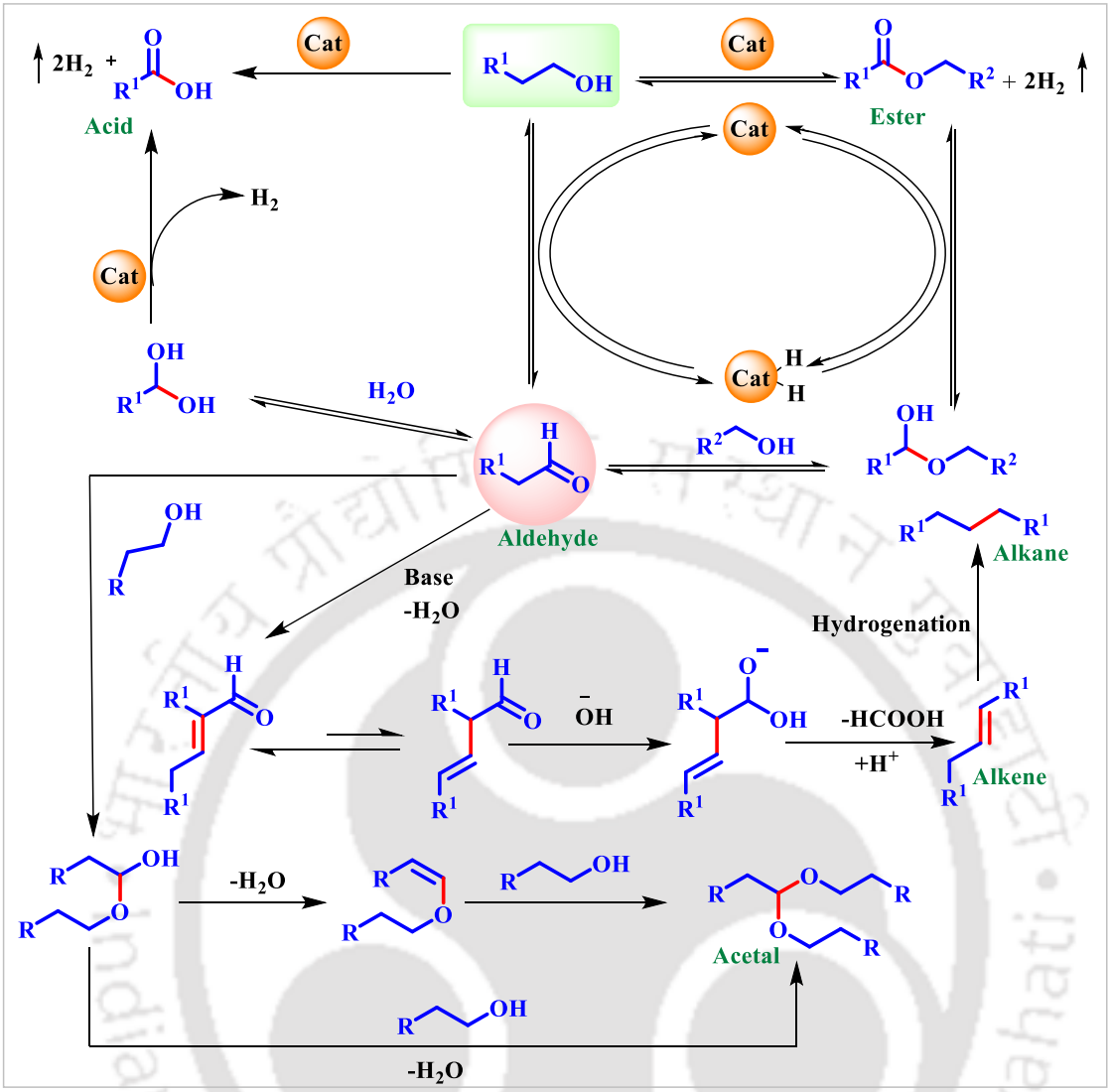
1.7.2. Ester synthesis from alcohol via double dehydrogenation:

Ester is an essential functional group at its core. Esters and their derivatives have a wide range of uses in the biological and chemical sciences, as well as in the polymer and chemical industries.[12] Thus synthesis of ester derivatives from easily available starting materials is fascinating and gaining much attention. In this regards, alcohol to ester transformation via ADC using transition metal would be interesting in terms of sustainability. In 1987 Hiroshi Taki and coworkers first demonstrated $RuH_2(PPh_3)_4$ catalysed ester synthesis from alcohol with the evolution of molecular hydrogen.[13] Then in 2005 Milstein first introduced aromatization-dearomatization concept for alcohol to ester via double dehydrogenation using NNP-Ru complex (**Ru-4**).[14] From the same group in 2012 another Ru-catalyst (**Ru-5**) was reported for cross coupling of primary alcohol and secondary alcohol to cross ester under neutral reaction condition.[15] Gauvin and coworkers[16] described Mn-amido complex(**Mn-1**) of PNP-MACHO ligand backbone for homoester synthesis. To understand the mechanistic aspect of alcohol to ester synthesis various experimental and theoretical studies were performed. In 2019, Milstein group advanced the ADC strategy for synthesizing homo and cross-esters employing NNP-Mn(I) dicarbonyl complex (**Mn-2**).[17] Mechanistic study suggested that reaction goes via similar pathway proposed by Gauvin et al. In 2018 Ding group reported well defined tetra coordinated tripodal Co(II) complex (**Co-1**) for ADC of alcohol to homo ester.[18] A primary mechanistic investigation recommends a plausible reaction

path that comprises Co-catalysed acceptorless dehydrogenation of alcohol to aldehyde, then an ester-mediated Tishchenko-type route via KO^{t}Bu.



Scheme 1.10. Diverse transformations of alcohol using transition metal catalysts.



Scheme 1.11. Mechanistic overview of aldehyde, ketone, acid, ester, alkene, alkane and acetal synthesis from alcohol via ADC and BH.

1.8. Direct acetal synthesis from alcohol:

Acetals are industrially important chemicals and serve as valuable intermediates for further functionalization into other functional groups.[19] Although variety of approaches have been exploited for acetals synthesis,[20] but the majority of them require an aldehyde or ketone as a reactant and the reaction was catalysed by strong acids and also used toxic reagents. In ADC reaction, alcohols reversible binds with in situ formed aldehyde to form hemiacetal. Then, reaction of hemiacetal with another molecule of alcohol which outcome in construction of acetal through the elimination of water. The first discovery associated to this transformation was described by Murahashi *et al.* using $RuCl_2PPh_3$ as an active catalyst.[21] Later the Thorp group[22] established an imidorhenium(V) complex which successfully catalysed the reaction with relatively higher TON. Sustainable direct catalytic conversation of alcohol to acetal was further reported by Milstein group

in 2009. This reaction was catalysed by acridine based Ru-hydride complex (**Ru-6**). They suggested that their Ru-hydride complex worked via unique type long range MLC in this transformation.

1.9. Synthesis of alkane and alkene via dual-deoxygenation pathway:

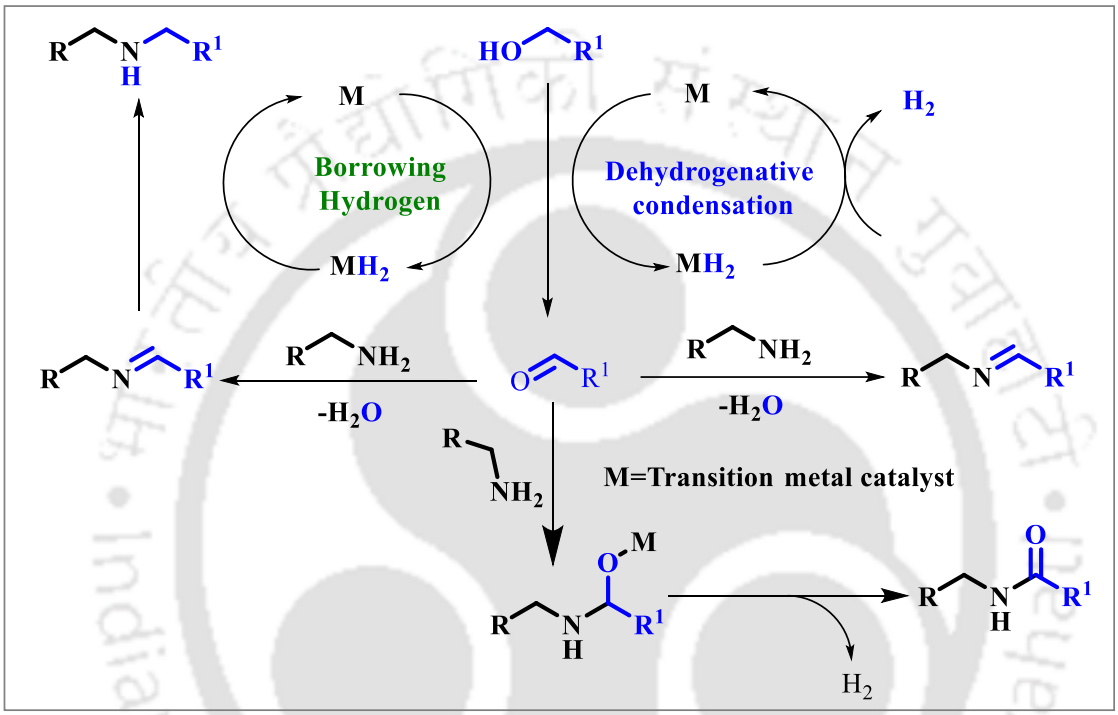
Deoxygenation of bio-mass derived alcohols deliver an efficient and environmentally benign technique for sustainable biomass-derived feedstocks to produce biofuels and platform chemicals. Deoxygenation of oxygen rich biomass derived chemical like alcohols using transition metal catalysts employs an efficient technique for the production of high energy hydrocarbons. Breaking of strong two "C-O" bonds in such type of transformation is challenging.[24] In 2011, Ishii, Obora *et al.* developed a ground breaking method for transforming ω-arylalkanols into *α, ω*-diarylalkanes in two steps using two different iridium catalysts (only **Ir-3** and DPPC with **Ir-3**).[25] Johnson and his group[26] later reported $[Ru(PPh_3)_3Cl_2]$ with combination of DPPP ligand for selectively corresponding alkene synthesis. In 2018, Liu *et al*. first demonstrated manganese-catalyzed dual deoxygenative coupling protocol of different aryl alcohols to corresponding alkene analogue and prepared alkene derivatives were further hydrogenated under 20 bar H_2 pressure by using $Ni@SiO_2{-}Al_2O_3$ catalyst.[27] Very recently, Srimani group[28] described acridine SNS-Ru catalyst (**Ru-8**) for selectively olefins formation from alcohols. Further, same catalyst is applied for olefins to alkane under only 3 bar H_2 pressure. Various homo as well as hetero coupled alkene and alkane products were isolated with good yields.

1.10. Alcohol to acid synthesis:

Carboxylic acid derivatives and its salts are widely utilized in both our everyday life and the chemical industry. In organic synthesis primary alcohols to carboxylic acid transformation is one of the most common reaction. But in ADC this transformation is less common as in de(hydrogenative) strategy utilization of O-nucleophiles has been less studied compared to C- and N-nucleophiles. In this context, homogeneous noble metals catalytic system such as Rh, Ir and Ru complexes have been established by pioneer groups like Milstein, Beller, Madsen and Williams for one step oxidation of alcohols to carboxylic acids or its salts.[29] In this transformation first alcohol is converted to corresponding aldehyde intermediate by metal catalyst and under strong aqueous alkaline medium, hydroxyl nucleophile attack to electrophilic carbon centre of insitu formed aldehyde intermediate. Then through liberation of second hydrogen molecule leads to the formation desired carboxylic acid derivatives or its salts. Gauvin and coworkers[30] first introduced base metal manganese and iron MACHO complexes (**Fe-1**) for this transformation and in the same year Peng *et al*.[31] established NNN-Ni(II) tridenate complex (**Ni-1**) for the same. In 2018 Liu[32] upgrade this alcohol oxidation method to carboxylic acid by modifying the reaction condition using manganese complex (**Mn-3**). The **Co-2** catalysed direct alcohols to carboxylic acids conversation was first reported very recently by Gunanathan group[33] in 2020 under oxidant free conditions.

1.11. Reaction of alcohols and amines:

Amines and other nitrogenous chemicals are found in many synthetic and natural compounds, and they play a significant role in the chemical and pharmaceutical sectors. More than, 25% market available drugs contained C-N bond in terms of imine, amines or amide group.[34] Thus, one of the key goal in catalysis is the development of new an atom-economic, environmentally safe catalytic method for the formation of the C-N bond. Depending on catalyst and reaction conditions the reaction between alcohols and amines sometimes delivered imines, amines or amides or all of them.



Scheme 1.12. General mechanistic overview of imine, amine and amide synthesis from alcohol and amine.

Mechanistically, at first, metal catalyst oxidised the starting material alcohol via acceptorless dehydrogenation. The borrowed hydrogen atoms from the alcohol at dehydrogenation step, are stored on metal centre. Then subsequent formation of carbonyl intermediate (aldehyde or ketone). Now, the produced carbonyl intermediate reacts with primary amine and forms hemiaminal intermediate. Then, this hemiaminal intermediate either eliminate water to form imine or liberate hydrogen gas in presence of catalyst and deliver amide. The imine can have hydrogenated using the borrowed hydrogen in the dehydrogenation step by metal catalyst and active catalyst is regenerated.

1.11.1. Imine and amine synthesis:

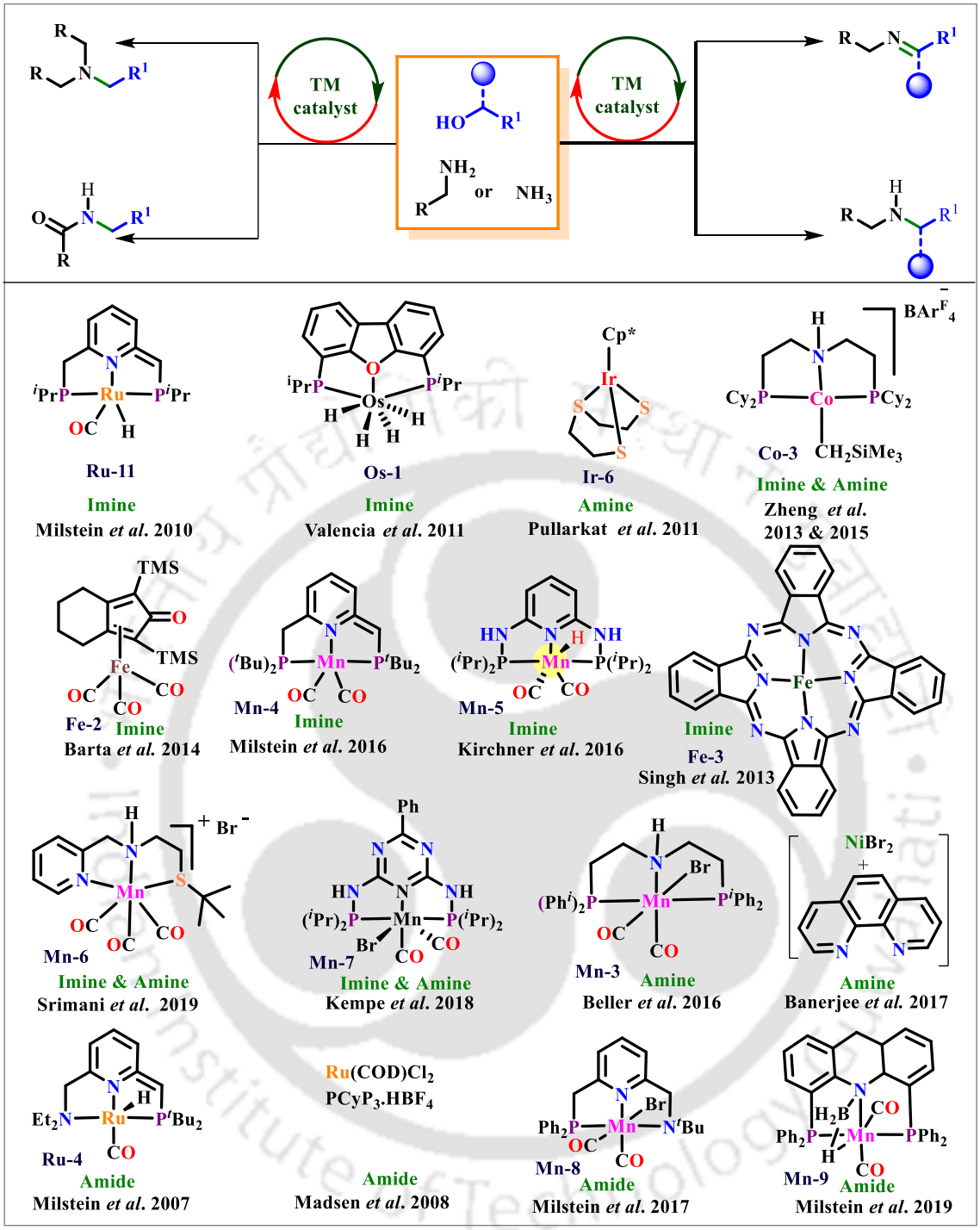
Winans and Adkins group[35] in 1932 first discovered heterogeneous Ni-catalyst for N-alkylation reaction from alcohol and amine. Grigg[36] and Watanabe[37] reported the first homogeneously catalysed aminations of alcohols in 1981, employing primary and secondary amines in the presence of ruthenium complexes. Then, inspired by this discovery several uses for complexes mostly based

on ruthenium or iridium and osmium have been reported by Beller, Fujita, Yamaguchi, Williams, Yus, Kempe and other via BH methodology.[38] The journey of base metal catalysis in this reaction was started since 2014 by Barta using Fe-Knölker complex (**Fe-2**).[39] Then exponential advances have been made employing different variety of Fe complex[40] and other earth abundant transition metals[41] such as Mn, Ni and Cr. Only two reports are known literature for direct tertiary amine synthesis via BH strategy. In 2010 first report was developed by Yamaguchi group[42] in presence of air and water stable $[Cp^*Ir(NH_3)_3][I]_2$ complex using ammonia (aqueous) as a nitrogen source. Recently, Barta et al. established improved catalytic methods using same **Fe-2** for direct tertiary benzyl amines synthesis from secondary amines and alcohols via BH process with good to excellent yields.[43] Their, protocol also adaptable for the one-pot synthesis of non-symmetric tertiary amines.

Acceptorless de(hydrogenative) coupling (ADC) is an environmentally friendly and sustainable method for producing imines from alcohols and amines in which H_2 and H_2O as an only byproduct. In this path, pioneer group Milstein and co-workers[44] in 2010 first introduced PNP-ruthenium pincer complex (**Ru-11**) as a precatalyst for selective imine synthesis. Following this pioneer work, several noble metal catalytic system have been developed for imine synthesis.[45] In 2013, Hanson *et al*. first introduced earth abundant PNP-Co (**Co-3**) catalyst for the synthesis of imines.[46] Kumar/Singh et al. in 2013 synthesized imines from alcohols and amines using a Fe-phthalocyanine complex (**Fe-3**) precatalyst.[47] In 2016 Milstein's [48] and Kirchner and co-workers[49] independently reported two different Mn-PNP complexes (**Mn-4** & **Mn-5**) for dehydogenative imine synthesis. Then, various research group like Kempe,[50a] Srimani,[41d] Madsen[50b,c] and Zhang[50d] were developed mainly manganese based different catalytic system for this same transformation.

1.11.2. Amide synthesis:

Elimination of dihydrogen in presence of catalyst instead of non-catalytic water elimination of in situ formed hemiaminal (mechanism is described in scheme 1.12) is the crucial step in direct amide formation. Direct amidation of amines with alcohols through release of two molecules of dihydrogen, is an environmentally friendly method for synthesising amides. The ruthenium NNP-pincer complex (**Ru-4**) catalysed this unprecedented direct amide bond formation from alcohols and amines was first described by Milstein group[51] in 2007. Next year, Madsen et al. discovered that $Ru(COD)Cl_2$ in combination with NHC-carbene precursor exclusively formed amide from alcohols and amines instead of corresponding imines or amines.[52] In 2017, Milstein group[53] further introduced more economical procedure for this same reaction employing NNP-Mn(I) catalyst (**Mn-8**). In continuous investigation on developing more sustainable catalytic protocol for this reaction, they recently developed acridine-derived **Mn-9** catalytic system for direct secondary amide synthesis employing liquid ammonia as a nitrogen source under 7 bar ammonia pressure in presence of stoichiometric amount of KH.[54]

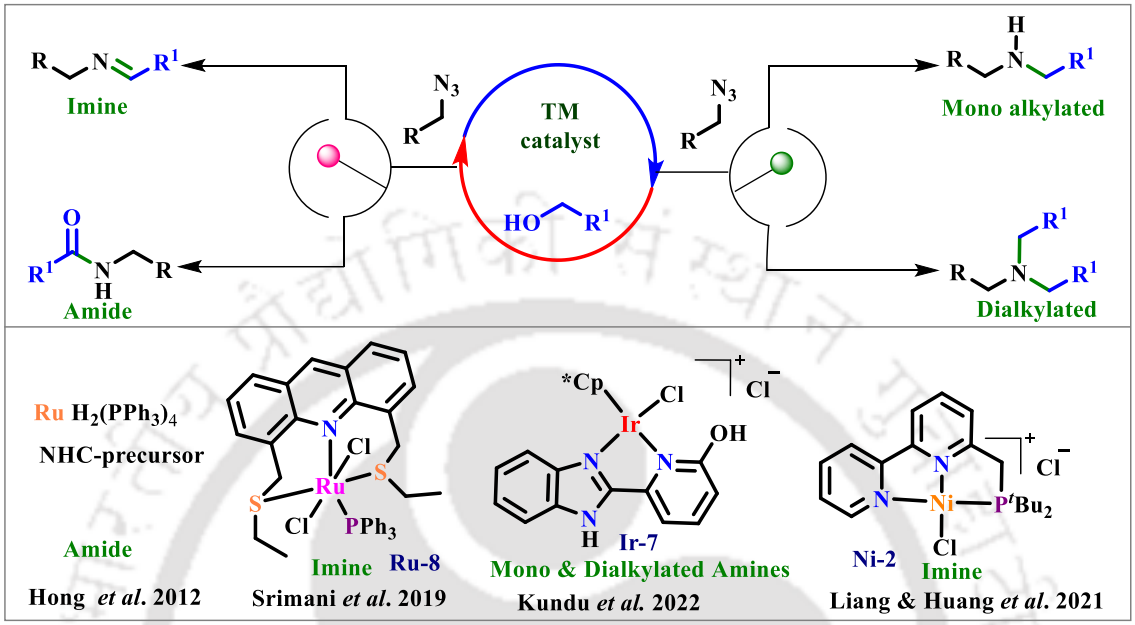


Scheme 1.13. Synthesis of imine, amine, amide and tertiary amine from alcohols and amine or ammonia.

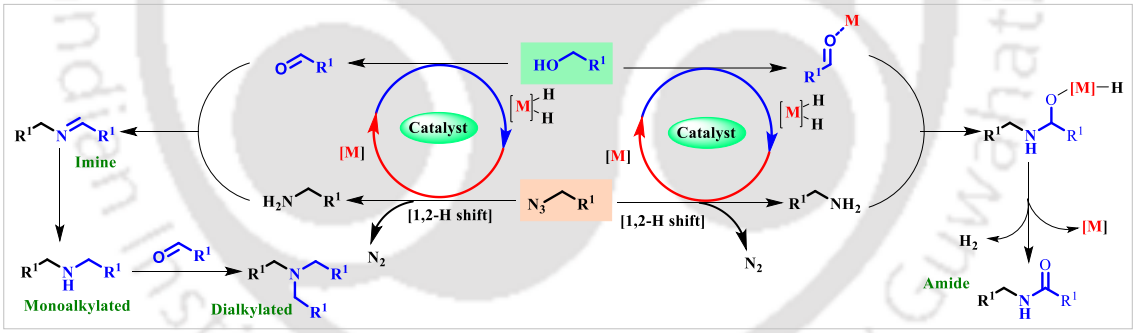
1.12. Reaction between alcohol and azide:

Imine, amine and amide can be also synthesised by reacting with alcohol and azide via aza-Wittig reaction. Hong group[55] in 2012 first reported the synthesis of amide from azides and alcohols in the presence of $RuH_2(PPh_3)_4$ and NHC-carbene. In 2019 Srimani and coworkers[56] developed SNS-Ru catalyst (**Ru-8**) for selective imines synthesis from azides and alcohols. Later, earth abundant PN^3-Ni precatalyst (**Ni-2**) was reported for redox-neutral imination process.[57] In this protocol Huang *et al*. prepared wide variety of imines with good yields. They proposed non MLC-catalytic pathway

this transformation on the basis of experimental and theoretical calculations. Recently, Kundu and coworkers[58] demonstrated **Ir-7** catalysed new catalytic protocol for secondary and tertiary amines synthesis selectively by controlling the alkylating source. A general catalytic pathway of all possible products from alcohols and azides is depicted in scheme 1.15.



Scheme 1.14. Synthesis of imine, amine, amide and tertiary amine from alcohols and azides.

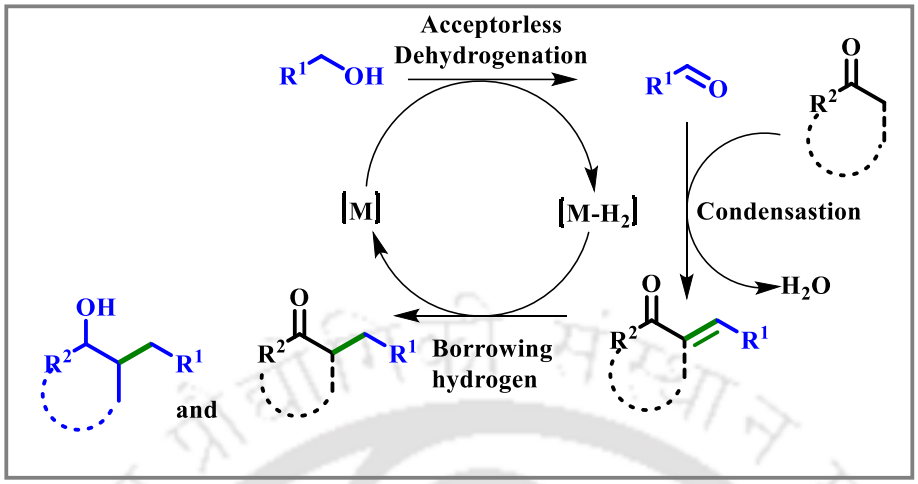


Scheme 1.15. General mechanistic pathway for imine, amine and amide synthesis from alcohols and azides using transition metal catalysts.

1.13. Synthesis of α-branch ketone from methyl ketone and primary alcohols:

The functionalization of *α*-C-H bonds of carbonyl compounds to construct C-C bond is a fundamental technique in synthetic organic chemistry. In this regard, using alcohols as an alkylating reagent instead of alkyl halides via hydrogen borrowing or the hydrogen auto-transfer process is a waste-free and high atom economic strategy, as only water is extracted as a byproduct. Mechanistically, in presence of catalyst insitu reactive electrophile of corresponding alcohols is produced. After that, in the presence of a base, additional carbonyl compounds exit in enolate form, which is coupled with aldehyde and results in an *α, β*-unsaturated ketone upon exclusion of water as the only byproduct. The abstracted hydrogen at the first step "returns" to the *α, β*-unsaturated

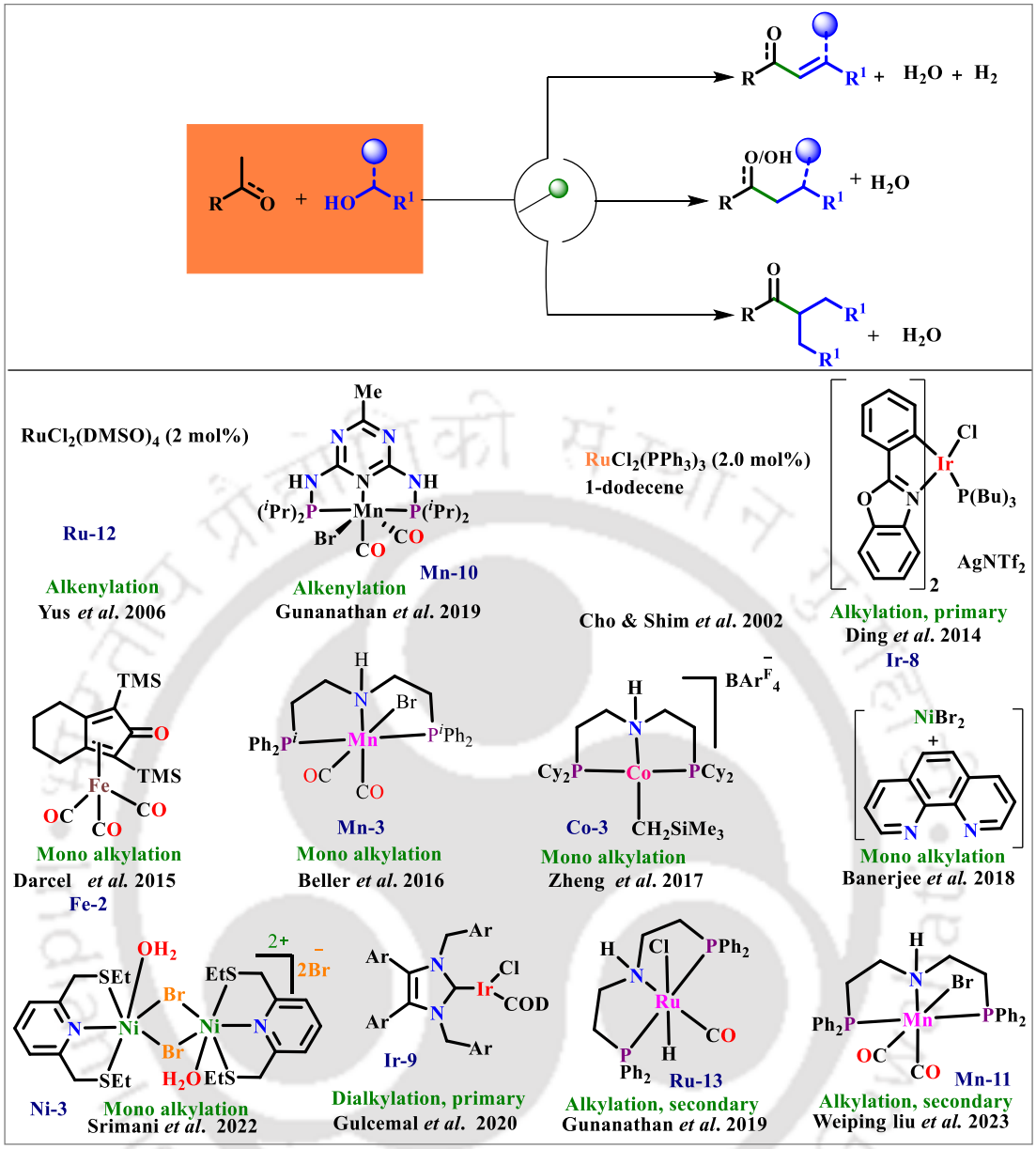
carbonyl intermediate and results in the corresponding *α*-alkylated ketone. In this overall process, metal catalysts play a crucial role in hydrogen shuttling.



Scheme 1.16. General mechanistic pathway for *α*-functinalization of ketones using alcohols.

Selectively, the synthesis of any intermediate product in catalysis is always a challenging task. In the *α*-alkylation of ketones, the intermediate *α, β*-unsaturated ketone is prone to undergo hydrogenation reaction by in situ generated metal hydride, but selectively, *α, β*-unsaturated synthesis by restricting the hydrogenation was first discovered in 2006 by pioneer group Yus and Ramon using $RuCl_2(DMSO)_4$ catalyst (**Ru-12**). But their protocol is limited only to hindered ketones.[59a] Recently, Gunanathan *et al*. found a more practical protocol where reaction has been stopped at the reactive *α*-alkenylated ketone stage employing a triazine-based **Mn-9** pincer catalyst (0.3 mol%) in the presence of 5 mol% weak base Cs_2CO_3. The protocol is applicable to a broad range of substrates with promising isolated yields.[59b]

Applying hydrogen auto-transfer strategy in 2002, Cho and Shim *et al*. first introduced $[RuCl_2(PPh_3)_3]$ catalyst for *α*-alkylation of ketones.[60] Under their method, 1.0 equiv. of KOH and 2 mol% of Ru-catalyst were used to alkylate ketones with different primary alcohols in 1,4-dioxane at 80 °C. It has been observed that due to the formation of *β*-alkylated alcohol as a side product, in many cases, yields of the desired *α*-alkylated ketones were very low, to minimize the side product formation 1-dodecene is used as an external hydrogen acceptor. Inspired by the pioneer works, various groups contributed various precious metals such as Ir, Ru, Pd and Os based modified catalytic protocols for this transformation.[61] Among the non-precious metal catalysts, Knölker-type Fe-catalyst (**Fe-2**) is first used in *α*-alkylation reaction of ketones with various primary alcohols via BH methodology.[62]



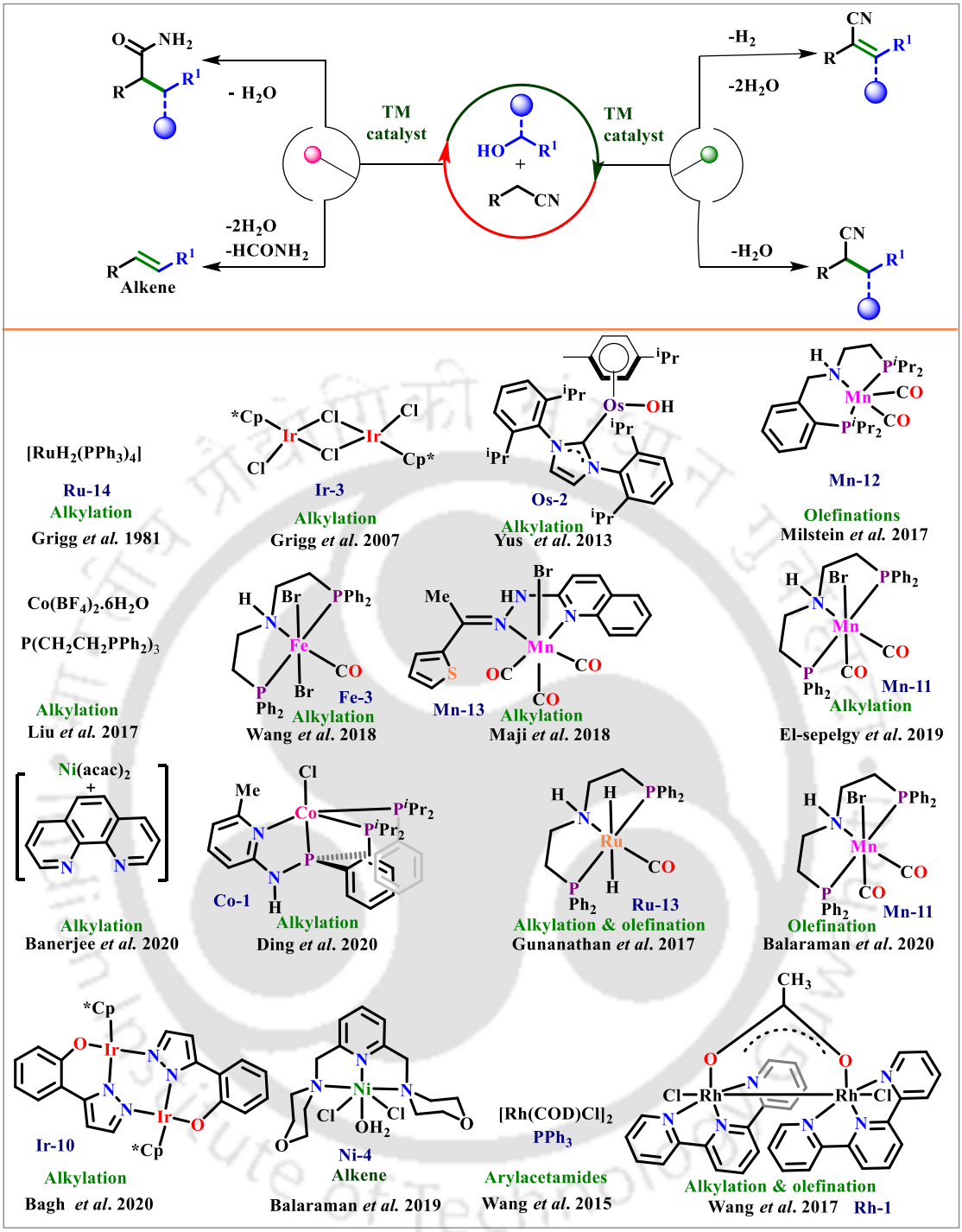
Scheme 1.17. Reported catalysts for *α*-functionalization of ketones using alcohols.

The active catalyst was produced in situ with the reaction of tricarbonyl Fe-complex and PPh_3 in using a 1:1 ratio. The developed catalytic protocol enabled the synthesis of diversely substituted α-branched ketones, notably, 22 examples were successfully prepared in moderate to good yields. In 2016, **Mn-3** catalyzed *α*-alkylation of ketones and related compounds with primary alcohols was reported by Beller and coworkers.[63] In this study they screened three MACHO Mn-bromide complexes and they found that MACHO ligand containing isopropyl phosphine ends with Mn-showed highest catalytic performance in presence of Cs_2CO_3. Later on, Zheng[64] and Banerjee coworkers[65] were described cobalt and nickel catalysed same protocol. Following these discoveries, many other research groups established *α*-alkylation protocol with different variety of modified ketones and alcohols using different transition metals.[66] Recently, one pot direct dialkylation of ketones were disclosed by Gulcemal *et al*. using **Ir-9** carbene precatalyst.[67] Direct cross coupling

of two symmetrical as well as unsymmetrical secondary alcohols employing transition metal catalysts were also started exploring applying BH-strategy.[68]

1.14. Functionalization of nitrile:

The presence of nitrile functionality in organic moiety has potential application in synthetic chemistry as it may have transformed into others important functional group like amines, amides, aldehyde, ketones and carboxylic acids etc. Therefore, de(hydrogenative) *α*-functionalization of nitriles with alcohols has become significant and advantageous in terms of sustainability. Pioneer researcher Grigg[69] in 1981 first *α*-alkylation of acetonitriles protocol was published in presence of $RuH_2(PPh_3)_4$ catalyst. After this pioneer work several noble metals such as Rh, Ir, Ru, Os etc based state-of-art were established for *α*-alkylation of nitrile employing primary alcohols and various active *α*-methylene containing nitriles.[70] However, there are several potential advantages for investigating catalytic activity of earth-abundant transition metals based catalysts (Fe, Co, Mn, Ni) over the rare transition metal catalysts. In this regards, in 2017 Milstein *et al*. [71] first introduced PNP-Mn hydride complex (**Mn-12**) catalysed olefination of nitriles using alcohols without adding any additives. This protocol works smoothly for a variety of alcohols and nitriles, with excellent yields of the desired olefinated nitriles. In the same year, Liu group[72] revealed *α*-methylation of nitrile in the presence of market-available Co-salt in combination with the tetradentate phosphine ligand $P(CH_2CH_2PPh_2)_3$ and 1 equiv. K_2CO_3 at 100 °C. After few years, Ding[73] proposed tripodal tertradenated phosphine based cobalt catalyst (**Co-1**) for this same reaction. In 2018, the BH protocol for the **Fe-4** catalyzed α-alkylation of nitriles with primary alcohols was first discovered by the Wang group.[73] Simultaneously, Maji *et al*.[74] demonstrated nitrile α-alkylation reaction catalyzed by phosphine free hemi labile ligand derived **Mn-13** complex. In a subsequent study, El-Sepelgy and Rueping[75] disclosed an effective method for chemoselective *α*-alkylation and methylation of nitriles by PNP manganese pincer complex (**Mn-11**). Their experimental studies suggested that the manganese catalyst is responsible for triggering both reacting partners and hydrogenating the intermediate alkenyl nitrile to valuable *α*-alkylated nitriles. The nickel catalysed *α*-alkylated nitriles were reported Banerjee *et al*. in presence of $Ni(acac)_2$ and bipyridine ligands with K_2CO_3 base under nitrogen atmosphere.[76] In 2011, Obora *et al*. first revealed the utilization of secondary alcohols in this reaction.[70d] They successfully alkylated acetonitrile using secondary alcohols in the presence of an $[Ir(OH)(cod)]_2$ catalyst and ^{t}BuOK as a base with only four examples. Gunanathan and co-workers[77] extended this ADC methodology to MACHO-based **Ru-13** catalyst-mediated coupling with nitriles and secondary alcohols to provide *β*-disubstituted vinyl nitriles. Recently, Bagh *et al*.[78] developed new Ir-bridge complex (**Ir-10**) which has potential for the α-alkylation of arylacetonitriles using inert secondary alcohols with the release of green byproducts water. For activating the secondary alcohols using earth-abundant transition metals for this transformation was started in 2019 by Balaraman group.[79]



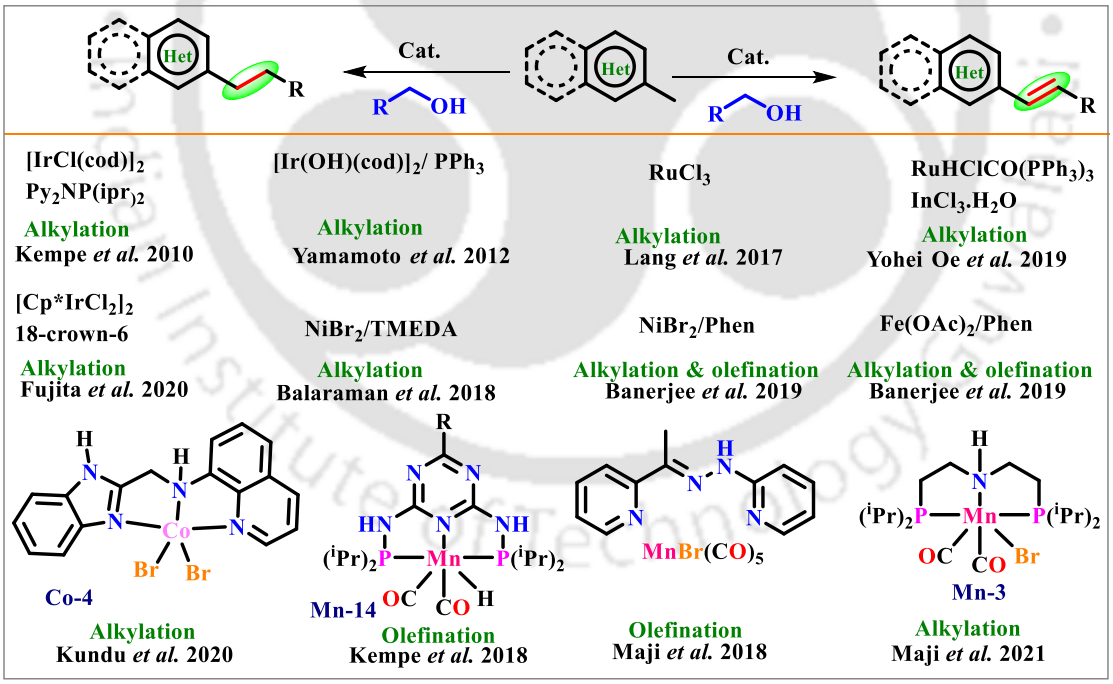
Scheme 1.18. Reported catalysts for synthesis of α-olefinated, alkylated nitriles, α-substituted arylacetamide and trans alkene from alcohols and nitriles.

They used the well-known Mn-MACHO complex (**Mn-11**) for synthesizing a range of benzylic, cyclic, and acyclic substituted *α*-olefinated nitriles with excellent yields. To understand the role of reactants, concentration of base, and catalyst loading, they performed a series of kinetic and control studies. Following up this report, another group found that in presence of $[Cp^*Co(CO)I]_2$, 2-(diphenylphosphino) benzoic acid as the ligand and 2 equiv. KO^{t}Bu under argon atmosphere various secondary alcohols successfully incorporated at *α*-position of different aryl acetonitrile with

excellent yields.[80] Only single report on both alkylation and alkenylation of nitriles using single catalyst was first reported by Wang group.[81] They found that binuclear rhodium complex (**Rh-1**) which can deliver both *α*-olefinated and alkylated arylacetonitrile products by just tuning the reaction atmosphere. Under argon atmosphere Rh-catalyst undergo BH process where as in presence of oxygen environment catalyst is suitable for only acceptorless dehydrogenation. For the first time, same group demonstrated a protocol that can directly deliver *α*-alkylated arylacetamide[82] from arylacetonitriles and primary alcohols under microwave conditions employing rhodium complex $[Rh(cod)Cl]_2$ /triphenylphosphine and potassium hydroxide. Very recently, Balaraman et al. established an unprecedented direct alkene-producing methodology through the elimination of formamide as a byproduct using their NNN-Ni dichloride aqua complex (**Ni-4**).[83] This protocol is highly *E*-selective and well-functional group-compatible, with excellent isolated yields.

1.15. Selective functionalization of methyl heteroarenes:

The de(hydrogenative) diversification of methyl heteroarenes via the activation of weakly acidic C-H bonds was completely untapped till 2010. The pioneering work of Kempe and his team opened new opportunities for organic chemists to develop different efficient catalytic methods for de(hydrogenative) functionalization of methyl-*N*-heteroaromatics.[84]



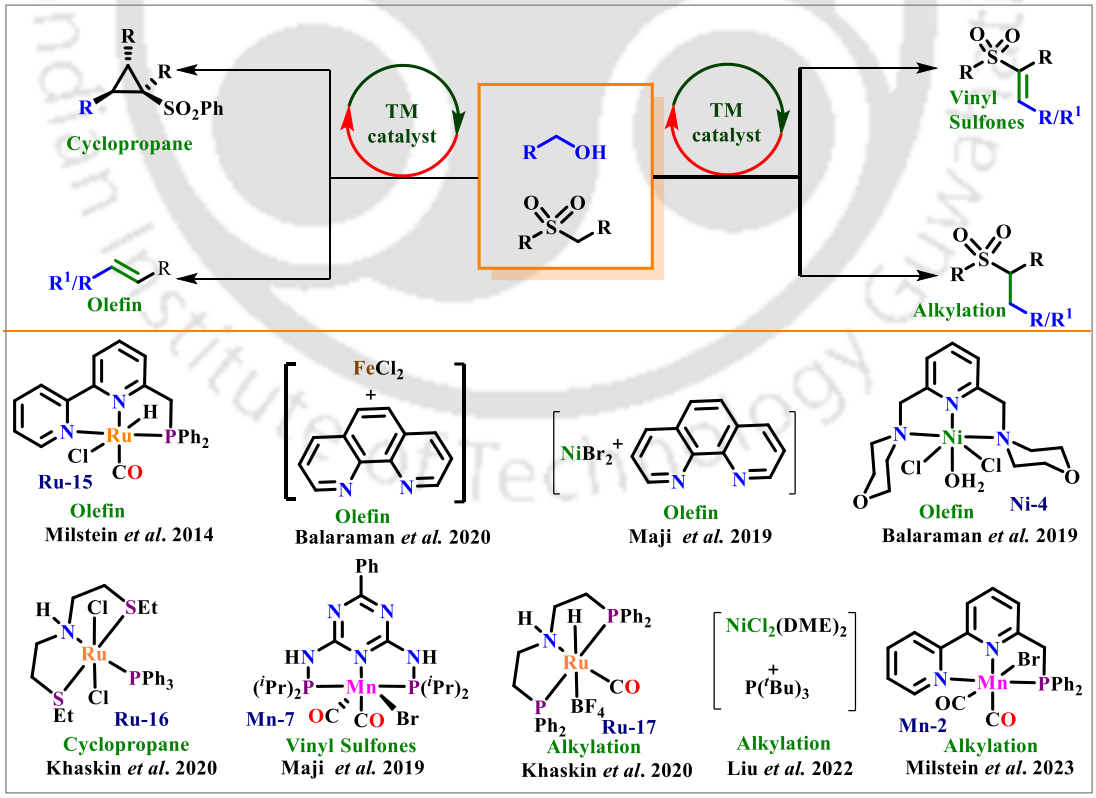
Scheme 1.19. Reported catalysts for synthesis of olefinated, alkylated methyl heteroarenes.

Inspired by kempe's work later on Yamamoto, Lang, Oe and Fujita with their team established various catalytic methods utilizing noble metal based catalyst.[85] In recent years, various group were utilized low-cost and environmental friendly 3d-transition metal catalysts like Ni, Co and Fe for this functionalization reaction.[86] Recently, Maji[87] and Kempe[88] used Mn(I) complexes synthesized

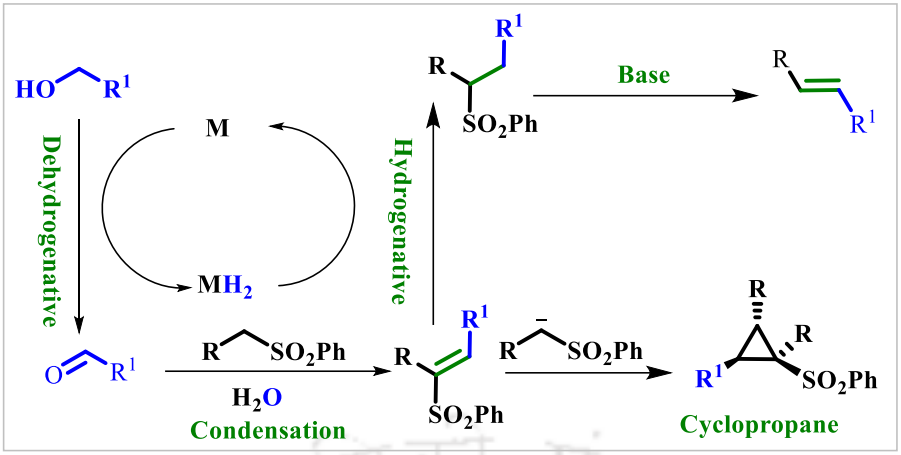
from expensive Mn(I) precursors such as $Mn(CO)_5Br$ for alkenylation of methyl heteroarenes but both catalytic protocol failed to produced alkylated heteroarenes. Later, Maji[89] and his group revealed that more nucleophilic Mn–H species are required to alkylate methyl-*N*-heteroaromatics. For this purpose, they used **Mn-3** catalyst.

1.16. Reaction between alcohol and sulfones:

Sulfone and its functionalized analogue have significant applications in synthetic chemistry. In 2014, Milstein group was first established **Ru-15** pincer-catalysed terminal and internal alkene synthesis in one-step from sulfones and alcohols.[90] In this protocol, metal−ligand cooperation (MLC) plays crucial role to activate alcohol via aromatization-dearomatization mechanism and consequently carbonyl intermediate was formed which reacted with sulfones equivalent to construct C-C bond, this protocol could be perfectly sustainable alternative of traditional Julia-olefination process. Later on, applying ADC Maji *et al.*[91] and Balaraman *et al.*[92] developed earth abundant metal catalysts such as based on Ni-and Fe-metal precursor with 1,10-phenanthrene ligand. But both protocols only suitable for aromatic alcohols, probably due to aromatic alcohols delivered more thermodynamically stable olefins than aliphatic alcohols. Along with olefins synthesis from alcohol and sulfones there are other possibilities to synthesise vinylated, alkylated sulfones and sulfone functionalized cyclopropane.



Scheme 1.20. Reported catalysts for synthesis of *α*-olefinated, alkylated sulfone, cyclopropane and trans alkene.

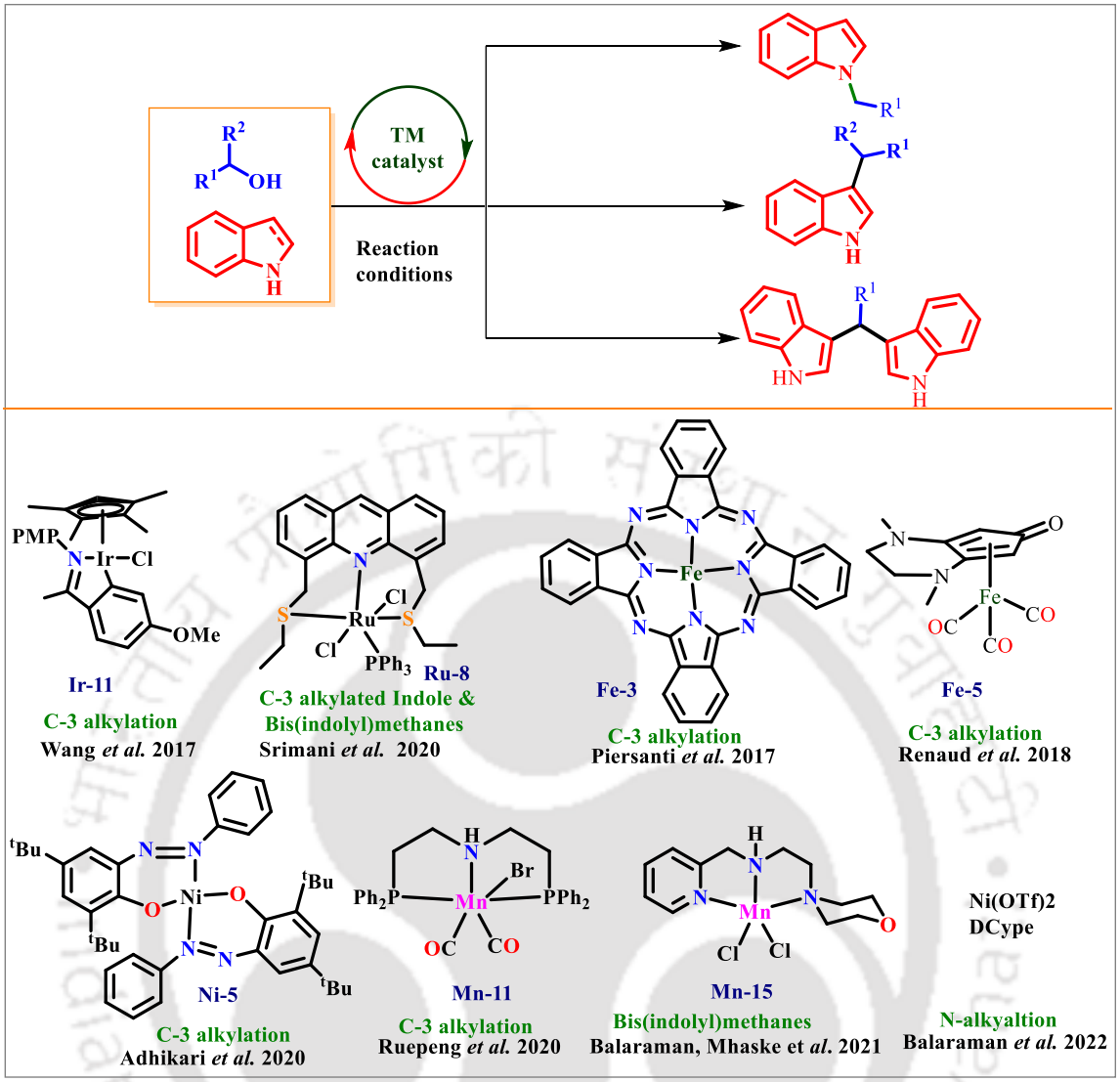


Scheme 1.21. General mechanistic path for α-olefinated, alkylated sulfone, cyclopropane and trans alkene using transition metal catalysts.

But selectively, alkylated sulfone or vinylated sulfones synthesis is more challenging as sulfonyl group has good leaving property and also insitu generated *α, β*-unsaturated intermediate sulfone is very reactive either it decomposed to Julia-olefinated product or reacted with another sulfone carbanion to deliver cyclopropane derivatives. In 2018 Khaskin and coworkers[93] first developed SNS-Ru (**Ru-16**) catalysed [1+1+1] cyclopropanation technology for sulfone functionalized cyclopropane construction via three component coupling. In 2019 Maji group first reported an elegant protocol for the selective synthesis of vinyl sulfones using Kempe's triazine based PNP-Mn(I) complex (**Mn-7**).[94] Next year, Khaskin found that **Ru-17** complex has potential in selective *α*-alkylation of sulfone with alcohols.[95] Very recently, base metal catalysts like Ni[96] and Mn[97] have been utilized for this alkylation reaction. Liu's group developed $NiCl_2$(DME) and P(*t*Bu)$_3$ catalytic system where only aliphatic alcohols are used as an alkyl coupling partner. But use of aromatic alcohols for this transformation is challenging as it leads to deliver Julia-olefinated products. This problem has been overcome by Milstein's developed NNP-**Mn-2** based catalytic system.

1.17. Selective functionalization of indole:

In 2017, Wang *et al*. demonstrated **Ir-11** catalyzed selective C-3 alkylation of indoline and various primary alcohols.[98] They also highlighted broad substrate scope with good yields of the desired alkylated products. Later on, Srimani *et al*. established an elegant protocol for selective functionalization of C-3 alkylated indole and BIMs using single SNS-Ru acridine based complex (**Ru-8**).[99] In homogeneous catalysis reusability of catalyst is major concern. Thus, replacement of precious noble metal by abundant base metals is current trend in catalysis. In 2018, Piersanti group[100] presented first base metal, **Fe-3** catalyst for C-3 benzylation of indoles via borrowing hydrogen catalysis. Afterward, Renaud and co-workers[101] employed well known cyclopentadienone iron carbonyl complex (**Fe-5**) for this C-3 functionalization of indoles.

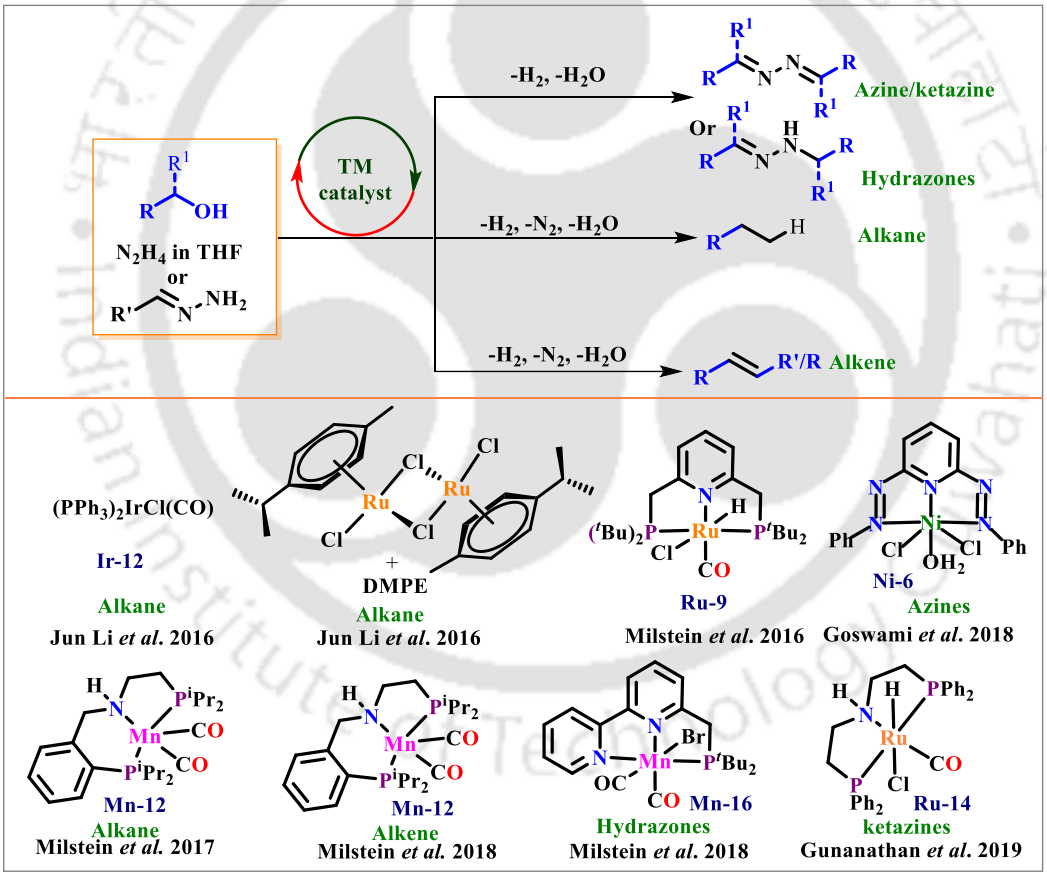


Scheme 1.22. Various catalysts for functionalization of indole and indoline.

They covered aromatic, aliphatic and challenging methanol as an alkylating source and isolated good yields of the desired C-3 alkylated indole derivatives. Adhikari and coworkers,[101] utilized redox non-innocent nickel catalyst (**Ni-5**) for synthesizing C-3 alkylated indoles via radical mediated pathway. Recently, Rueping and coworkers[103] elegantly demonstrated a switchable de(hydrogenative) C vs N alkylation of indolines using **Mn-11**. Their strategy involves de(hydrogenation) of indoline to indole followed by C-3 alkylation with alcohols. This was confirmed by reacting indole with benzyl alcohol. However, BIMs were not selectively synthesized in their protocol. In 2021, the group of Balaraman and Mhaske demonstrated the de(hydrogenative) synthesis of BIMs using NNN Mn(II) complex (**Mn-15**). However, their protocol failed to accomplish C-3 alkylated of indoles.[104]

1.18. Reaction of alcohols and hydrazine derivatives:

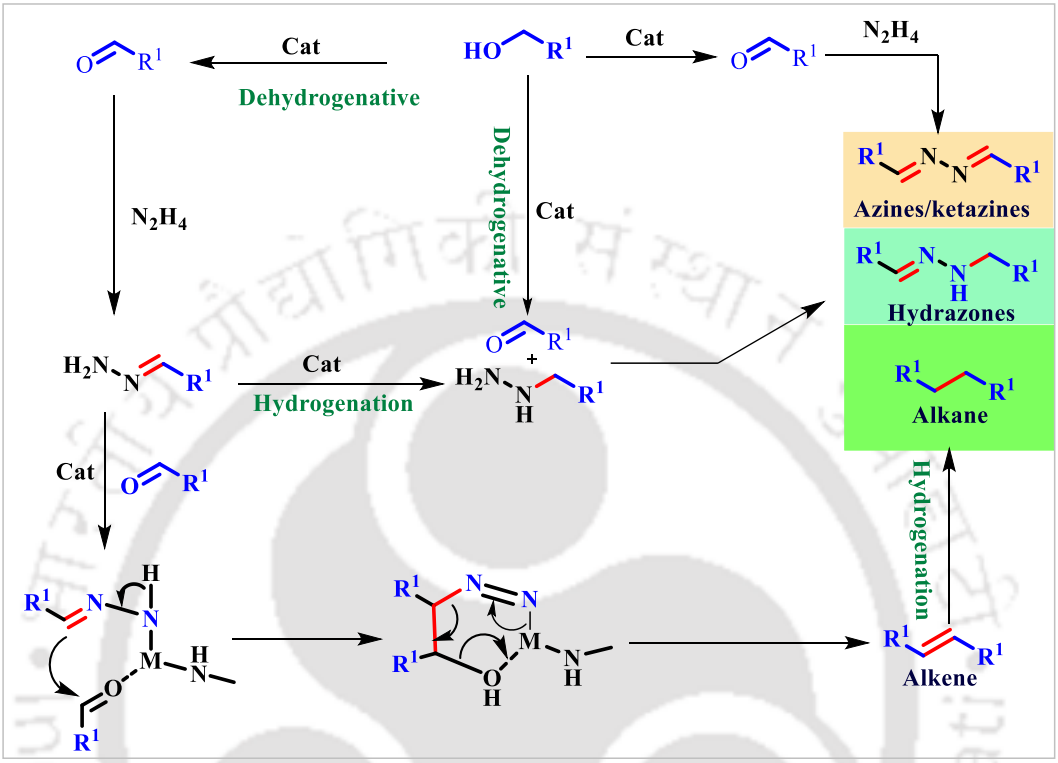
The hydrazine or its analogous are commercially abundant chemicals but it uses in synthetic chemistry is challenging. Pioneer research group Dai and Li first invented the method for direct use of N_2H_4 in deoxygenation reaction employing **Ir-12** catalyst.[105] Their initial development very much substrate specific and required harsh reaction conditions. Later they upgraded[106] the protocol and develop ruthenium catalysed a practically applicable method which covered all types substrate including functional group containing aliphatic primary alcohols with high regio and chemo selectivity. Same year, Milstein coworkers[107] developed de(hydrogenative) direct symmetrical azines synthesis from alcohol and hydrazine hydrate using PNP-Ru complex (**Ru-9**). Different spectroscopic analysis indicated that in presence of base active dearomatized Ru-complex was obtained which coordinated with hydrazine and coordinated hydrazine formed supramolecular network with another hydrazine



Scheme 1.23. Various catalysts for synthesis of azine, ketazine, hydrazine and trans alkenes.

molecule through hydrogen bonding. Goswami *et al*. in 2018 also developed **Ni-6** catalysed azine synthesis.[108] Later on, Milstein discovered that depending on Mn-catalysts, different products were obtained from the reaction of alcohols and hydrazine. The **Mn-12** catalyst suitable for both alkane[109] and alkene[110] synthesis but **Mn-16** complex selectively delivered hydrazone derivatives via partial borrowing hydrogen pathway. Azofra and Poater collaboratively, performed theoretical calculation

for better understanding of **Mn-12** catalysed alkene synthesis from hydrazine and alcohols.[111] Recently, Gunanathan *et al*. extended the protocol of azines synthesis using **Ru-14** complex.[112] They, employed secondary alcohols instead of primary alcohols which delivered ketazine derivatives with excellent selectivity

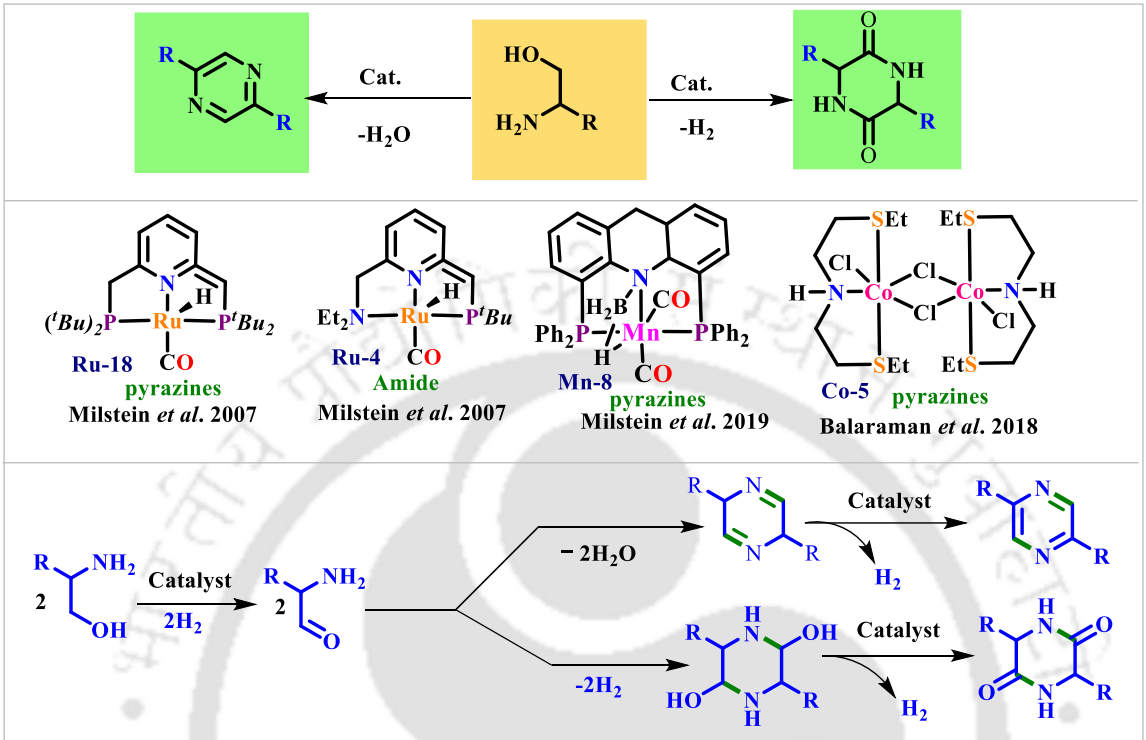


Scheme 1.24. General mechanistic route for synthesis of azine, ketazine, hydrazine and trans alkene.

1.19. Synthesis of pyrazines and cyclic dipeptide piperazine-2,5-dione:

Combining different coupling partner with *β*-amino alcohols to produce multiple useful *N*-heterocycles is known in literature but utilizing *β*-amino alcohols as a coupling partner of another *β*-amino alcohol via self-coupling can deliver useful *N*-heterocycles such as 2,5-dione and pyrazine were first demonstrated by Milstein and co-workers.[113] They observed that the change of ligand arm of ruthenium catalyst can tune this selective synthesis of cyclic dipeptide piperazine-2,5-dione and pyrazine. Interestingly, a small variation of ligand frameworks can have led to the removal of either water or hydrogen, which produced two distinct products selectively. When the amine side arm of ligand is substituted by bulky *tert*-butyl group of the PNP-**Ru-18** gave pyrazine derivatives whereas comparatively less bulky ethyl substituent (**Ru-4**) afforded piperazine-2,5-diones in good to excellent (up to 99% yield) isolated yield. Subsequently, the same group reported a similar synthesis of pyrazines via the de(hydrogenative) self-coupling of *β*-amino alcohols in the presence of a catalytic quantity (3 mol%) of KH base utilizing an acridine-based PNP-**Mn-9** pincer complex.[114] To gain understanding of the likely process, a number of control tests and kinetic studies were conducted. Based on this, the authors postulated that the weakly basic *N*-atom of the acridine ring

took up the alcohol's proton during the dehydrogenation process, and the C-H bond moved to the Mn-center via an outer-sphere mechanism. Balaraman *et al*. (2018) have documented a comparable synthesis that was facilitated by a **Co-5** chloride bridge complex.[115]

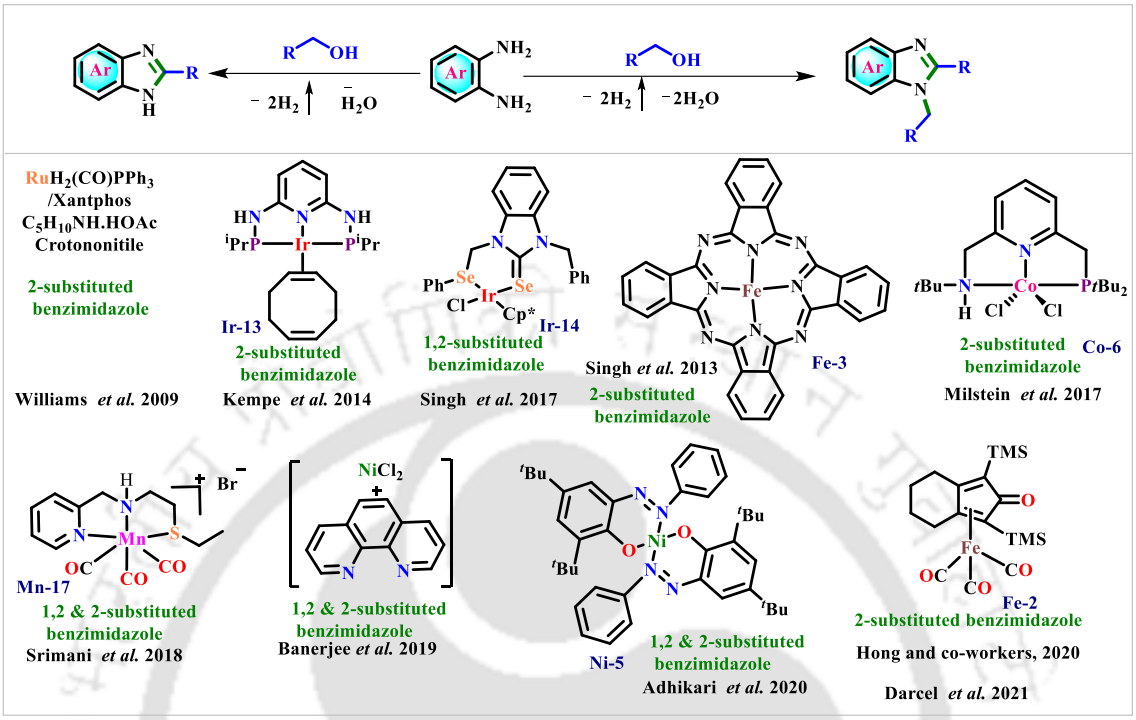


Scheme 1.25. Various catalysts and general route for synthesis of pyrazines and cyclic dipeptide piperazine-2,5-dione.

1.20. Synthesis of 2-substituted and 1,2-disubstituted benzimidazole:

The sustainable synthesis of benzimidazole has received the utmost interest due to its profound significance in a variety of biological and pharmacological aspects.[116] In this direction, Watanabe group[117] first invented sustainable protocol for benzimidazole synthesis via ADC using precious metal Ru-precatalyst at 215 °C. In 2009, Williams and coworkers[118] utilizing both Ir or Ru-metal precursor and combination with various additives showcased 2-substituted benzimidazole synthesis. Thereafter, synthetic accomplishment of ADC protocol was disclosed for 2-substituted benzimidazoles selectively synthesized using molecularly defined **Ir-13** catalyst by Kempe *et al*. in 2014.[119] The continuous efforts of the scientific community in search of more efficient and cheap earth-abundant catalysts. In 2013, Singh and co-workers[120] conducted a study on Fe(II) phthalocyanine complex (**Fe-3**) catalyzed dehydrogenation of alcohols and subsequent coupling with diamines to a synthesize 2-substituted benzimidazole. However, only 8 examples for the synthesis of 2-substituted benzimidazole were described, out of which benzyl alcohols outperform aliphatic alcohols. Later on, several comprehensive mechanistic investigations were accompanied by various groups.[121] In 2017, Milstein and co-workers[122] introduced for the first time base free PNN-Co complex (**Co-6**) to catalyze the synthesis of 2-substituted benzimidazole from 1,2

diaminobenzene and various primary alcohols. 5 mol% of **Co-6** in the presence of 5 mol% of $NaEt_3BH$ is sufficient to carry out the reaction at 140 ºC. 4Å MS is found to be essential to achieve the highest yield.



Scheme 1.26. Various catalysts for selective synthesis of 2-substitued and 1,2-disubstituted benzimidazoles.

The protocol furnishes the quantitative yield of the product utilizing challenging substrates like primary aliphatic alcohols and various benzyl alcohols. However, many benzyl alcohols having electron withdrawing substituents afforded low to moderate yields of the resultant products. Mechanistic studies reveal that the reaction proceeds via the initial formation of Co(I)-chloride (after the reaction of PNN-$CoCl_2$ with $NaEt_3BH$) species which performs the actual dehydrogenation reaction giving aldehyde and H_2. The formed aldehyde subsequently coupled with *o*-phenylenediamine to result in the formation corresponding benzimidazole and H_2O. Very recently, other cobalt catalysed[123] benzimidazole synthesis was also reported using a cobalt complex to couple o-phenylenediamine and various alcohols. The reaction condition demonstrated was very mild and the methodology shows a wide range of substrate tolerance, however, the reaction follows an oxidative coupling pathway utilizing oxygen as a sole oxidant. Srimani and co-workers[124] developed a phosphine-free NNS-Mn catalyst (**Mn-17**) for the coupling of different o-phenylenediamines with various benzyl alcohols. This methodology is found to be attractive, for its ability to build selectively both 2-substituted and 1,2-disubstituted benzimidazole simply by fine-tuning the reaction conditions. The protocol is suitable for various benzyl alcohols having different electron donating and electron withdrawing groups. Several heteroaromatic alcohols also gave a good yield of the corresponding benzimidazoles. However aliphatic alcohols delivered poor yield. The author also provided a mechanistic study on the formation of 2-substituted and 1,2-disubstituted

benzimidazole. Out of the three possible pathways, the reaction was found to follow path **III** via the formation of bisimine intermediate (Figure 1.27).

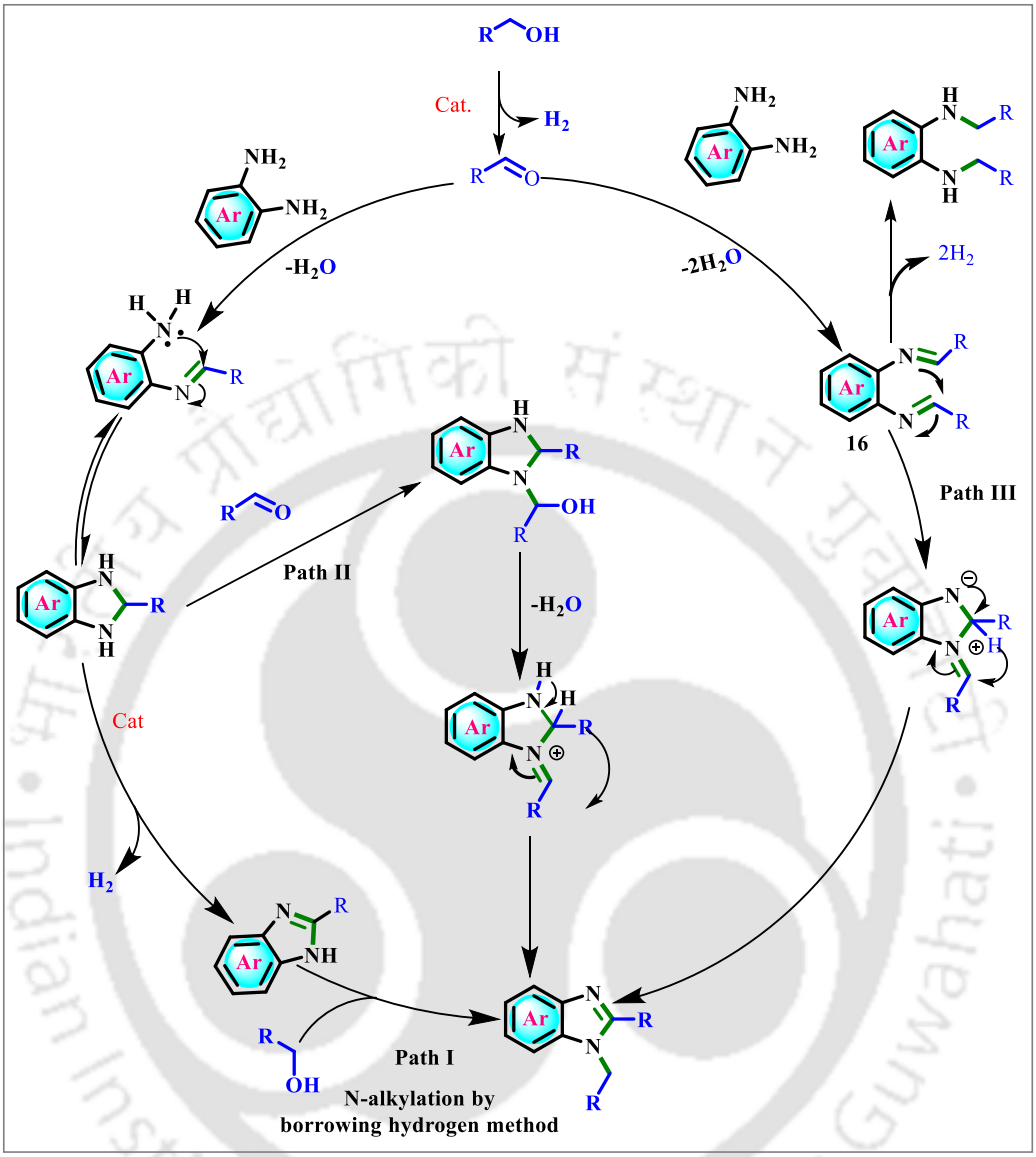


Figure 1.27. Plausible catalytic road map for selective synthesis of 2-substitued and 1,2-disubstituted benzimidazoles.

Banerjee and co-workers[125] shortly illustrated the synthesis of both 2-substitute and 1,2-disubstituted benzimidazole employing same the set of substrates using $NiCl_2$ as precatalyst in combination with 1,10-phenanthroline as a ligand. The reaction worked well with a wide range of benzyl and heteroaromatic alcohols to yield good yields of the corresponding benzimidazoles whereas for primary aliphatic alcohols the yield is low to moderate. In 2020, Adhikari and co-workers[126] introduced a molecularly well-defined nickel complex (**Ni-5**) that regulates the formation of both 2-substituted and 1, 2-disubstituted benzimidazoles via hydrogen atom transfer (HAT) mechanism. The reaction conditions used were comparatively mild where the 5 mol% of **Ni-5** in the presence of 0.5 equiv. of KO^{t}Bu in toluene at 80 ^{o}C was found sufficient to afford the

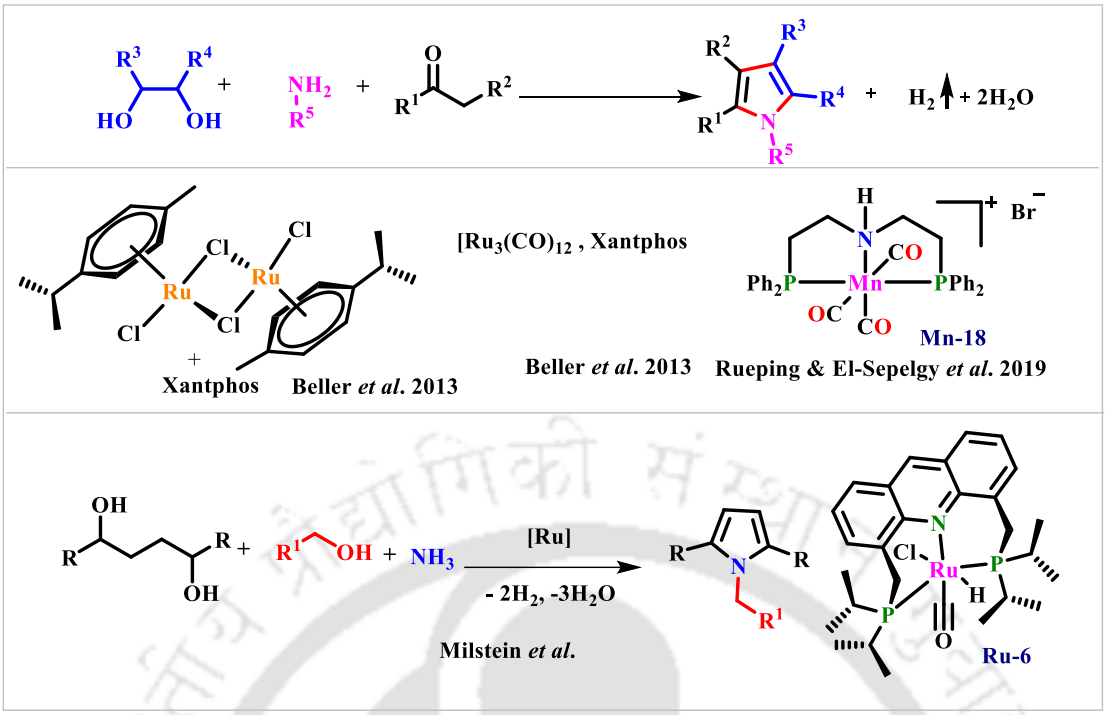
benzimidazole in good yield. Not only benzyl alcohols but also aliphatic alcohols as well as heterocyclic alcohols gave moderate to high yield of the desired benzimidazole products (5 examples). The present protocol is also applied to furnish 1,2-disubstituted benzimidazoles (6 examples). In 2020, Hong and co-workers[127] demonstrated tricarbonyl (η^4-cyclopentadienone) iron complex (**Fe-2**) catalyzed 1,2-disubstituted benzimidazole synthesis using substituted *o*-phenylenediamine (1 equiv.) and various alcohols (2.5 equiv.) in the presence of trimethyl *N*-Oxide (8 mol%) and KO^{t}Bu (1.5 equiv.) in a relatively higher temperature (150 °C). Various benzyl alcohols, naphthyl alcohol and heteroaromatic alcohols responded very well with the catalyst furnishing good to excellent yield whereas, primary aliphatic alcohols afford low yield of the desired heterocycle. Recently, Darcel and co-worker[128] applied the same iron catalyst (**Fe-2**) system, but an additional use of additives such as DDQ at very high temperature, for the synthesis of 2-substituted benzimidazoles starting from 2-nitroaniline and benzyl alcohols and only 3 examples are reported.

1.21. Multicomponent strategy:

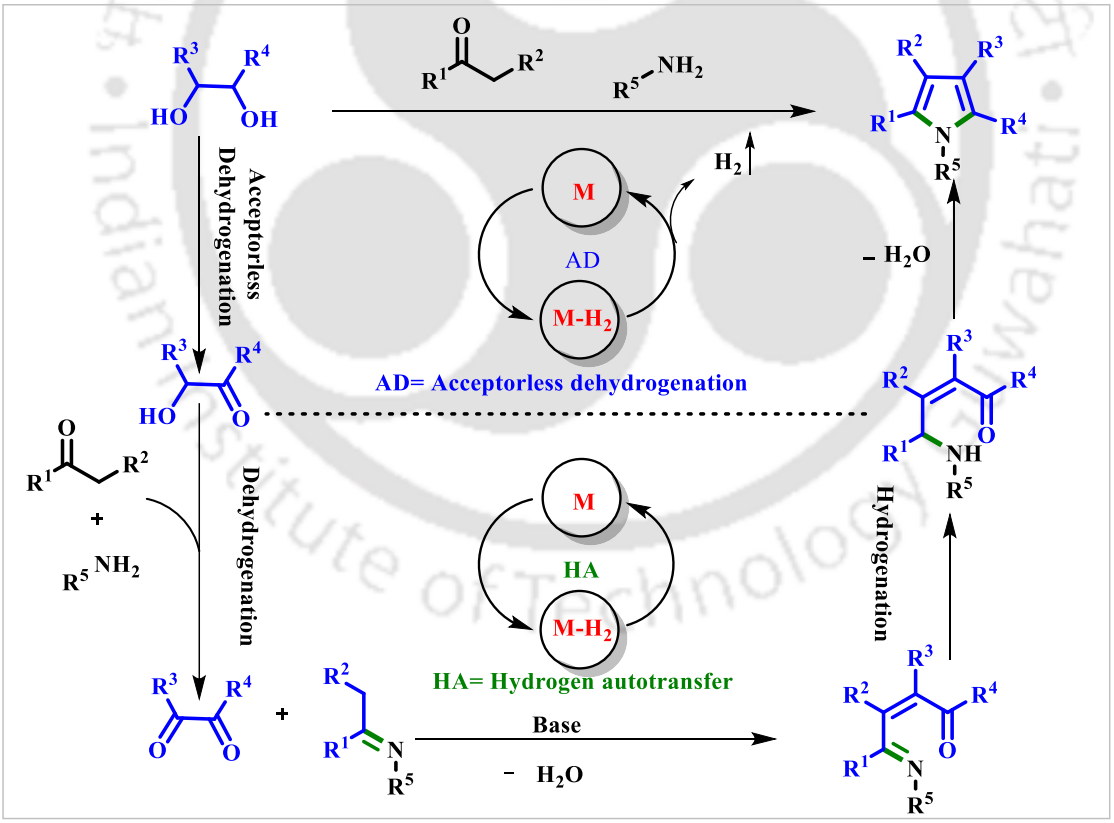
Compared to any conventional methods, multicomponent strategy offers several advantages, including simpler operations, less expensive stages, the avoidance of laborious purification procedures, increased energy efficiency, and reduced waste production.

1.21.1. Pyrrole synthesis:

Pyrrole is a crucial chemical motif in innovative functional materials, agrochemicals, and pharmaceuticals. Multicomponent coupling is one of the noteworthy strategy to synthesize pyrrole via transition metal catalysed de(hydrogenative) protocol. In 2013, the Beller group presented Ru-catalysed a three-component coupling technique for the synthesis of pyrroles.[129a] To get the highest yields of the desired pyrrole they were screened several Ru-precursors with combination of various phosphorus based ligands and out of them [Ru(*p*-cymene)$_2$Cl$_2$]$_2$/Xanthphos displayed the maximum yield of the targeted pyrrole product. Library of different functionalized pyrroles were synthesised by changing the coupling partners. Interestingly, same strategy was further improved strategy was established in the same year just only varying ruthenium precursor as precatalyst.[129b] In 2019, Rueping and El-Sepelgy[129c] introduced potential **Mn-18** catalytic protocol for three component pyrrole synthesis via AD and BH process in the presence of a catalytic amount of KO^{t}Bu. In this catalytic system, a variety of amines and vicinal diols worked well with an assortment of alkyl and aryl ketones to produce moderate to excellent yields of the target pyrroles. Computational analysis recommended that reaction probably goes via the C–H alkylation of insitu formed enamine and glyoxal. Then selective hydrogenation of enamine and condensation delivered highly substituted pyrrole. A general mechanistic path was drawn in scheme 1.29. Another challenging **Ru-6** catalysed multicomponent approach was demonstrated by Milstein group[129d] using liquid ammonia (7 bar pressure) as a nitrogen source.



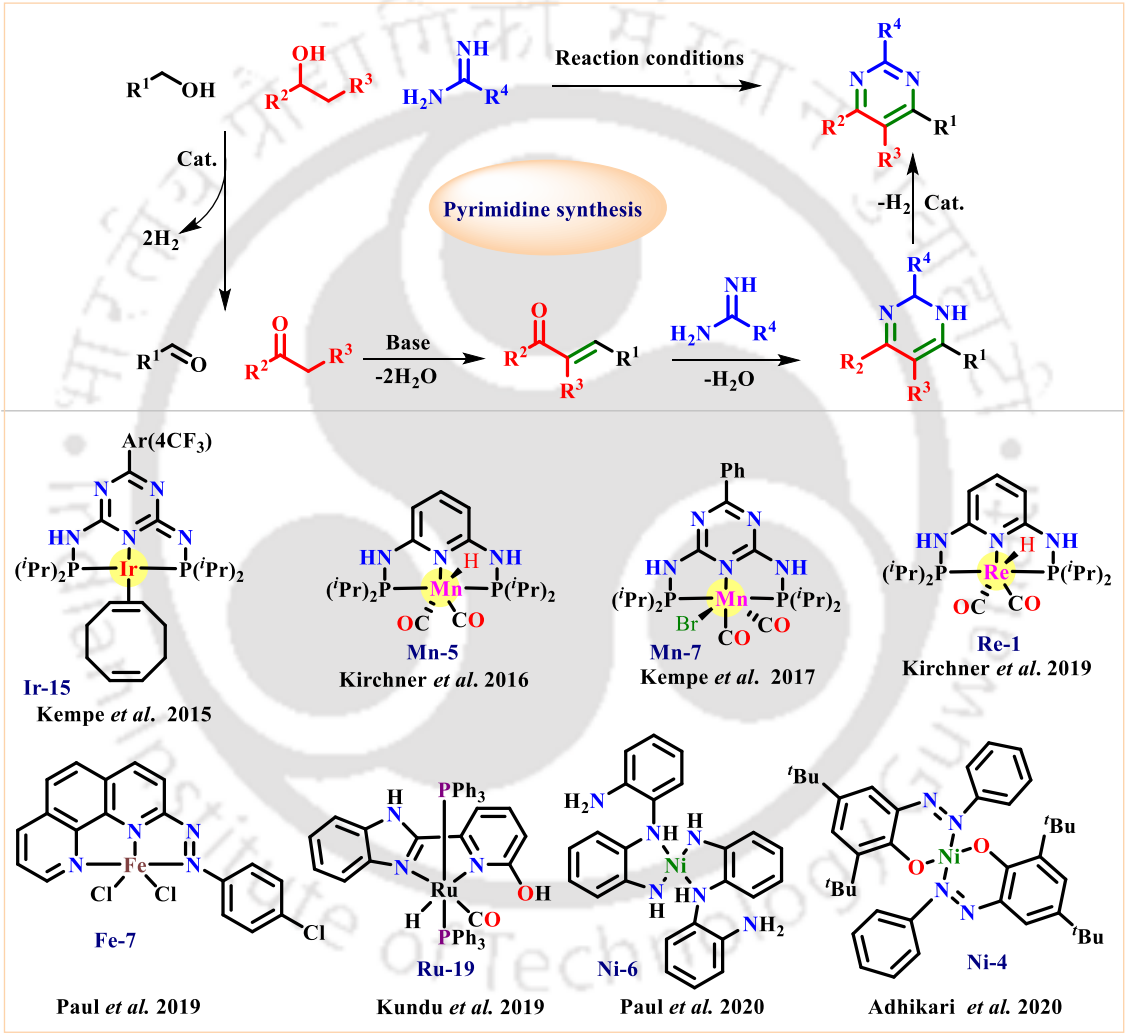
Scheme 1.28. Three component synthesis of pyrrole using various catalysts.



Scheme 1.29. General mechanistic route for multicomponent pyrrole synthesis via ADC.

1.21.2. Pyrimidine synthesis:

Over the decades, for the synthesis of pyrimidines, a variety of classical and transition metal-catalysed synthetic techniques were reported. Nevertheless, such protocols face a number of challenges, including the lack of expensive and moisture-sensitive starting materials, multi-step synthesis, and the creation of a stoichiometric amount of salt waste, which highlights the need for the creation of more environmentally friendly techniques. Kempe *et al*.[130] was the first showed that combination of primary, secondary alcohols and amidines may be used for the multi-component synthesis of pyrimidines using a transition metal catalyst.



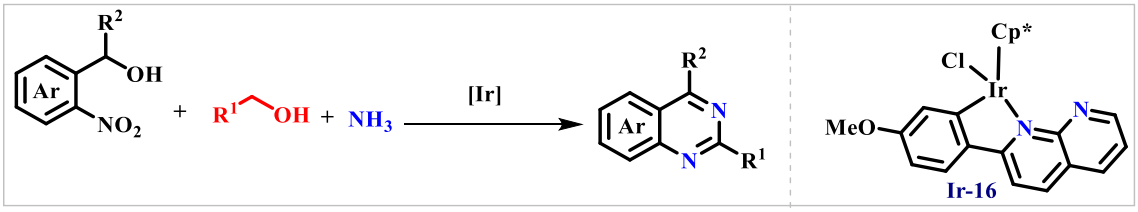
Scheme 1.30. Multicomponent pyrimidine synthesis via ADC and used various catalysts.

Using both heterogeneous and homogeneous precatalysts, Kempe, Shimizu, Kirchner, Kundu, Zhang, and others developed a comparable reaction protocol. The pyrimidine synthesis from amidine and alcohols using the acceptorless de(hydrogenative) coupling approach is illustrated (Scheme 1.30). Kempe's group[131] described a multi-component pyrimidine synthesis in 2015 employing a (PNP) **Ir-15** complex via ADC approach. Numerous primary, secondary alcohols, and amidines were successfully coupled under developed three-component reaction, producing poly-

substituted pyrimidine derivatives in good to outstanding isolated yields up to 93%. The authors also disclosed the four-component sequential strategy for the synthesis of highly substituted pyrimidine derivatives, in a single pot. Kirchner *et al*. reported a seminal work in 2016 that a (PNP)**Mn-5** catalysed a three-component coupling reaction.[132] Kempe and colleagues further revealed a similar to **Ir-15** three-components and four component coupling process employing **Mn-7** pincer complex. Similarly, Kirchner and associates also repeated same transformation to their previously developed **Mn-5** catalysed three-component coupling reaction just changing metal precursor **Mn** to **Re** in 2019. In comparison to the **Mn-5** catalysed protocol present **Re-1** catalytic protocol functions comparatively higher catalyst loading and reaction time.[134] In the present **Re-1** catalytic process the range of substrates was also restricted, only applicable for small number of aromatic substrates. Kundu and colleagues[135] recently established a three-component ADC protocol for the synthesis of pyrimidines catalysed by ruthenium bidentate complex (**Ru-19**). Authors, prepared six novel bidentate Ru-complexes to find the best precatalyst for this transformation and also performed several mechanistic studies. Herbert *et al*. have recently disclosed a same reaction in presence of **Ru-20** complex based on P^N quinoline ligand.[136] Paul and colleagues[137] described similar reaction using a redox-non innocent **Fe-6** complex. These co-workers suggested that redox-active aryl azo ligand and iron metal worked cooperatively to contribute in the dehydrogenation of alcohol. They suggested participation of single electron in the catalytic cycle, in which the oxidation state of iron centre lies between +2 and +1. From the same group Ni-non innocent ligand supported Ni-complex (**Ni-6**) was reported for same transformation.[138] Adhikari *et al*.[139] have disclosed comparatively milder reaction conditions to the previous reports for pyrimidine synthesis in presence of **Ni-5** catalyst containing redox-active azophenolate ligand framework. Their Ni-catalyst also works via one electron transfer HAT mechanism to active alcohols.

1.21.3. Multicomponent quinazolines synthesis:

In 2020 Zhang[140] first revealed multicomponent strategy for valuable quinazolines synthesis in one pot from readily available 2-nitrobenzyl alcohols with alcohols and ammonia as a one of the nitrogen source. They found that 2-(4-methoxyphenyl)-1,8-naphthyridyl ligand supported iridium complex (**Ir-16**) showed the paramount catalytic performance. The comprehensive mechanistic study suggested that non-coordinated N-arm in the ligand backbone plays an important role to accelerate the condensation of step via hydrogen bonding.

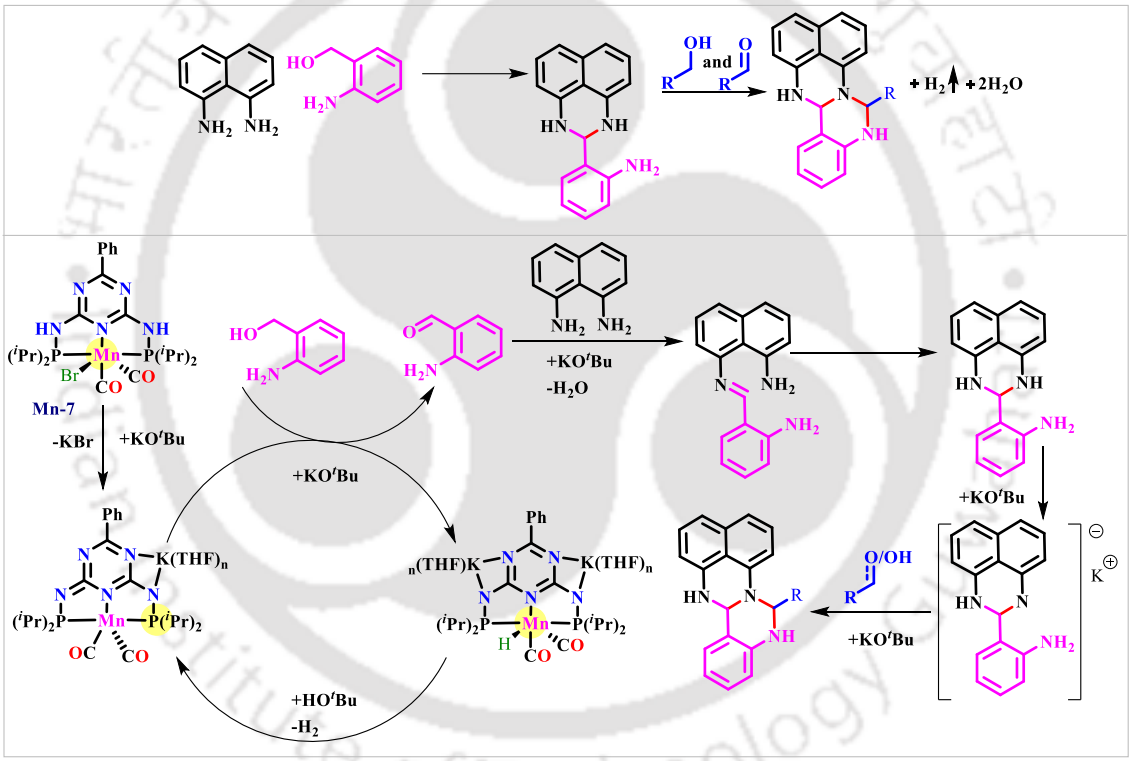


Scheme 1.31. Multicomponent quinazoline synthesis from alcohols, nitro alcohol and ammonia.

This catalytic reaction conditions applicable for broad range of substrate with good functional group tolerance.

1.21.4. Consecutive multicomponent strategy for fertigine synthesis:

In 2023 Kempe and co-workers[141] discovered new heterocyclic molecular scaffolds name as "Fertigine". The synthetic method of this scaffolds involved manganese catalysed dehydrogenation of amino alcohol, condensation and cyclisation with diamine and generates new pairs of amine functionality which reacted with dehydrogenated alcohol, aldehyde or carbonyldiimidazole, delivered targeted heterocyclic scaffolds. On the basis of their previous studied on triazine based **Mn-7** catalyst for dehydrogenation reactions and also some other control experiments for this current study, Kempe group sketched the catalytic cycle for fertigine synthesis which is highlighted in scheme **1.32**.

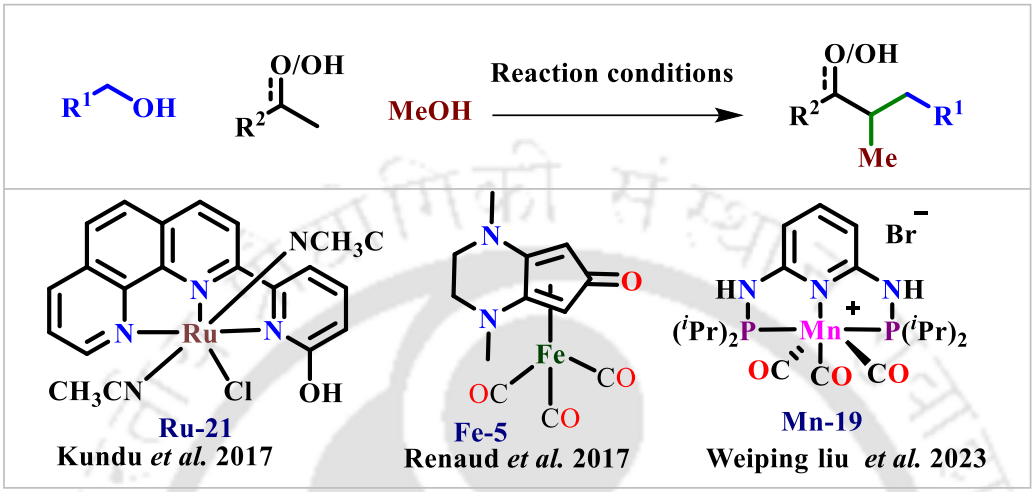


Scheme1.32. Manganese catalysed multicomponent fertigine synthesis.

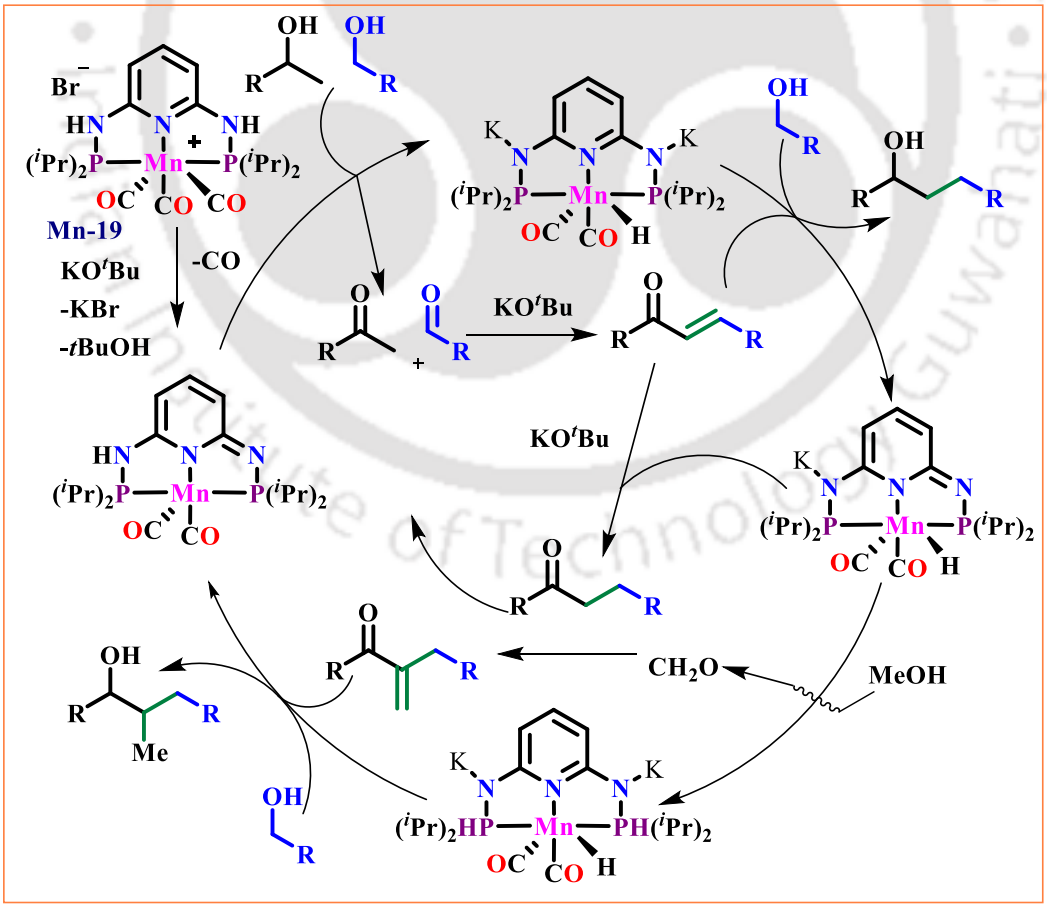
1.21.5. Utilization of methanol in tandem three-component coupling approach:

In 2017, Kundu and co-workers[142] were the first to develop the NNN-**Ru-21** complex for one pot three component *α, α*-branched ketone using ketones, primary alcohols and methanol as methylating source via BH process. The catalysis permitted the large number of primary alcohol, including three-member cyclic ketone with various primary alcohols. Deuterium scrambling experiments and theoretical analysis delineated the important participation of non-coordinated hydroxyl group on ligand backbone in this catalytic three component protocol. In the same year, Renaud[143] developed

iron Knölker-type complexes (**Fe-5**) for the same tandem transformation. Very recently three component coupling of primary, secondary alcohols and methanol employing homogeneous manganese complex (**Mn-19**) for *β, β*-methylated/alkylated secondary alcohols synthesis was reported by Liu group.[144] According to their mechanistic investigations, the final product of the process is produced by methylation of *α*-branched ketone intermediate.



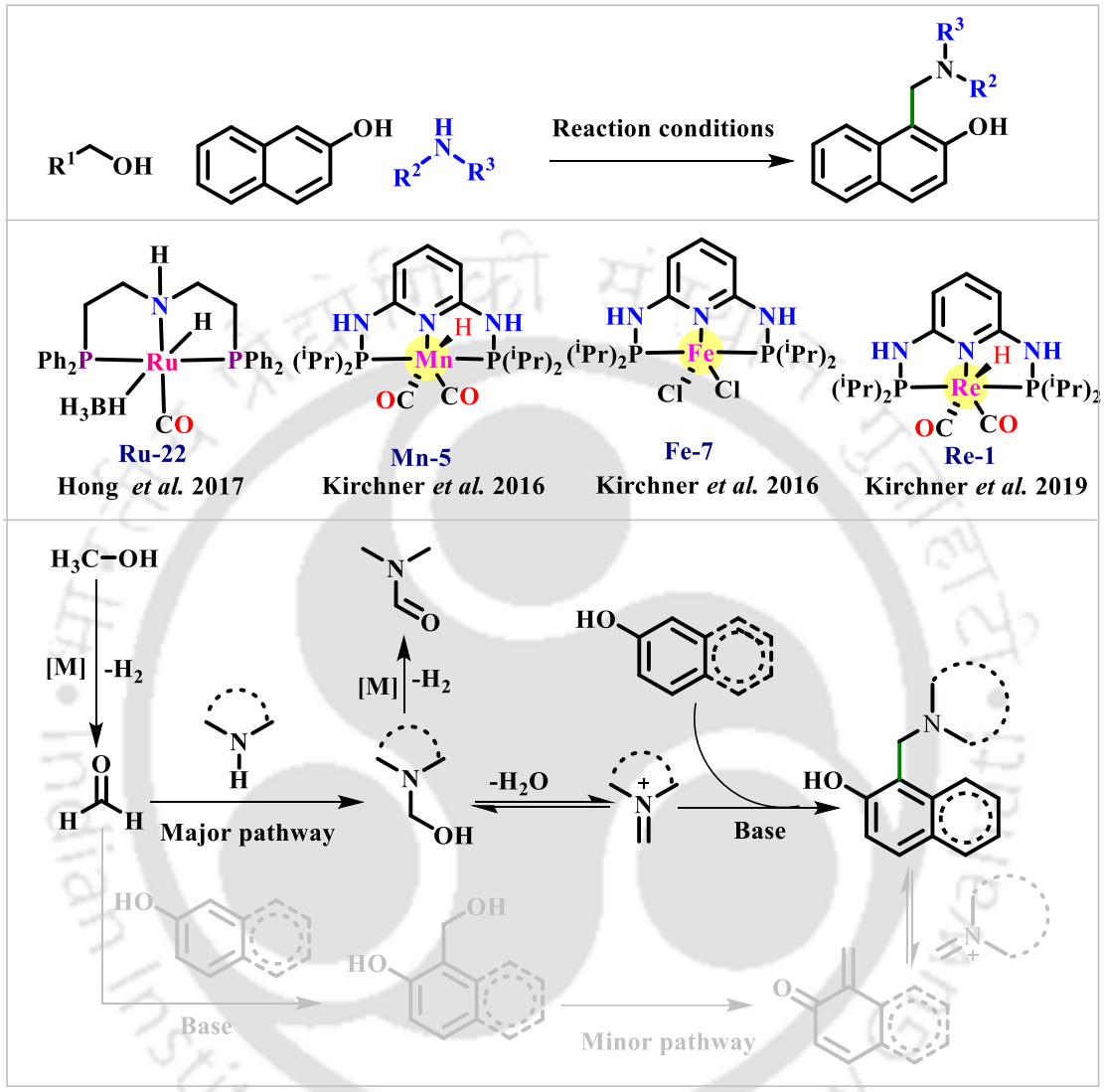
Scheme 1.33. Three components cross coupling reaction of primary, secondary and methanol.



Scheme 1.34. Manganese catalytic cycle for three components cross coupling reaction of primary, secondary and methanol.

1.21.6. Aminomethylation of aromatic compounds:

The development of three component o-aminomethylation of phenol was first reported by the Hong group employing **Ru-22** in 2017.[145]



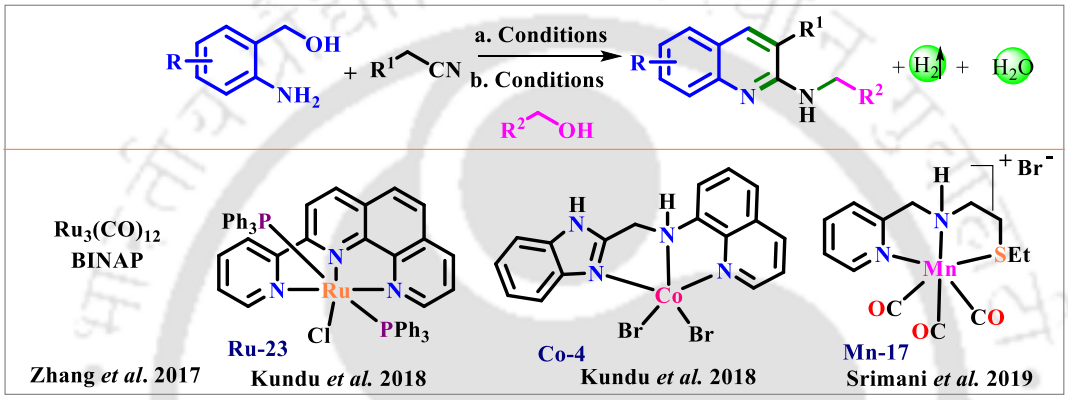
Scheme 1.35. Synthesis of aminomethylated aromatic compounds using transition metal and its general catalytic cycle.

It involves **Ru-22** catalysed dehydrogenation of methanol, as a C1 building block. Their experimental observation suggested that formamide rarely contributes to the reaction, which mostly happens through an iminium cation intermediate. Interestingly, under similar reaction conditions, when naphthol derivatives were introduced only methylated products were obtained in major amount. In the same year, improved protocol of this transformation was established by Kirchner group.[146] Under this extended **Mn-5** catalysed protocol various activated aromatic compounds, such as phenols, naphthols, indoles, pyridines, thiophenes and carbazoles different amines and MeOH as a C1 source successfully aminomethylated with up to 91% yields. When they used isoelectronic PNP-Fe(II) complex (**Fe-7**) in this reaction only methylated naphthol product was formed instead

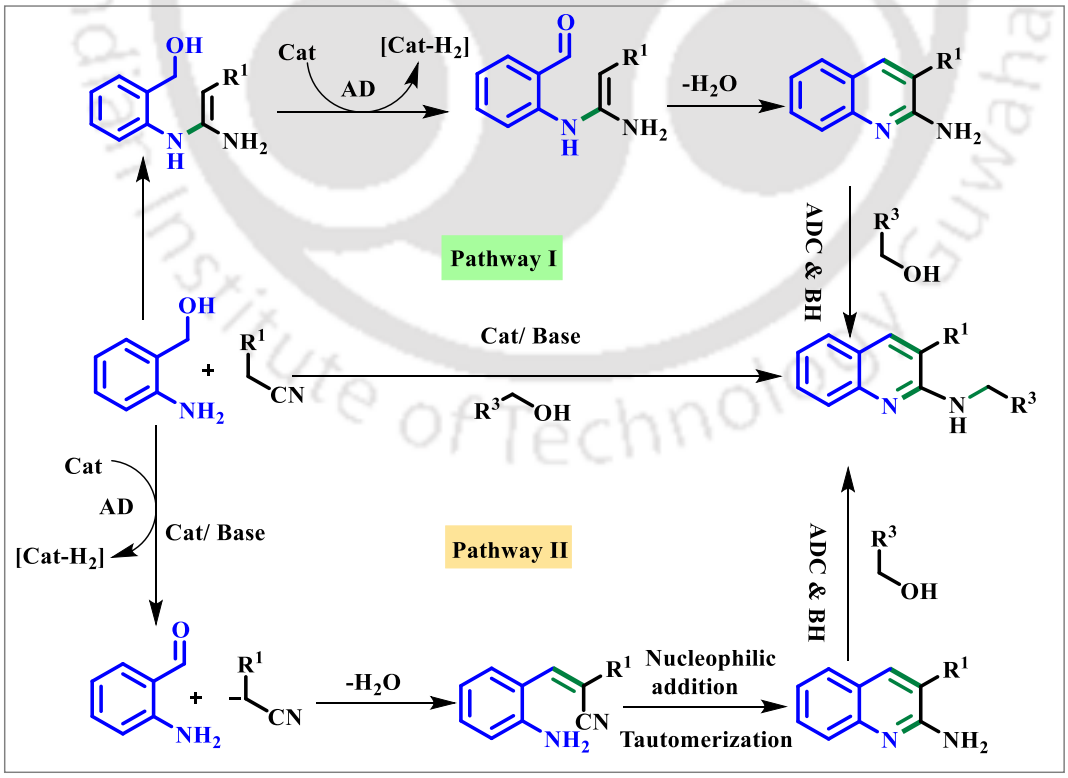
of o-aminomethylated products. In 2019 same group same study was conducted using PNP-Re(I) complex (**Re-1**).[147] Compared to isoelectronic **Mn-5** pincer catalysts, in the majority of circumstances, faster reaction times and significantly smaller catalyst loadings could be used. Since N-protected Re-complex of **Re-1** is catalytically inactive for this action, therefore, formation of amido complex via deprotonation/protonation could be the active complex for alcohol activation through an outer-sphere hydride transfer mechanism.

1.21.7. Synthesis of 2-alkylaminoquinolines:

Zhang *et al*. in 2017 first developed a one-pot consecutive/*N*-alkylation protocol towards the de(hydrogenative) construction of 2-alkylaminoquinolines.[148]



Scheme 1.36. Synthesis of 2-alkylaminoquinolines using transition metal catalysts.



Scheme 1.37. General mechanistic path of 2-alkylaminoquinolines synthesis using transition metal catalysts.

This three-component coupling reaction used a commercially available ligand (BINAP) and Ru-precursor [$Ru_3(CO)_{12}$] to efficiently combine different 2-aminoarylmethanols, alkyl nitrites, and alcohols. Their experimental observation revealed that the reaction predominantly moves via pathway-I. Kundu *et al*. described a comparable transformation in 2018 utilizing a well-defined cooperative NNN-Ru complex (**Ru-23**) based on 2-hydroxypyridine that is free of alkyl phosphine.[149] In the same year, Kundu and associates[150] presented more economical methods for 2-alkyl-aminoquinolines synthesis in presence of **Co-4** via ADC technique. First Mn-catalysed protocol for the same was disclosed by Srimani group in 2019. Their previously developed **Mn-17** is used for this reaction, the reaction commences with 2-amino benzyl alcohol, alkyl nitrile and after 36 h they added primary alcohol, and 5 mol% **Mn-17**.[151]

1.22. Concluding remarks:

The above discussion displays that transition metals based acceptorless de(hydrogenative) coupling technology has a tremendous contribution in chemistry for developing green, environmentally clean and atom economical methodology. The main feature of this catalysis is mimicking the biological bond activation mechanism i.e.; bond activation through cooperation between the metal and ligand which can be accomplished by ligand protonation/deprotonation, aromatization-dearomatization, hemilability or, in rare instances, redox-active ligands. The metal–ligand bifunctionality or cooperativity controls the different kinetic and thermodynamic parameters during the bond activation process. Therefore, judicially design of ligand backbones offers a prospect to regulate the selectivity and reactivity provided by the catalysts. This area of research was dominated by transition metal catalysts containing sophisticated phosphine based ligands backbone. Despite the fact that phosphine-based ligands have made great progress, they are less cost-effective because of the difficult preparation process, need of expensive equipment and high moisture sensitivity. Therefore, replacement of phosphine based ligands framework by phosphine free arms such as NNS, NNN, NNO and CNC ligands and study the reactivities of corresponding catalysts remains in the budding stage, especially in non-precious 3d-metals. Considering the abundance of Mn-metal in earth crust in this area of Mn-catalysed de(hydrogenative) reactions started since 2016. Furthermore, since manganese is the element that underlies the different spin and oxidation states, creating a variety of manganese catalysts based on distinct oxidation states would lead to the innovation of distinct catalytic species with a range of coordination patterns, which could impart unique bond activation modes. It has been observed that the same set of starting materials can produce distinct products depending on the catalyst design and experimental reaction conditions. Thus, developing Mn-catalysts that are stable in both air and moisture and investigating their catalytic reactivity would be interesting and beneficial. This present thesis explores the selective catalytic activity of many new bifunctional NNS, NNN, and NNO Mn-catalysts in a various control de(hydrogenative) transformations.

1.23. References:

[1] J. Khusnutdinova, D. Milstein, *Angew. Chem. Int. Ed*. **2015**, *54*, 12236 – 12273.

[2] L. Alig, M. Fritz, S. Schneider, *Chem. Rev*. **2019**, *119*, 2681 – 2751.

[3] I. Moritani, Y. Fujiwara, *Tetrahedron Lett*. **1967**, *8*, 1119 – 1122.

[4] a) T. Ohkuma, H. Ooka, S. Hashiguchi, T. Ikariya, R. Noyori, *J. Am. Chem. Soc.* **1995**, *117*, 2675 – 2676. a) P. A. Dub, Orcid, J. C. Gordon, *ACS Catal*. **2017**, 7, 6635–6655; c) H. Shimizu, I. Nagasaki, Matsumura, N. Sayo, T. Saito, *Acc. Chem. Res.* **2007**, *40*, 1385 - 1393

[5] a) C. Gunanathan, D. Milstein, *Acc. Chem. Res*. **2011**, *44*, 588 – 602. b) S. Kuwata, T. Ikariya, *Chem. Commun*. **2014**, *50*, 14290 – 14300. c) H. Li, T. Gonc¸alves, D. Lupp, K.-W. Huang, *ACS Catal*. **2019**, *9*, 1619 – 1629.

[6] C. Gunanathan, D. Milstein, *Science* **2013**, *341*, 249.

[7] M. G. Edwards, R. F. R. Jazzar, B. M. Paine, D. J. Shermer, M. K. Whittlesey, J. M. J. Williams, D. D. Edney, *Chem. Commun*. **2004**, 90 – 91.

[8] A. Corma, J. Navas, M. J. Sabater, *Chem. Rev.* **2018**, *118*, 1410–1459; b) M. R. Elsby, R. T. Baker, *Chem. Soc. Rev.* **2020**, *49*, 8933–8987.

[9] K. Das, S. Waiba, A. Jana, B. Maji, *Chem. Soc. Rev*. **2022**, *51*, 4386–4464; b) T. Irrgang, R. Kempe, *Chem. Rev*. **2019**, *119*, 2524–2549; c) M. Maji, D. Panja, I. Borthakur, S. Kundu, *Org. Chem. Front*. **2021**, *8*, 2673–2709; d) A. Mondal, R. Sharma, D. Pal, D. Srimani, *Eur. J. Org. Chem*. **2021**, 3690–3720; e) M. Subaramanian, G. Sivakumar, E. Balaraman, *Org. Biomol. Chem*. **2021**, *19*, 4213–4227.

[10] and [11] references cited in-A. E. Filkale, M. K. Gangwar, I. K. Pandeyc, R. Butcher, *New J. Chem*. **2023**, *47*, 19657–19671.

[12] M. A. Ogliaruso, J. F. Wolfe, *John Wiley & Sons Ltd:* Hoboken, NJ, **1991**; p-684.

[13] S.-I. Murahashi, T. Naota, K. Ito, Y. Maeda, H. Taki, *J. Org. Chem*. **1987**, *52*, 4319.

[14] J. Zhang, G. Leitus, Y. Ben-David, D. Milstein, *J. Am. Chem. Soc.* **2005**, *127*, 10840 – 10841.

[15] D. Srimani, E. Balaraman, B. Gnanaprakasam, Y. Ben-David, D. Milstein, *Adv. Synth. Catal.* **2012**, *354*, 2403 – 2406.

[16] D. H. Nguyen, X. Trivelli, F. Capet, J.-F. Paul, F. Dumeignil, R. M. Gauvin, *ACS Catal*. **2017**, *7*, 2022 – 2032.

[17] U. K. Das, Y. Ben-David, G. Leitus, Y. Diskin-Posner, D. Milstein, *ACS Catal*. **2019**, *9*, 479–484.

[18] K. Paudel, B. Pandey, S. Xu, D. K. Taylor, D. L. Tyer, C. L. Torres, S. Gallagher, L. Kong, K. Ding, *Org. Lett.* **2018**, *20*, 4478 – 4481.

[19] Pillai, U. R.; Dessie, E.-S. *Appl. Catal*. *A* **2003**, *245*, 103.

[20] N. M. Leonard, M. C. Oswald, D. A. Freiberg, B. A. Nattier, R. C. Smith, R. S. Mohan, *J. Org. Chem.* **2002**, *67*, 5202 – 5207.

[21] S.-I. Murahashi, T. Naota, K. Ito, Y. Maeda, H. Taki, *J. Org. Chem.* **1987**, *52*, 4319 – 4327.

[22] A. L. Suing, C. R. Dewan, P. S. White, H. H. Thorp, *Inorg. Chem.* **2000**, *39*, 6080–6085.

[23] C. Gunanathan, L. J. W. Shimon, D. Milstein, *J. Am. Chem. Soc*. **2009**, *131*, 3146 – 3147.

[24] – [28] references are cited there in- B. Sardar, N. Biswas, D. Srimani, *Organometallics* **2023**, 42, 55−61.

[29] – [32] all references cited there in reference- [33] D. R. Pradhan, S. Pattanaik, J. Kishore, C. Gunanathan, *Org. Lett.* **2020**, *22*, 1852 – 1857.

[34] S. A. Lawrence *Amines: Synthesis Properties and Applications*, Cambridge University Press, Cambridge, **2004.**

[35] C. F. Winans, H. Adkins, *J. Am. Chem. Soc.* **1932**, *54*, 306 – 312.

[36]- [41] all references are cited in T. Irrgang and R. Kempe, *Chem. Rev*. **2019**, *119*, 2524−2549.

[42] R. Kawahara, K.-i. Fujita, R. Yamaguchi, *J. Am. Chem. Soc*. **2010**, *132*, 15108 – 15111.

[43] T. Yan, B. L. Feringa, K. Barta, *ACS Catal.* **2016**, *6*, 381 – 388.

[44] T. M. Trost, *Science* **1991**, *254*, 1468 – 1471.

[45] – [50] all references are cited there in [50] H. Chai, K. Yu, B. Liu, W. Tan, G. Zhang, *Organometallics* **2020**, *39*, 217– 226.

[51] C. Gunanathan, Y. Ben-David, D. Milstein, *Science* ***2007***, *317*, 790.

[52] L. U. Nordstrøm, H. Vogt, R. Madsen, *J. Am. Chem. Soc.* **2008**, *130*, 17672 – 17673.

[53] A. Kumar, N. Espinosa Jalapa, G. Leitus, Y. Diskin Posner, L. Avram, D. Milstein, *Angew. Chem. Int. Ed.* **2017**, *56*, 14992 – 14996; *Angew. Chem.* **2017**, *129*, 15188 – 15192.

[54] P. Daw, A. Kumar, N. A. Espinosa-Jalapa, Y. Ben-David, D. Milstein, *J. Am. Chem. Soc.* **2019**, *141*, 12202 – 12206.

[55] – [57] references are cited there in [58] I. Borthakur, M. Maji, A. Joshi, S. Kundu, *J. Org. Chem*. **2022**, *87*, 628–643.

[59] a) R. Martínez, D. J. Ramón and M. Yus, *Tetrahedron*, **2006**, *62*, 8988–9001; b) S. S. Gawali, B. K. Pandia, C. Gunanathan, *Org. Lett*. **2019**, *21*, 3842−3847.

[60] & [61] references cited there in- R. Sharma, A. Samanta, B. Sardar, M. Roy, D. Srimani, *Org. Biomol. Chem*. **2022**, *20*, 7998–8030.

[62] S. Elangovan, J.-B. Sortais, M. Beller, C. Darcel, *Angew. Chem. Int. Ed*. **2015**, *54*, 14483 – 14486; *Angew. Chem*. **2015**, *127*, 14691 – 14694.

[63] M. PeÇa-Llpez, P. Piehl, S. Elangovan, H. Neumann, M. Beller, *Angew. Chem. Int. Ed*. **2016**, *55*, 14967 – 14971; *Angew. Chem*. **2016**, *128*, 15191 – 15195.

[64] W. Zuo, A. J. Lough, Y. F. Li, R. H. Morris, *Science*, **2013**, *342*, 1080 – 1083.

[65] J. Das, K. Singh, M. Vellakkaran, D. Banerjee, *Org. Lett*. **2018**, *20*, 5587–5591.

[66] all references cited there in T. Irrgang and R. Kempe, *Chem. Rev*. **2019**, *119*, 2524−2549.

[67] S. Genc, S. Gülcemal, S. Günnaz, B. Çetinkaya, D. Gülcemal, *J. Org. Chem*. **2020**, *85*, 9139−9152.

[68] a) S.Thiyagarajan, C. Gunanathan, *J. Am. Chem. Soc*. **2019**, *141*, 3822−3827; b) D. Bhattacharyya, B. K. Sarmah, S. Nandi, H. K. Srivastava, A. Das, *Org. Lett*. **2021**, *23*, 869−875.

[69] R. Grigg, T. R. B. Mitchell, S. Sutthivaiyakit, N. Tongpenyai, *Tetrahedron Lett*. **1981**, *22*, 4107-4110.

[70] a) C. Lçfberg, R. Grigg, M. A. Whittaker, A. Keep, A. Derrick, *J. Org. Chem*. **2006**, *71*, 8023–8027; b) M. Morita, Y. Obora, Y. Ishii, *Chem. Commun*. **2007**, 2850- 2852; c) T. Sawaguchi, Y. Obora, *Chem. Lett*. **2011**, *40*, 1055 – 1057; d) M. L. Buil, M. A. Esteruelas, J. Herrero, S. Izquierdo, I. M. Pastor, M. Yus, *ACS Catal*. **2013**, *3*, 2072 – 2075; e) S. Thiyagarajan, C. Gunanathan, *ACS Catal*. **2017**, *7*, 5483– 5490.

[71]- [77] all references are cited there in [78] S. Panda, R. Saha, S. Sethi, R. Ghosh, B. Bagh, *J. Org. Chem*. **2020**, *85*, 15610–15621. [79] V. Yadav, V. G. Landge, M. Subaramanian, E. Balaraman, *ACS Catal*. **2020**, *10*, 947–954.

[80] P. Chakraborty, N. Garg, E. Manoury, R. Poli, B. Sundararaju, *ACS Catal*. **2020**, *10*, 8023–8031.

[81] J. Li, Y. Liu, W. Tang, D. Xue, C. Li, J. Xiao, C. Wang, *Chem. Eur. J*. **2017**, *23*, 14445 – 14449.

[82] F. Li, X. Y. Zou, N. N. Wang, *Adv. Synth. Catal*. **2015**, *357*, 1405 – 1415.

[83] S. P. Midya, M. Subaramanian, R. Babu, V. Yadav, E. Balaraman, *J. Org. Chem*. **2021**, *86*, 7552–7562.

[84] B. Blank, R. Kempe, *J. Am. Chem. Soc*. **2010**, *132*, 924.

[85] a) J. Org. Chem. 2012, 77, 9429; b) Y. Obora, S. Ogawa, N. Yamamoto, *J. Org. Chem*. **2012**, *77*, 9429–9433; c) Y. Nakamura, A. Azuma, S. Kato, Y. Oe, T. Ohta, *Chem. Lett.* **2019**, *48*, 1192–1200; d) M. Onoda, K.-I. Fujita, *Org. Lett*. **2020**, *22*, 7295–7299.

[86] all references cited there in-T. Irrgang and R. Kempe, *Chem. Rev*. **2019**, *119*, 2524−2549.

[87] M. K. Barman, S. Waiba, B. Maji, *Angew. Chem., Int. Ed*. **2018**, 57, 9126–9130.

[88] G. Zhang, T. Irrgang, T. Dietel, F. Kallmeier, R. Kempe, *Angew. Chem., Int. Ed*. **2018**, *57*, 9131–9135.

[89] A. Jana, A, Kumar, B. Maji, *Chem. Commun.* **2021**, *57*, 3026–3029.

[90] – [96] all references are cited in [97] L. Lu, J. Luo, D. Milstein, *ACS Catal*, **2023**, *13*, 5949-5954.

[98] – [103] all references are cited in- [104] V. Yadav, E. Balaraman, S. B. Mahaske, *Adv. Synth. Catal*. **2021**, *363*, 4430–4439.

[105] – [107] all references are cited there in- [108] M. Chakraborty, D. Sengupta, T. Saha, S. Goswami, *J. Org. Chem*. **2018**, *83*, 7771−7778.

[109] J. Bauer, S. Chakraborty, D. Milstein, *ACS Catal*. **2017**, *7*, 4462–4466.

[110] U. K. Das, S. Chakraborty, Y. Diskin-Posner, D. Milstein, *Angew. Chem. Int. Ed*. **2018**, *57*, 13444–13448.

[111] L. M. Azofra, A. Poater, *Dalton Trans*. **2019**, *48*, 14122–14127.

[112] J. Kishore, S. Thiyagarajan, C. Gunanathan, *Chem. Commun*. **2019**, *55*, 4542–4545.

[113] B. Gnanaprakasam, E. Balaraman, Y. Ben-David, D. Milstein, *Angew. Chem. Int. Ed*. **2011**, *50*, 12240–12244; *Angew. Chem*. **2011**, *123*, 12448– 12452.

[114] P. Daw, A. Kumar, N. A. Espinosa-Jalapa, Y. Diskin-Posner, Y. Ben-David, D. Milstein, *ACS Catal*. **2018**, *8*, 7734–7741.

[115] S. P. Midya, V. G. Landge, M. K. Sahoo, J. Rana, E. Balaraman, *Chem. Commun*. **2018**, *54*, 90–93.

[116] – [128] All references for substituted benzimidazole synthesis are cited there in-[9d] reference.

[129] a) M. Zhang, X. Fang, H. Neumann, M. Beller, *J. Am. Chem. Soc*. **2013**, *135*, 11384–11388; b) M. Zhang, H. Neumann, M. Beller, *Angew. Chem. Int. Ed*. **2013**, *52*, 597–601; *Angew. Chem*. **2013**, *125*, 625–629; c) J. C. Borghs, L. M. Azofra, T. Biberger, O. Linnenberg, L. Cavallo, M. Rueping, O. El-Sepelgy, *ChemSusChem*, **2019**,*12*, 3083–3088; d) P. Daw, Y. Ben-David, D. Milstein, *J. Am. Chem. Soc*. **2018**, *140*, 11931– 11934.

[130] – [139] all references are cited there in-reference [9c]

[140] Z. Tan, Z. Fu, J. Yang, Y. Liang, H. Jiang, M. Zhang, *iScience* **2020**, *23*, 101003.

[141] R. Fertig, F. L. -Künstler, T. Irrgang, R. Kempe, *Nat. Commun*. **2023**, *14*, 5.

[142] K. Chakrabarti, M. Maji, D. Panja, B. Paul, S. Shee, G. K. Das, S. Kundu, *Org. Lett*. **2017**, *19*, 4750–475.

[143] L. Bettoni, C. Seck, M. D. Mbaye, S. Gaillard, J.-L. Renaud, *Org. Lett*. **2019**, *21*, 3057–306.

[144] J. Tang, J. He, S. Y. Zhao, W. Liu, *Angew. Chem. Int. Ed*. **2023**, *62*, e202215882.

[145] Kim, S.; Hong, S. H. *Adv. Synth. Catal*. **2017**, 359, 798−810.

[146] M. Mastalir, E. Pittenauer, G. Allmaier, K. Kirchner, *J. Am. Chem. Soc*. **2017**, *139*, 8812 – 8815.

[147] M. Mastalir, M. Glatz, E. Pittenauer, G. Allmaier, K. Kirchner, *Org. Lett*. **2019**, *21*, 1116–1120.

[148] W. Lv, B. Xiong, H. Jiang, M. Zhang, *Adv. Synth. Catal*. **2017**, *359*, 1202–1207.

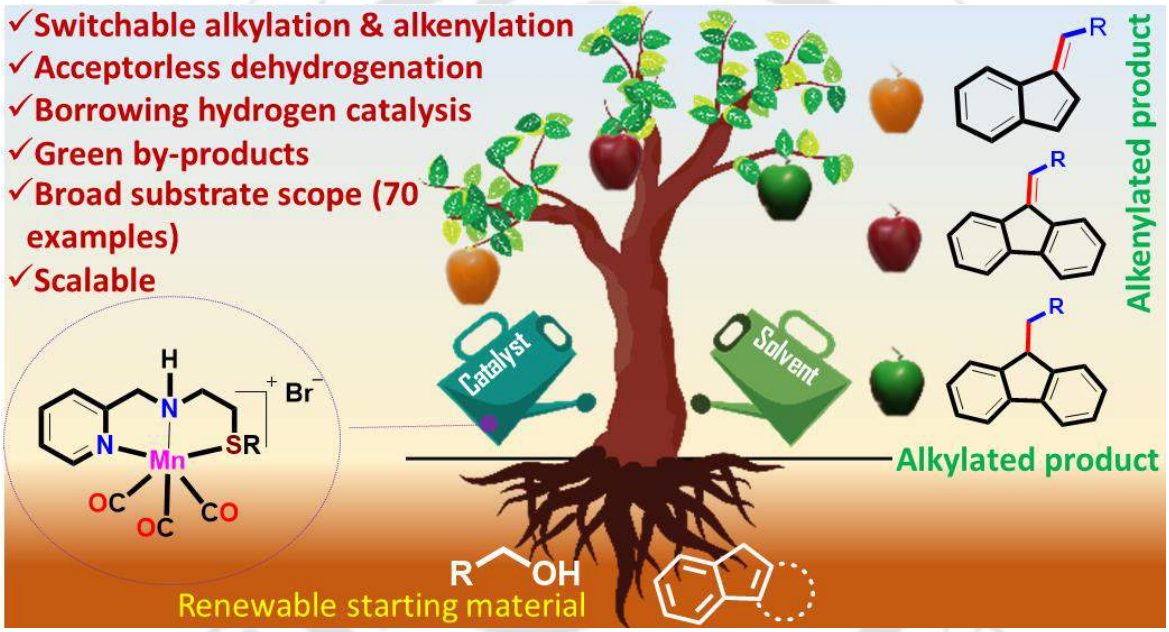
[149] M. Maji, K. Chakrabarti, B. Paul, B. C. Roy, S. Kundu, *Adv. Synth. Catal*. **2018**, *360*, 722–729.

[150] S. Shee, K. Ganguli, K. Jana, S. Kundu, *Chem. Commun*. **2018**, *54*, 6883 – 6886.

[151] K. Das, A. Mondal, D. Srimani, *Chem. Commun*. **2018**, *54*, 10582–10585.

CHAPTER 2

NNS-Mn(I) Catalysed Switchable C-Alkylation/Alkenylation of Fluorenes and Indene with Alcohols



A. Mondal, R. Sharma, D. Pal, D. Srimani, *Chem. Commun.* **2021**, *57*, 10363-10366.

2.1. Introduction:

From eco-friendly and cost-effective perspective, the development of new catalytic strategy for carbon-carbon (C−C) bond formation by avoiding prefunctionalized alkylating agents and waste free manner is highly desirable in synthetic chemistry. In this regard, transition metal catalysed acceptorless dehydrogenation and borrowing hydrogen catalysis has gained a tremendous attention from past few decades.[1] As, H_2 and water are the only by product formed in this process. Rare noble metals are extensively used to perform such processes.[2] In homogeneous catalysis where reusability is a vital issue, the replacement of noble metals by earth abundant transition metals is highly desirable. Therefore, the last few years witnessed an exponential growth in catalysis by earth-abundant transition metals.[3]

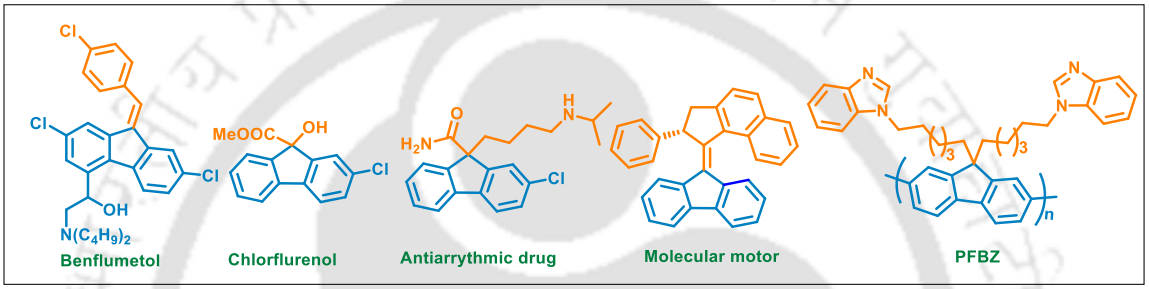
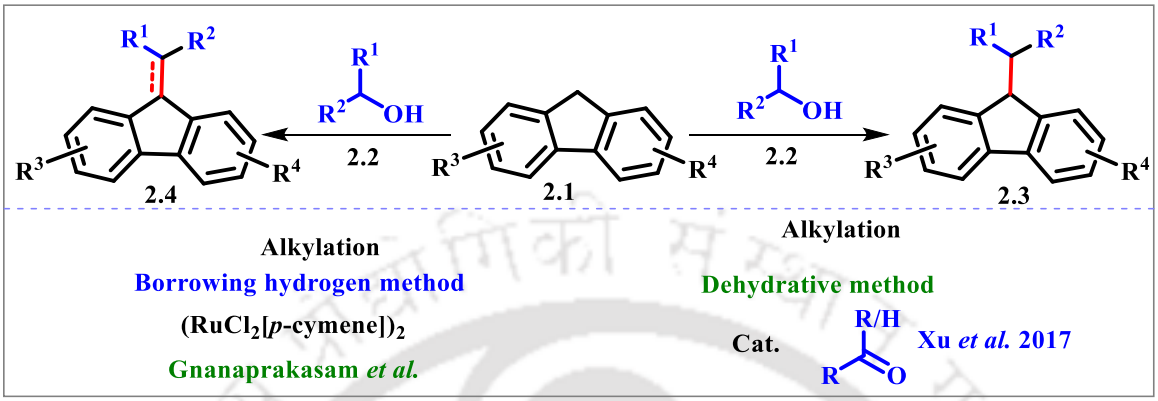


Figure 2.1. Important molecular scaffolds of functionalized fluorene.

Particularly, the use of Mn-complexes in dehydrogenative transformations became prominent after 2016. Mn-complexes have recently been used for the catalytic *α*-alkylation of ketones[4a, c,d] esters 7b,c amides[4b,c] and nitriles.[5] Of late, Mn-catalysed selective C-alkylation and alkenylation of methyl-substituted N-heteroarenes with alcohol have been described. In 2018, the group of Kempe[6] and Maji[7a] independently demonstrated the first Mn-catalysed olefination methyl-substituted *N*-heteroarenes. Subsequently, in 2021, Maji[7b] and co-workers described C-alkylation of methyl *N*-heteroarenes using phosphine-based Mn-complex. But weakly acidic methylene C-H bonds of carbocycles like fluorene and indene functionalization is remains unexplored using this sustainable strategy. Moreover, the alkylated products of fluorene and indene have profound applications in pharmaceutical and material science.[8] These are also used as photoelectric materials, semiconducting materials and solar cells.[9] Classically these type of compounds can be made by using excess amount of alkyl halides in the presence of stoichiometric amount of strong bases[10] which generates stoichiometric amount of waste. Thus, the dehydrogenative functionalization of these structural motifs has various advantages.

2.2. Literature survey: In 2017, Xu group and co-workers reported aldehyde and ketone catalysed alkylation of *9H*-fluorene via dehydrative strategy where CsOH was used as a base, and the reaction was catalysed by aldehyde and ketone[11a] (Scheme 2.1.). Very recently, commercially

available [Ru(*p*-cymene)Cl_2]$_2$ complex catalysed another an elegant method for C(sp^3)-H functionalization of fluorene was established by Gnanaprakasam *et al*. via borrowing hydrogen strategy. Various aromatic, aliphatic alcohols have been explored employing their developed protocol.[11b]



Scheme 2.1. Functionalization of fluorene employing alcohol.

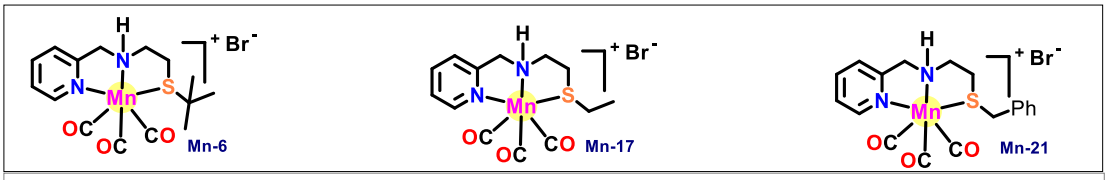
The literature reports suggest that the de(hydrogenative) functionalization of carbocycles is in a nascent stage and the utilization of earth-abundant transition metal for this process is unknown. So using 3d-transition metal catalyst for selective C-alkylation and olefination of fluorenes and related carbocycles using alcohols would be interesting.

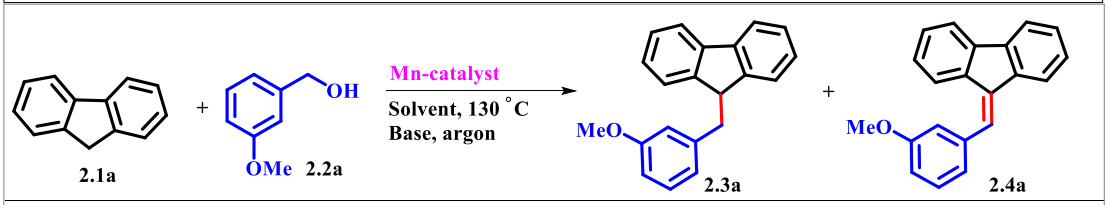
2.3. Present work: Herein, the catalytic applicability of various well-defined NNS-Mn(I) complexes were explored in selective *C*-alkylation and olefination of fluorene, and indene with alcohols. Various substrates including benzylic, heteroaromatic, and aliphatic primary and secondary alcohols are employed as alkylating agents. Mechanistic investigations and a kinetic study underpin the involvement of the olefinated intermediate to furnish the alkylated product.

2.3.1. Results and discussion:

Table 2.3.1.1: Reaction optimization for selective functionalization of fluorenes[a,b]

First, the reaction was optimized by thoroughly studying the reaction fluorene (**2.1a**) and 3-methoxybenzyl alcohol (**2.2a**) as model substrates. When, 3-methoxybenzyl alcohol, **2.2a** (0.5 mmol) and fluorene, **2.1a** (0.5 mmol) was reacted at 130 °C in toluene, under argon atmosphere in the presence of 5 mol% **Mn-6** and 0.5 mmol ^{t}BuOK, 50% yield of desired alkylated product (**2.3a**) was isolated after 24 h (Table 2.3.1.1, entry 1). Pleasingly, the yield of **2.3a** was further improved (98%) simply by increasing the fluorene and alcohol ratio to1:2 (Table 2.3.1.1, entry 4). The solvents such as xylene, ^{t}AmOH and dioxane were found inferior compared to toluene in this reaction (Table 2.3.1.1, entries 5-7).





Entry	Cat	Base (mmol)	Solvent (ml)	Time (h)	Fluorene : Alcohol (mmol)	% Yield [b] 2.3a	2.4a
1	1	^{t}BuOK (0.5)	Toluene(2)	24	0.5 : 0.5	50	Trace
2	1	^{t}BuOK(0.5)	Toluene(2)	36	0.5 : 0.5	51	Trace
3	1	^{t}BuOK(0.5)	Toluene(2)	24	0.5 : 0.75	65	--
4	1	^{t}BuOK(0.5)	Toluene(2)	24	0.5 : 1.0	98	--
5	1	^{t}BuOK(0.5)	Xylene(2)	24	0.5 : 1.0	52	Trace
6	1	^{t}BuOK (0.5)	^{t}AmOH(2)	24	0.5 : 1.0	12	--
7	1	^{t}BuOK (0.5)	Dioxane(2)	24	0.5 : 1.0	Trace	--
8	1	Na_2CO_3(0.5)	Toluene(2)	24	0.5 : 1.0	--	--
9	1	K_2CO_3(0.5)	Toluene(2)	24	0.5 : 1.0	--	--
10	1	NaOH(0.5)	Toluene(2)	24	0.5 : 1.0	10	--
11	1	KOH (0.5)	Toluene(2)	24	0.5 : 1.0	10	--
12	1	$CsOH.H_2O$(0.5)	Toluene(2)	24	0.5 : 1.0	15	Trace
13	1	^{t}BuOK (0.5)	Neat	24	0.5 : 1.0	40	--
14	1	^{t}BuOK (0.25)	Toluene(2)	24	0.5 : 1.0	8	78
15	1	^{t}BuOK (0.15)	Toluene(2)	24	0.5 : 1.0	--	48
16	1	^{t}BuOK (0.25)	Toluene(2)	24	0.5 : 0.55	--	83
17	1	^{t}BuOK (0.25)	Toluene(2)	24	0.5 : 0.5	--	78
18	--	^{t}BuOK (0.25)	Toluene(2)	24	0.5 : 0.55	nr	nr
19	1	---	Toluene(2)	24	0.5 : 1.0	Trace	--
20	2	^{t}BuOK (0.5)	Toluene(2)	24	0.5 : 1.0	98	--
21	3	^{t}BuOK (0.5)	Toluene(2)	24	0.5 : 1.0	95	--
22[c]	1	^{t}BuOK (0.5)	Toluene(2)	24	0.5 : 1.0	60	--
23[d]	1	^{t}BuOK (0.5)	Toluene(2)	24	0.5 : 1.0	75	--
24	$MnBr(CO_5)$	^{t}BuOK (0.5)	Toluene(2)	24	0.5 : 1.0	20	Trace

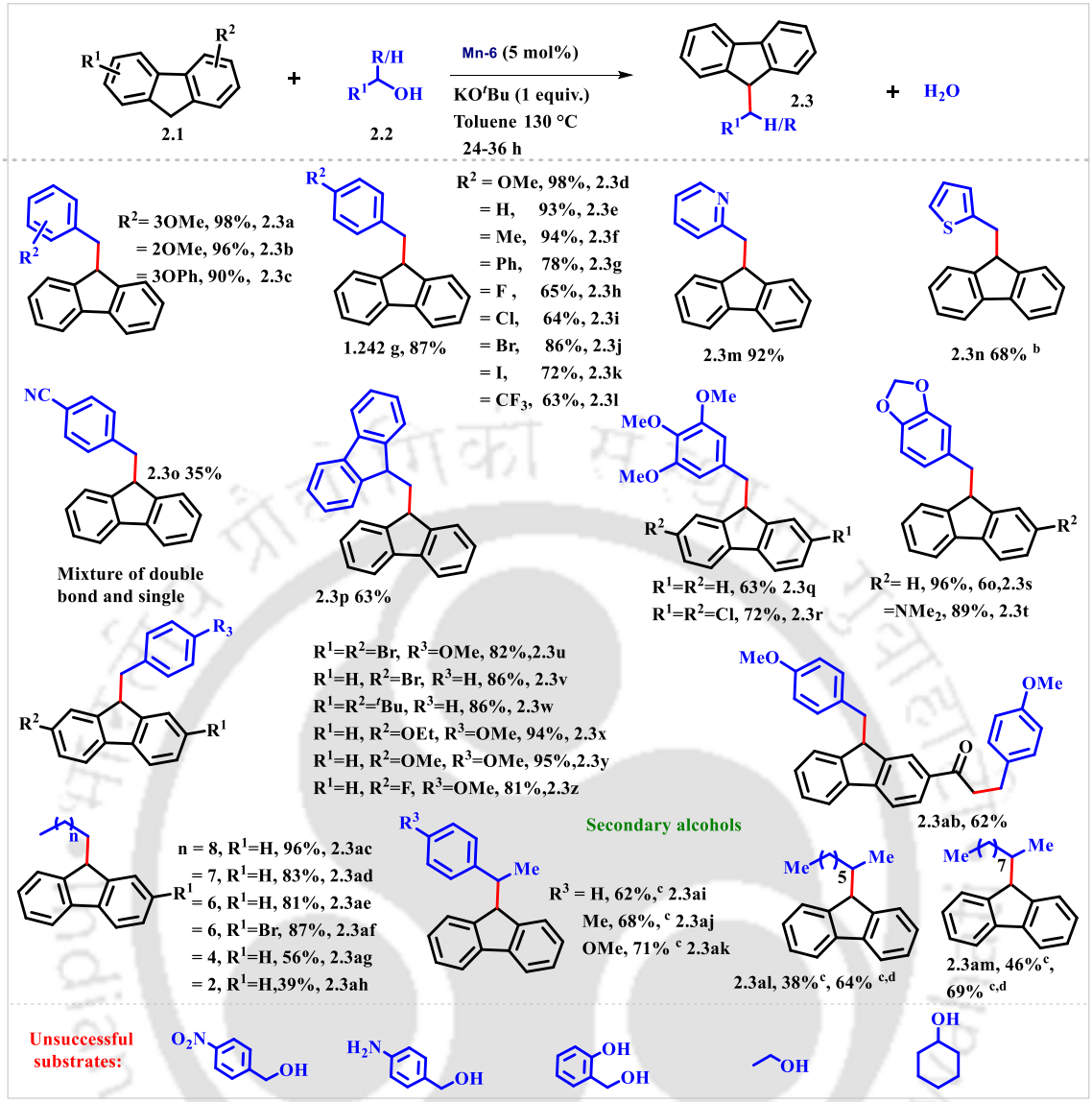
[a]**Conditions: 2.1a** (0.5 mmol), **2.2a** (0.5-1.0 mmol), KO^{t}Bu (0.15-0.5 mmol), Mn-catalyst (5 mol %), Under argon. [b]Isolated yield, nr = no reaction. [c]Catalyst loading 2.5 mol%. [d]Temperature 110 °C.

Next, the effect of the bases in this reaction were screened. Weak bases like Na_2CO_3 or K_2CO_3 failed to give any product and bases like NaOH, KOH and $CsOH.H_2O$ gave only small amount (10-15%) of alkylated product (Table 2.3.1.1, entry 10-12). In an attempt to lower the amount of ^{t}BuOK, the alkenylated product 2.4a in 78% yield was isolated. (Table 2.3.1.1, entry 14). Notably, the yield of **2.4a** was slightly increased to 83% by decreasing the amount of alcohol to 0.55 mmol keeping the other parameters as constant (Table 2.3.1.1, entry 16). Without the presence of any catalysts, 0.25 mmol KO^{t}Bu failed to give any desired product (**2.3a**/**2.4a**) (Table 2.3.1.1, entry 18). Similarly,

in the absence of base, **Mn-6** furnished only trace amount of **2.3a**. So, the presence of catalyst, particular amount of base and alcohol are essential for the selective synthesis of **2.3a** or **2.4a**. Similar results were obtained in presence of other two NNS-Mn(I) catalysts (Table 2.3.1.1, entry 20 & 21). Lower catalyst loading (2.5 mol%) or lower reaction temperature (110 °C) afforded inferior yield (Table 2.3.1.1, entry 22 & 23). Only $MnBr(CO)_5$ under the standard reaction conditions could not able to delivered desired product (Table 2.3.1.1, entry 24).

2.3.2. Manganese catalysed direct alkylation of *9H*-fluorene using various alcohols and fluorenes: substrate scope[a,b]

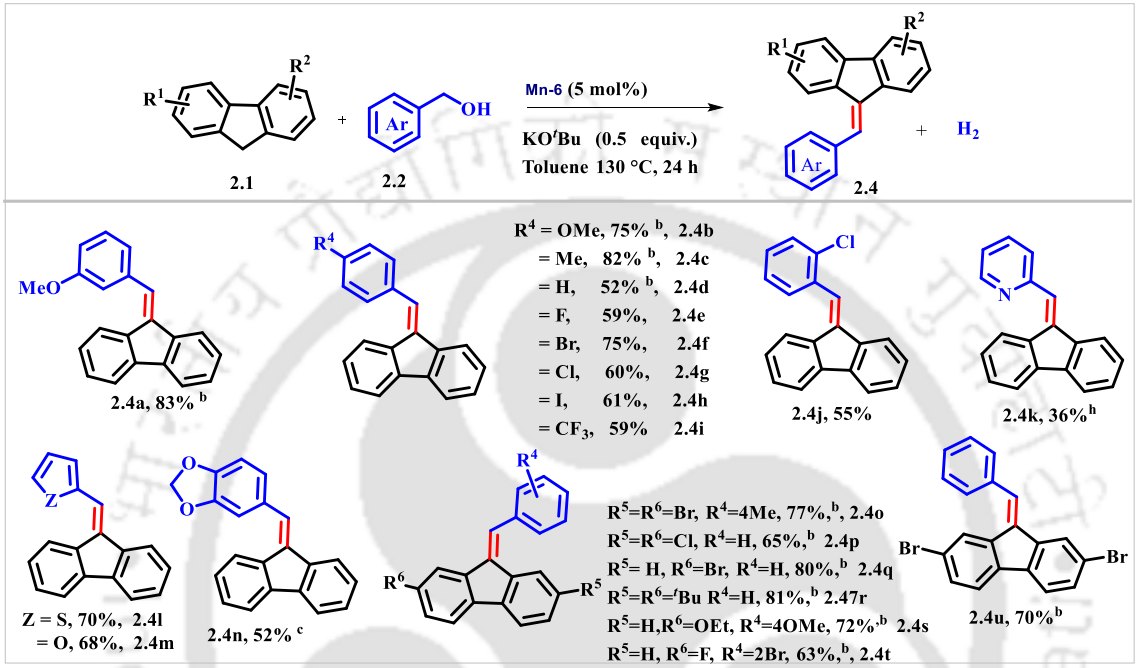
To evaluate the scope and limitation of the present protocol for C-alkylation of fluorene (**2.1a**) with various alcohols. Benzyl alcohols bearing various electron-donating substituents at *o*-, *p*- and *m*-position in the aromatic nucleus were tested, which were found to be well tolerated to give excellent yields (78-98%) of the targeted product (**2.3a**-**2.3g**). Of note, halo substituted aromatic alcohols were well compatible in this reaction condition to give a good to excellent yields (**2.3h**-**2.3k**). It is worth revealing that halo substituted products are used as promising materials because they can be easily converted to other key compounds via coupling reactions. Notably, strong electron withdrawing substituent trifluoromethyl at *p*-position also afforded good yield (**2.3l**). But a nitro group at *p*-position showed incompatibility towards this catalytic alkylation. The compatibility of the catalytic alkylation of fluorene (**2.1a**) was also tested with respect to the heteroaromatic alcohols. Delightfully, a good to excellent yield of the monoalkylated fluorene product was obtained with pyridine alcohol, thiophene methanol (**2.3m** & **2.3n**). Next, the scope of differently substituted fluorenes was examined. Fluorenes having electron withdrawing or donating substituents were reacted well with various alcohols to furnish good to excellent yield (72-95%) of the alkylated products. When 2-acetyl fluorene was used as a substrate, both the C-9 position of fluorene, the keto-methyl group were alkylated and **6ab** was isolated in 62% yield. Delightfully, more challenging aliphatic alcohols were also found suitable coupling partners for this reaction. 1-octanol, 1-nonanol and 1-decanol furnished excellent yield (81-96%) of the alkylated product (**2.3ac**- **2.3af**). However, only a moderate yield was obtained for short chain alcohols (**2.3ag**-**2.3ah**). Unfortunately, ethanol failed to give the desired product. Additionally, the compatibility of secondary alcohols as the coupling partner was also tested. Higher catalyst and base loading and longer reaction time are essential to furnish the good yield of the product (**2.3ai**-**2.3am**).



[a]**Conditions:2.1** (0.5 mmol), **2.2** (1.0 mmol), KO^{t}Bu (0.5-1.0 mmol), **Mn-6** (5 mol%), time: 24-36 h at 130 °C (oil bath), [b]1.3 mmol, [c]2 equiv. base, [d]12 mol% **Mn-6**, all yields are isolated.

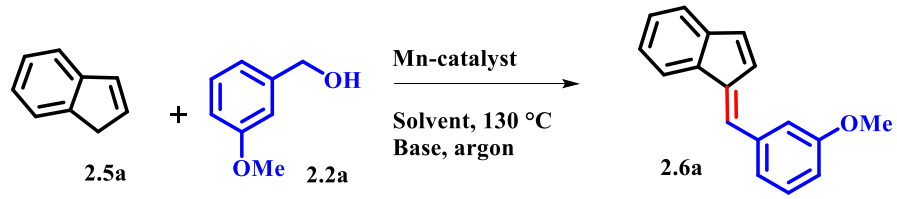
2.3.3. Manganese catalysed direct alkenylation of *9H*-fluorene using various alcohols and fluorenes: substrate scope: Methylidenefluorenes are ubiquitous in many bioactive compounds[12] and broadly used as optoelectronic materials.[13] These are classically synthesized via Wittig olefination[14] or Peterson olefination[15] with the generation of toxic waste. Several de novo catalytic strategies to synthesize methylidenefluorenes have also been developed by the use of expensive transition metals.[16] Therefore, dehydrogenative construction of methylidenefluorenes directly from fluorene and alcohols catalysed by earth-abundant manganese catalyst is highly desirable. So, next, the scope of the olefination reaction of fluorene was tested with different alcohols by adopting the reaction conditions described in table 2.3.1.1, entry 4. Benzyl alcohols having methoxy and methyl at *p*- and *m*- positions afforded excellent yields (83%, 75% and 82% respectively) of the alkenylated product (**2.4a**-**2.4c**) along with a very small amount of

hydrogenated product. Halo-substituted benzyl alcohols also provided moderate to good yields (59-75%) of the alkenylated products (**2.4e-2.4h** & **2.4j**). Electron withdrawing substituent bearing benzyl alcohol such as (-CF_3) found to be suitable for the reaction and **2.4i** was isolated in good yield (59%) along with unreacted starting material fluorene (**2.1**) was recovered. 2-thiophene methanol and 2-furanmethanol delivered (**2.4l**, **2.4m**) in good yield (68-70%). However, the yield of the alkenylated product was relatively low in case of pyridine-2-methanol and



[a]**Conditions:2.1** (0.5 mmol),**2.2**(0.55 mmol), KO^{t}Bu (0.25 mmol), **Mn-6** (5 mol%), time: 24 h at 130 °C (oil bath), [b]trace amount of corresponding hydrogenated product was formed, [c]42% **2.4k** & 60% **2.4n** were isolated.

piperonyl alcohol (60% & 42% hydrogenated products were isolated). Comparative reactivity showed the higher affinity of the alkenylated product **2.2.4k** and **2.2.4n** towards hydrogenation (see experimental section). Substituted fluorenes also provided good yields of the alkenylated products, (**2.2.4o**–**2.2.4u**) with trace amount of corresponding hydrogenated products. Unfortunately, nitro bearing benzyl alcohol and aliphatic alcohols were found incompatible to deliver the alkenylated products selectively.

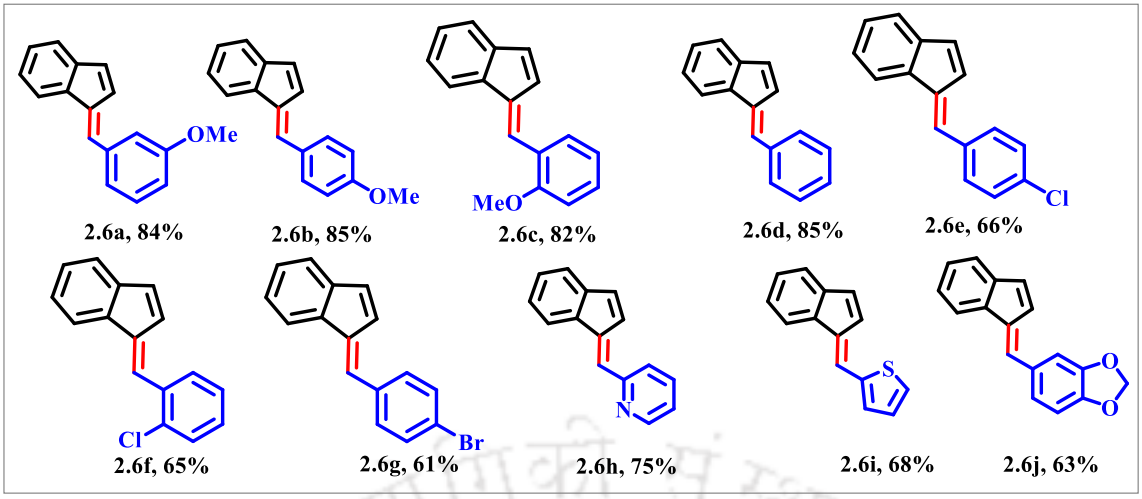


2.5a + 2.2a → 2.6a

Entry	Cat	Base (mmol)	Solvent (ml)	Time (h)	Tempr. (°C)	Indene : Alcohol (mmol)	% Yield [b] 2.6a
1	Mn-6	^{t}BuOK (0.5)	Toluene(2)	24	130 °C	0.5 : 1.0	Trace
2	Mn-6	*C*sOH.H_2O(0.5)	Toluene(2)	24	130 °C	0.5 : 1.0	Trace
3	Mn-6	*C*sOH.H_2O(0.5)	Toluene(2)	24	130 °C	0.5 : 1.0	Trace
4	Mn-6	*C*sOH.H_2O(0.5)	^{t}AmOH(2)	24	130 °C	0.5 : 1.0	20
5	Mn-6	*C*sOH.H_2O(0.5)	^{t}AmOH(1) + EtOH(1)	24	130 °C	0.5 : 1.0	22
6	Mn-6	NaOH(0.5)	^{t}AmOH(2)	24	130 °C	0.5 : 1.0	70
7	Mn-6	NaOH(0.5)	Toluene(2)	24	130 °C	0.5 : 1.0	10
8	Mn-6	^{t}BuOK (0.5)	^{t}AmOH(2)	24	130 °C	0.5 : 1.0	15
9	Mn-6	NaOH(0.5)	^{t}AmOH(2)	12	130 °C	0.5 : 1.0	46
10	Mn-6	NaOH(0.5)	Dioxane(2)	24	130 °C	0.5 : 1.0	85
11	Mn-6	NaOH(0.5)	Dioxane(2)	24	110 °C	0.5 : 1.0	85
12	Mn-6	NaOH(0.25)	Dioxane(2)	24	110 °C	0.5 : 1.0	32
13	Mn-6	KOH(0.5)	Dioxane(2)	24	110 °C	0.5 : 1.0	65
14	Mn-6	NaO^{t}Bu(0.5)	Dioxane(2)	24	110 °C	0.5 : 0.5	65
15	Mn-6	NaOH(0.5)	Dioxane(2)	24	110 °C	0.5 : 0.55	84
16	.....	NaOH(0.5)	Dioxane(2)	24	110 °C	0.5 : 0.55	Trace
17	Mn-6	.....	Dioxane(2)	24	110 °C	0.5 : 1.0	Trace
18	Mn-6	NaOH(0.5)	Dioxane(2)	24	100 °C	0.5 : 1.0	71
19	Mn2	NaOH(0.5)	Dioxane(2)	24	110 °C	0.5 : 1.0	81
20	Mn3	NaOH(0.5)	Dioxane(2)	24	110 °C	0.5 : 1.0	62

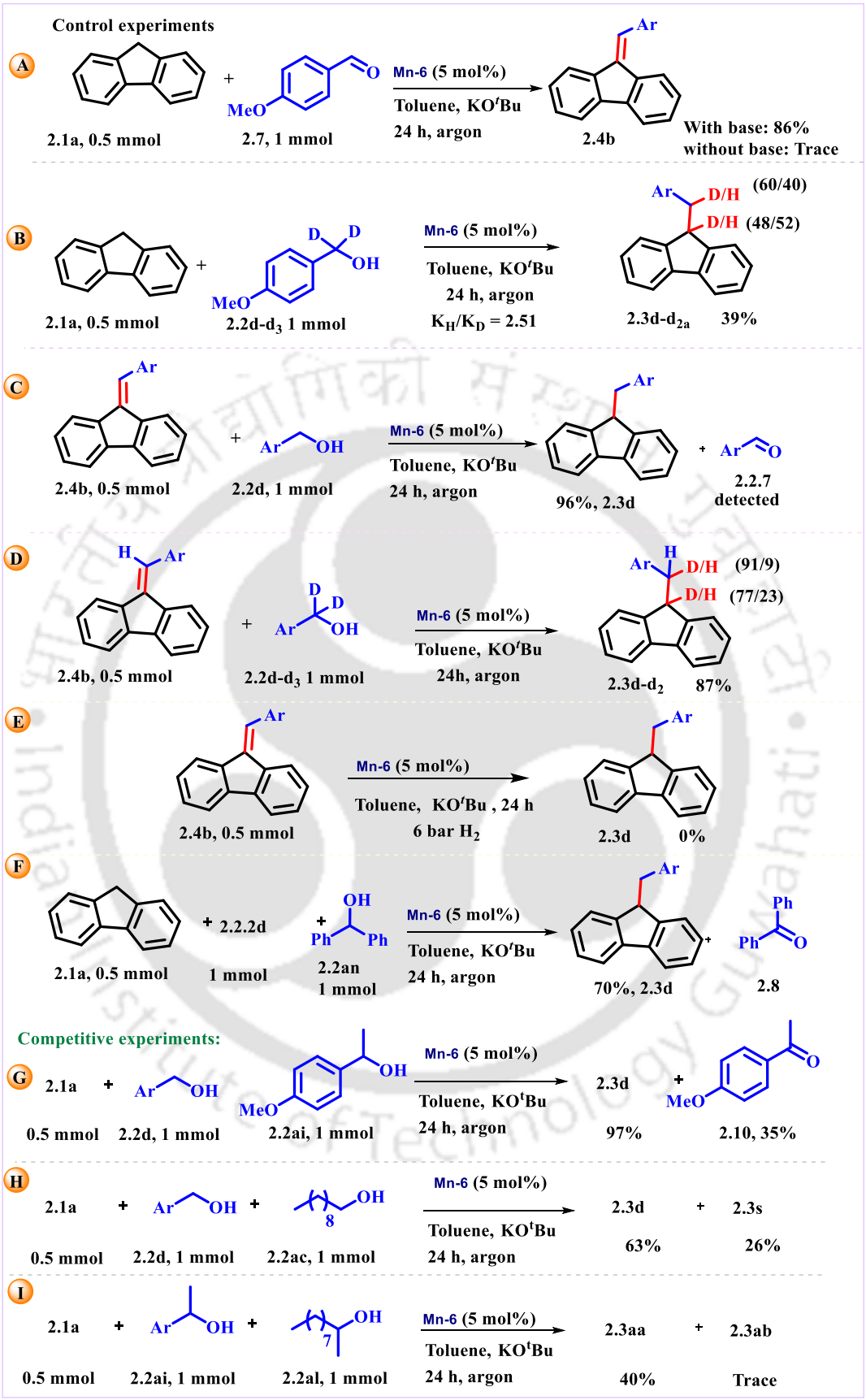
[a]**Conditions:2.5a** (0.5 mmol), **2.2a** (0.5-1.0 mmol), Base (0.25-0.5 mmol), Mn-Catalyst (5 mol%), Under argon. [b]Isolated yield, Temperature (130 °C –100 °C).

2.3.4. Manganese catalysed alkenylation of indene: Further, the present methodology for the olefination of fluorene was subjected to the alkenylation of indene with alcohols. Initially, it failed to give the desired product selectively; nevertheless, slight variation of reaction condition (see below in table) gave the alkenylated product (**2.6a**) in 84% yield. Delightfully, various aromatic, heteroaromatic and halo substituted alcohols reacted well with indene to provide the alkenylated products in good to excellent yield (**2.6a-2.6j**).



[a]**Conditions**: **2.5a** (0.5 mmol), **2.2a** (0.55mmol), NaOH (0.5 mmol), **Mn-6** (5 mol%), Under argon. [b]Isolated yield, Temperature (110 °C).

2.3.5. Mechanistic investigations: In order to understand the mechanistic insight, a series of control experiments were accomplished. Conversion of alcohol to the corresponding aldehyde was observed in presence of **Mn-6**. Further, during the alkenylation reaction, the evolution of H_2 was utilized in the hydrogenation reaction using Wilkinson catalyst. The study of the condensation reaction of benzaldehyde **2.7** with fluorene **2.1a** displays base is essential for this step whereas catalyst has no role in this process (**Scheme 2.2A**). When fluorene **2.1a** reacted with deuterated 4-methoxybenzyl alcohol **2.2d-d3**, 39% of the desired product (**2.3d-d_{2a}**) was formed which reveal K_H/K_D = 2.51 (**Scheme 2.2B**). In addition, when **2.4b** was reacted with alcohols, desired alkylated product (**2.3d**) formed in quantitative yield along with aldehyde formation (**Scheme 2.2C**). When the same experiment was conducted with deuterated alcohol, the alkylated product was obtained with 77/91% of the deuterium incorporation (**Scheme 2.2D**). However, under similar reaction condition **2.4b** at 6 bar H_2 failed to give any alkylated product (**Scheme 2.2E**). These experiments suggest that the alcohol is necessary to generate Mn-H species whereas formation Mn-H species via H_2 activation is not possible. Kinetic monitoring of C-alkylation reaction revealed that at 9 h the accumulation of the alkenylated product (**2.4b**) was maximum, which was gradually hydrogenated to furnish selectively **2.3d** in high yield at the end (**Figure 2.3.**). Study of comparative reactivities reveals that primary benzyl alcohols is more reactive than secondary benzyl alcohols/aliphatic alcohols and secondary benzyl alcohols showed higher reactivity than secondary aliphatic alcohols (**Scheme 2.2H & 2.2I.**).



Scheme 2.2. Control and competitive experiments.

2.2.6. Catalytic cycle: On the basis of these results and previous reports[17c,5a,5c] a plausible mechanism is presented (**Figure 2.2**). The amido complex **I** is first generated from **Mn-6** under the reaction condition that dehydrogenates alcohol to aldehyde via **II** and forms Mn-H species **III**. The liberated aldehyde undergoes condensation reaction to form **2.4b** and water. Next, the Mn-H species III hydrogenates the condensation product **2.4b** via **IV** and regenerates the active catalyst **I**.

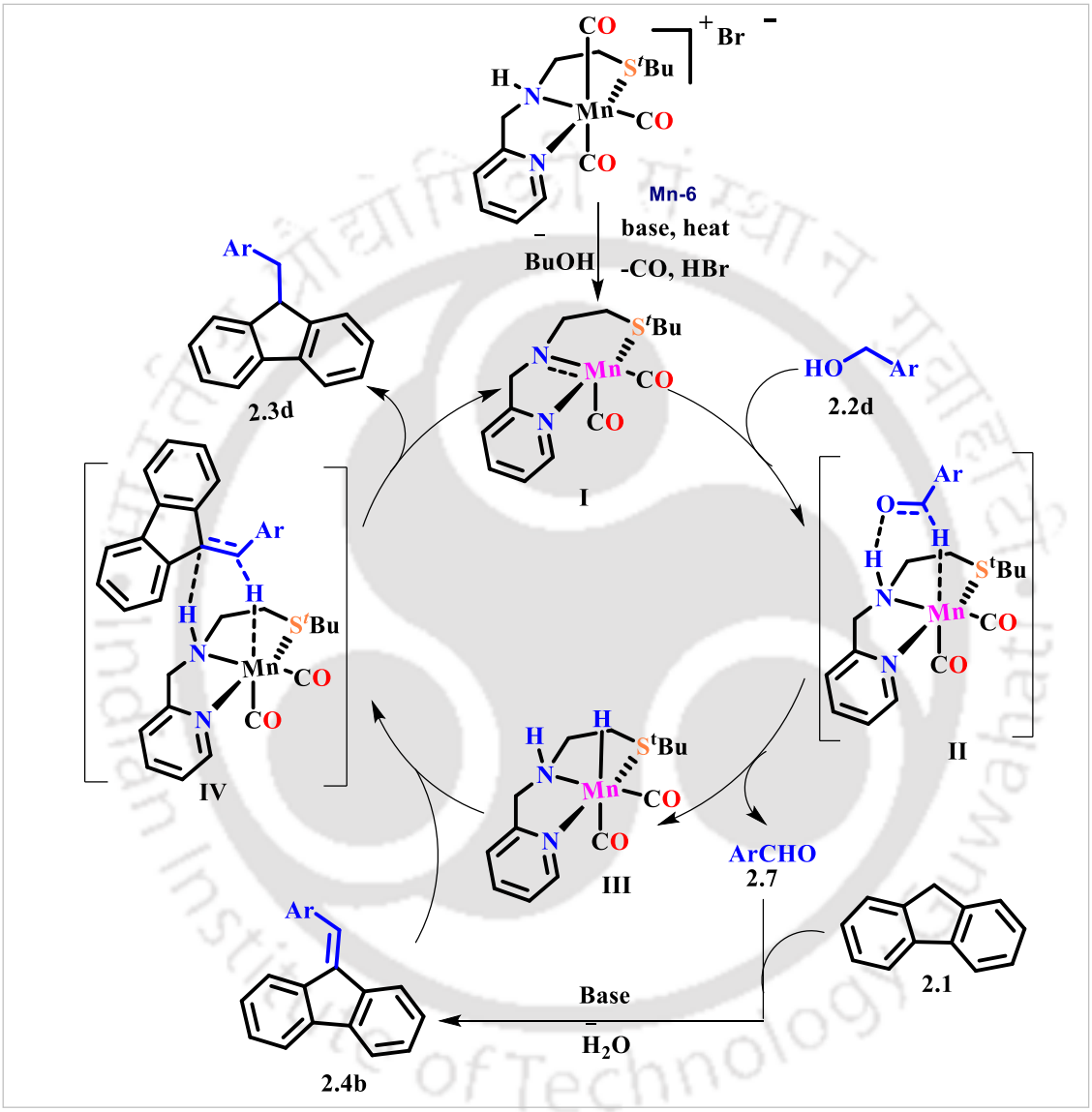


Figure 2.2. Catalytic cycle for selective functionalization of fluorene.

2.3. Conclusion: In summary, manganese catalysed selective alkylation and alkenylation of fluorene with alcohols was demonstrated. Single air and moisture stable phosphine-free manganese (I) catalyst can perform both the task under suitable reaction conditions. This elegant catalytic protocol validated a wide range of substrate scope including aromatic, heteroaromatic and aliphatic alcohols with good to excellent yields. Experimental studies indicate the alcohol is responsible to form the Mn-H species, which hydrogenates the alkenylated product under reaction conditions.

Notably, the liberation of hydrogen and/or water by-product makes this protocol environmentally green and sustainable.

2.4. Experimental Section:

2.4.1. Ligands synthesis: All three ligands were prepared according to previous reported literature methods.[17b] Pyridine-2-carboxaldehyde (10 mmol) and amino-thiol compound (10 mmol,) were dissolved in dry CH_2Cl_2 (30 mL) and then Na_2SO_4 (40 mmol) was added to it. The resulting suspension was stirred for 20 h at room temperature. Then, it was filtered and the residue was washed thoroughly with CH_2Cl_2 and the combined solvent was removed under reduced pressure. The residue obtained was directly used for the next step without further purification. The residue was dissolved in methanol (30 mL) and $NaBH_4$ (30 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 30 mL of water was added. After that, it was extracted by CH_2Cl_2 and the organic portion was collected and passed through Na_2SO_4. Then the solvent was evaporated to get the crude product, which was purified further by silica gel (100-200 mess) column chromatography using 20-40 % ethyl acetate in hexane.

2.4.2. Complex preparation: All three complexes (**Mn-6**, **Mn-17**&**Mn-21**) were prepared according to previous reported literature methods.[17b] Ligand [$(PyCH_2)HN(CH_2CH_2SR)$, R= Et, ^{t}Bu, Bn] (2.0 mmol) was taken in 5 mL dry THF and was added dropwise to the orange-yellow suspension of $[MnBr(CO)_5]$ (2.0 mmol) in 5 mL degassed dry THF. Afterward, the suspension was refluxed for overnight under argon atmosphere. After the completion of the reaction, the reaction mixture was cooled down to the room temperature, then 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.

2.4.3. General experimental procedure for the alkylation of fluorene: To an oven dried 10 mL round bottomed flask, fluorene derivative (**2.1**, 0.5 mmol), alcohol (**2.2** ,1.0 mmol), ^{t}BuOK (0.5 mmol) and **Mn-6** (5 mol%) were taken under argon atmosphere, after that 2 mL of toluene was added to the reaction mixture. The resulting mixture was heated in an oil bath at 130 °C for 24 h. After the completion of the reaction, the reaction mixture was cooled to room temperature and 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 hexane or 2%-5% ethyl acetate in hexane to get pure compound.

2.4.4. General experimental procedure for the alkenylation of fluorene: A mixture of aromatic primary alcohol (**2.2**, 0.55 mmol), fluorene (**2.1**, 0.5 mmol), ^{t}BuOK (0.25 mmol) and **Mn-6**(5 mol%) were stirred in toluene (2 mL) under argon atmosphere at 130 ˚C for 24 h. After the

reaction was completed, it was cooled to room temperature and 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 hexane or 2%-5% ethyl acetate in hexane to get pure compound.

2.4.5. General experimental procedure for the alkenylation of indene: To an oven dried 10 mL round bottom flask, aromatic primary alcohol (0.55 mmol), indene **2.5** (0.5 mmol), **Mn-6** catalyst (5 mol%), NaOH (0.5 mmol) and dioxane (2 mL) were added under argon atmosphere. The reaction mixture was kept for refluxing in preheated oil bath at 110 °C for 24 h. Then, the reaction was cooled at room temperature and ethyl acetate was added, diluted the mixture and filtered through celite. The filtrate was concentrated under reduced pressure and the residue was purified by silica gel column chromatography using hexane or 2%-5% ethyl acetate as an eluting system.

2.4.6. Manganese catalysed hydrogenation of intermediate (2.4b) by secondary alcohol (2.2ai): To an oven dried round bottomed flask intermediate **2.4b** (0.5 mmol), 4-methoxy alpha methyl benzyl alcohol **2.2ai** (1.0 mmol), KO^{t}Bu (0.5 mmol) and **Mn-6** (5 mol%) were taken, then toluene was added under argon atmosphere. The resulting mixture was then placed into the preheated oil bath at 130 °C for 24 h. After completion the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100-200 mesh) with hexane/ethyl acetate mixture (2-5%) as eluent, 76% of **2.3d** was obtained.

2.4.7. Manganese catalysed hydrogenation of intermediate (2.4b) by diphenyl methanol (2.2an): To an oven dried round bottomed flask intermediate **2.4b** (0.5 mmol), diphenyl methanol **2.2.an** (1.0 mmol), KO^{t}Bu (0.5 mmol) and **Mn-6** (5 mol%) were taken, then toluene was added under argon atmosphere. The resulting mixture was then placed into the preheated oil bath at 130 °C for 24 h. After completion the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum; the residue was used for ^{1}H NMR analysis which indicates 67% of **2.3d** was formed.

2.4.8. Manganese catalysed hydrogenation of intermediate (2.4b) by deuterated alcohol (2.2.2d-d$_3$): To an oven dried round bottomed flask intermediate **2.4b** (0.5 mmol), deuterated 4-methoxy benzyl alcohol **2.2d-d$_3$** (1.0 mmol), KO^{t}Bu (0.5 mmol) and **Mn-6** (5 mol%) were taken, then toluene was added under argon atmosphere. The resulting mixture was then placed into the preheated oil bath at 130 °C for 24 h. After completion the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100–200 mesh) with hexane/ethyl acetate mixture (2-5%) as eluent, 87% of **2.3d-d$_2$** was obtained. The ^{1}H analysis of the product **2.3d-d$_2$** revealed that 78-89% incorporation occurred.

2.4.9. Manganese catalysed alkylation of fluorene (2.1a) by deuterated labelled alcohol (2.2d-d_3): To an oven dried round bottomed flask fluorene, **2.1a** (0.5 mmol), deuterated 4-methoxy benzyl alcohol **2.2d-d_3** (1.0 mmol), KO^{t}Bu (0.5 mmol) and **Mn-6** (5 mol%) were taken, then toluene was added under argon atmosphere. The resulting mixture was then placed into the preheated oil bath at 130 °C for 24 h. After completion the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100–200 mesh) with hexane/ethyl acetate mixture (2-5%) as eluent, 39% of **2.2d-d_{2a}** was obtained. The ^{1}H analysis of the product **2.2d-d_{2a}** revealed that 48-60% incorporation occurred.

2.4.10. Manganese catalysed alkenylation of fluorene (2.1a) by 4-methoxy benzaldehyde (2.7): Fluorene (**2.1a,** 0.5 mmol), ^{t}BuOK (56 mg, 0.5 mmol) and 4-methoxy benzylaldehyde (**2.7,** 1.0 mmol) were charged in an oven dried round bottomed flask in toluene (2 mL) under argon. The flask was then placed in a preheated oil bath at 130 °C. After 24 h, the crude reaction mixture was diluted by ethyl acetate and filter through celite. The filtrate was concentrated under vacuum and resultant residue was purified by column chromatography using 100-200 mesh size silica with hexane / ethyl acetate as an eluent, 86% product (**2.4b**) was obtained. No product (**2.4b**) was formed in the absence of ^{t}BuOK.

2.4.11. Manganese catalysed hydrogenation of intermediate (2.24b) under hydrogen pressure: To an oven dried reaction vessel intermediate **2.4b** (0.25 mmol), KO^{t}Bu (0.25 mmol) and **Mn-6** (5 mol%) were taken, then toluene was added under 6 bar H_2 pressure. The resulting mixture was then placed into the preheated oil bath at 130 °C for 24 h. After completion the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. Then concentrated the filtrate under vacuum, then the crude residue was analysed by ^{1}H NMR which indicates no hydrogenated product was formed.

2.5. Competitive Experiments:

2.5.1. Manganese catalysed alkylation of fluorene (2.1a) with primary aromatic (2.2d) and aliphatic (2.2ac) alcohol: Fluorene, **2.1a** (0.5 mmol), 4-methoxy benzylalcohol, **2.2d** (1.0 mmol), 1-decanol **2.2ac** (1.0 mmol), **Mn-6** (5 mol%) and ^{t}BuOK (56 mg, 0.5 mmol) were charged in an oven dried round bottomed flask in toluene (2 mL) under argon. The flask was then placed in a preheated oil bath at 130 °C. After 24 h, the crude reaction mixture was diluted by ethyl acetate and filter through celite. The filtrate was concentrated under vacuum and resultant residue was purified by column chromatography using 100-200 mesh size silica with hexane / ethyl acetate as an eluent, 63% **2.3d** and 26% **2.3ac** were isolated

2.5.2. Alkylation of fluorene with primary and secondary aromatic alcohol: Fluorene **2.1a** (0.5 mmol), 4-methoxy benzylalcohol, **2.7**(1.0 mmol), 4-methoxy alpha methyl benzyl alcohol **2.2ai** (1.0 mmol), ^{t}BuOK (56 mg, 0.5 mmol) and **Mn-6** (5 mol%) were charged in an oven dried round bottomed flask in toluene (2 mL) under argon. The flask was then placed in a preheated oil bath at 130 °C. After 24 h, the crude reaction mixture was diluted by ethyl acetate and filter through celite. The filtrate was concentrated under vacuum and resultant residue was purified by column chromatography using 100-200 mesh size silica with hexane / ethyl acetate as an eluent, only 97% **2.3d** was isolated. The result indicates that primary alcohol is more reactive towards alkylation than seconadary alcohol.

2.5.3. Alkylation of fluorene with primary and secondary aromatic alcohol: Fluorene, **2.1a** (0.5 mmol), 4-methoxy alpha methyl benzyl alcohol **2.2ai** (1.0 mmol), and 2-decanol **2.2ac** (1mmol), ^{t}BuOK (56 mg, 0.5 mmol) and **Mn-6** (5 mol%) were charged in an oven dried round bottomed flask in toluene (2 mL) under argon. The flask was then placed in a preheated oil bath at 130 °C. After 24 h, the crude reaction mixture was diluted by ethyl acetate and filter through celite. The filtrate was concentrated under vacuum and resultant residue was purified by column chromatography using 100-200 mesh size silica with hexane / ethyl acetate as an eluent, only 40% **2.3ak** was isolated. The result indicates that secondary benzyl alcohol is more reactive towards alkylation than seconadary aliphatic alcohol.

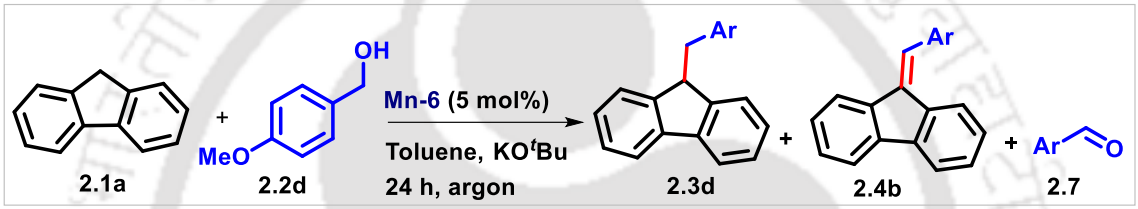
2.5.4. Manganese catalysed rate of hydrogenation of (2.4k) & (2.4b) in presence of 4-methoxy benzyl alcohol (2.2d): An equimolar mixture of **2.4k**, **2.4b** & 4-methoxy benzylalcohol (**2.2d)** were taken (0.3 mmol of each) in an oven dried round bottomed flask. Then **Mn-6** (5 mol%) and ^{t}BuOK (33.6 mg, 0.3 mmol) were charged in toluene (2 mL) under argon. The flask was then placed in a preheated oil bath at 130 °C. After 24 h, the crude reaction mixture was diluted by ethyl acetate and filter through celite. The filtrate was concentrated under vacuum and resultant residue was purified by column chromatography using 100-200 mesh size silica with hexane / ethyl acetate as an eluent, 73% **2.3m** & only 20% of **2.3d** was isolated which indicates that the rate of hydrogenation of coordinating substrate is greater than others.

2.5.5. Utilization of liberated hydrogen gas: To an oven dried 10 mL round bottomed flask (**A**) fluorene, **2.1a** (1.0 mmol), 4-methoxy benzyl alcohol **2.2d** (1.2 mmol), KO^{t}Bu (0.5 mmol) and **Mn-6** (5 mol%) were added, the entire system was degassed and flushed with argon for 5 minutes (three times), then dry toluene (2 mL) was added. To another 10 mL round bottomed flask (**B**) $RhCl(PPh_3)_3$ (6 mol%) catalyst, and intermediate **2.4b** (0.25 mmol) were dissolved in benzene (2 mL). Both the flask (**A** & **B**) were connected through a double headed syringe and allowed to equilibrate for 5 minutes. The mixture in the flask (**A**) was heated at 130 °C (oil-bath temperature), while the mixture in the flask (**B**) was stirred at 60 °C (oil-bath temperature). After 24 h, the organic

entities present in the flask (**B**) were analyzed by GC which showed a clean conversion (28%) of the **2.4b** to **2.3d**.

2.5.6. Gram scale synthesis: To an oven dried 50 mL round bottomed flask fluorene, **2.1a** (5.0 mmol), 4-methoxy benzyl alcohol (**2.2d** mmol), KO^{t}Bu (5.0 mmol) and **Mn-6** (5 mol%) were taken, then toluene was added under argon atmosphere. The resulting mixture was then placed into the preheated oil bath at 130 °C for 24 h. Upon completion the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100-200 mesh) with hexane/ethyl acetate mixture (2-5%) as eluent, and 87% of **2.3d** was obtained. Yield 87% (1.242 g)

2.6. Kinetic monitoring:



In a 10 mL 2-neck round bottomed flask, fluorene, **2.1a** (1.0 mmol), 4-methoxy benzyl alcohol **2.2d** (2.0 mmol), **Mn-6**(5 mol%) and ^{t}BuOK (1.0 mmol) were taken under argon atmosphere. After that the final mixture was placed in preheated oil bath at 130 °C. The reaction mixture was analyzed by GC using mesitylene as an internal standard at specified time interval.

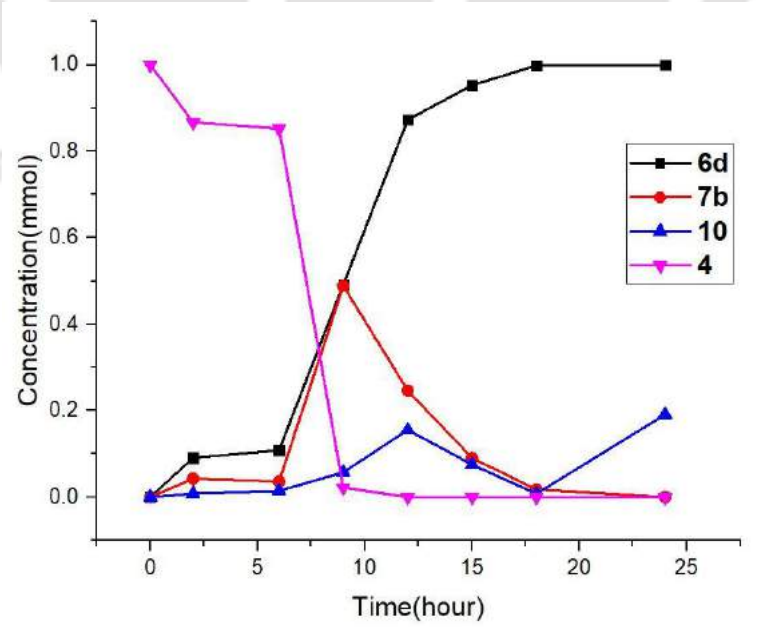
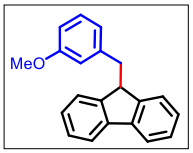


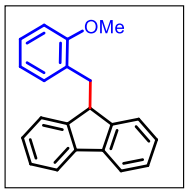
Figure 2.3. Reaction kinetics.

2.7. Characterization data:

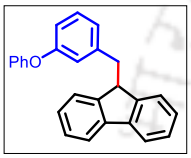
9-(3-methoxybenzyl)-*9H*-fluorene (2.3a):[18] Yellow solid, 98% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.72 (d, *J* = 7.6 Hz, 2H), 7.35 – 7.32 (m, 2H), 7.24 –7.19 (m, 5H), 6.86 – 6.75 (m, 3H), 4.23 (t, *J* = 7.5 Hz, 1H), 3.75 (s, 3H), 3.09 (d, *J* = 7.5 Hz, 2H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 159.6, 147.0, 141.5, 141.0, 129.3, 127.2, 126.8, 125.0, 122.1, 120.0, 115.0, 112.1, 55.3, 48.7, 40.2.



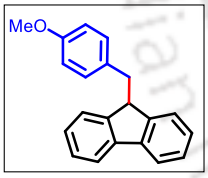
9-(2-methoxybenzyl)-*9H*-fluorene (2.3b):[19] Yellow solid, 96% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.75 (d, *J* = 7.5 Hz, 2H), 7.34 (t, *J* = 7.4 Hz, 2H), 7.30 (td, *J* = 8.1, 1.6 Hz, 1H), 7.22 – 7.16 (m, 4H), 7.05 (d, *J* = 7.5Hz, 1H), 6.95-9.89 (m, 2H), 4.36 (t, *J* = 7.5 Hz, 1H), 3.88 (s, 3H), 3.06 (d, *J* = 7.5 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 158.1, 147.8, 140.8, 131.7, 128.7, 128.0, 127.0, 126.6, 125.1, 120.3, 119.8, 110.4, 55.4, 46.8, 35.7.



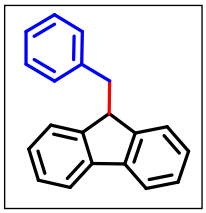
9-(3-phenoxybenzyl)-*9H*-fluorene (2.3c):[20] Yellow solid, 90% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.71 (d, *J* = 7.5 Hz, 2H), 7.34 – 7.29 (m, 4H), 7.24 – 7.19 (m, 5H), 7.07 (t, *J* = 7.3 Hz, 1H), 6.93 – 6.87 (m, 4H), 6.81 (s, 1H), 4.19 (t, *J* = 7.4 Hz, 1H), 3.09 (d, *J* = 7.4 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 157.5, 157.0, 146.6, 141.8, 141.0, 130.0, 129.6, 127.3, 126.8, 125.0, 124.7, 123.1, 120.3, 120.0, 118.7, 48.6, 40.0.



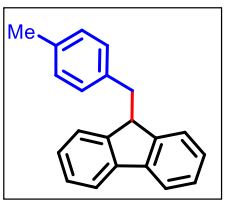
9-(4-methoxybenzyl)-*9H*-fluorene (2.3d):[21] White solid, 98% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.71 (d, *J* = 7.6 Hz, 2H), 7.32 (t, *J* = 7.6 Hz, 2H), 7.23 – 7.15 (m, 4H), 7.10 (d, *J* = 8.5 Hz, 2H), 6.82 (d, *J* = 8.5 Hz, 2H), 4.16 (t, *J* = 7.6 Hz, 1H), 3.78 (s, 3H), 3.03 (d, *J* = 7.6 Hz, 2H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 158.2, 147.0, 140.9, 131.9, 130.5, 127.2, 126.7, 125.0, 119.9, 113.7, 55.3, 49.0, 39.3.



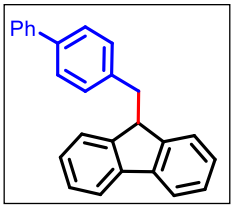
9-benzyl-*9H*-fluorene (2.3e):[22] White solid, 93% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.73 (d, *J* = 7.6 Hz, 2H), 7.36 – 7.15 (m, 11H), 4.23 (t, *J* = 7.6 Hz, 1H), 3.11 (d, *J* = 7.6 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 147.0, 141.0, 140.0, 129.7, 128.4, 127.2, 126.8, 126.5, 125.0, 120.0, 48.8, 40.2.



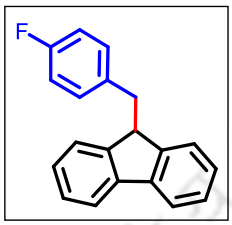
9-(4-methylbenzyl)-*9H*-fluorene (2.3f):[19] White solid, 94% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.74 (d, *J* = 7.6 Hz, 2H), 7.36 – 7.32 (m, 2H), 7.24 – 7.17 (m, 4H), 7.14 – 7.10 (m, 4H), 4.21 (t, *J* = 7.6 Hz, 1H), 3.07 (d, *J* = 7.6 Hz, 2H), 2.36 (s, 3H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 147.1, 141.0, 136.9, 135.9, 129.5, 129.1, 127.2, 126.8, 125.0, 119.9, 48.9, 39.8, 21.3.



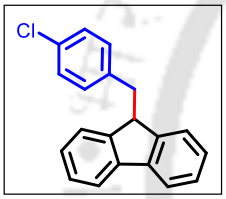
9-([1,1'-biphenyl]-4-ylmethyl)-*9H*-fluorene(2.3g):[19] White solid, 78% Yield. ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.74 (d, *J* = 7.6 Hz, 2H), 7.62 (d, *J* = 7.8 Hz, 2H), 7.54 (d, *J* = 8.0 Hz, 2H), 7.44 (t, *J* = 7.6 Hz, 2H), 7.36 – 7.32 (m, 3H), 7.29 (d, *J* = 8.0 Hz, 2H), 7.25 – 7.19 (m, 4H), 4.26 (t, *J* = 7.6 Hz, 1H), 3.14 (d, *J* = 7.6 Hz, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 146.9, 141.0, 141.0, 139.3, 139.1, 130.1, 128.9, 127.3, 127.1, 127.1, 126.8, 125.0, 120.0, 48.8, 39.9.



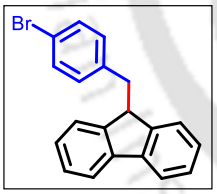
9-(4-fluorobenzyl)-*9H*-fluorene (2.3h):[19] White solid, 65% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.71 (d, *J* = 7.5 Hz, 2H), 7.32 (t, *J* = 7.3 Hz, 2H), 7.23 – 7.18 (m, 4H), 7.11– 7.09 (m, 2H), 6.94 (t, *J* = 8.6 Hz, 2H), 4.17 (t, *J* = 7.4 Hz, 1H), 3.09 (d, *J* = 7.4 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 161.7 (d, *J* = 241.5 Hz), 146.6, 141.0, 135.3 (d, *J* = 3.0 Hz), 131.0 (d, *J* = 7.5 Hz), 127.3, 126.8, 124.9, 120.0, 115.1 (d, *J* = 21.0 Hz), 48.8, 39.2.



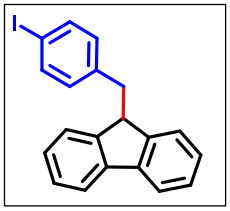
9-(4-chlorobenzyl)-*9H*-fluorene (2.3i):[18] White solid, 64% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.72 (d, *J* = 7.5 Hz, 2H), 7.35 (t, *J* = 7.4 Hz, 2H), 7.25 – 7.18 (m, 6H), 7.09 (d, *J* = 8.3 Hz, 2H), 4.19 (t, *J* = 7.4 Hz, 1H), 3.10 (d, *J* = 7.4 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 146.5, 141.0, 138.1, 132.2, 131.0, 128.4, 127.4, 126.8, 124.8, 120.0, 48.6, 39.4.



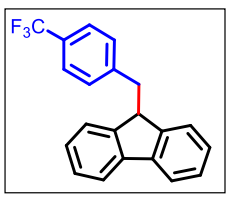
9-(4-bromobenzyl)-*9H*-fluorene (2.3j):[18] White solid, 86% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.72 (d, *J* = 7.6 Hz, 2H), 7.38 – 7.32 (m, 4H), 7.25 – 7.19 (m, 4H), 7.03 (d, *J* = 8.3 Hz, 2H), 4.19 (t, *J* = 7.3 Hz, 1H), 3.09 (d, *J* = 7.3 Hz, 2H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 146.5, 141.0, 138.6, 131.4, 131.4, 127.4, 126.9, 124.8, 120.3, 120.0, 48.5, 39.4.



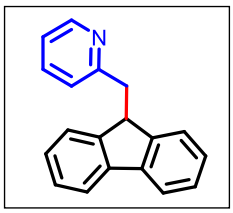
9-(4-iodobenzyl)-*9H*-fluorene (2.3k):[20] White solid, 72% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.72 (d, *J* = 7.5 Hz, 2H), 7.58 (d, *J* = 7.9 Hz, 2H), 7.35 (t, *J* = 7.3 Hz, 2H), 7.26 – 7.19 (m, 4H), 6.92 (d, *J* = 7.9 Hz, 2H), 4.19 (t, *J* = 7.3 Hz, 1H), 3.08 (d, *J* = 7.3 Hz, 2H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 146.5, 141.0, 139.4, 137.4, 131.7, 127.4, 126.9, 124.9, 120.1, 91.7, 48.5, 39.6.



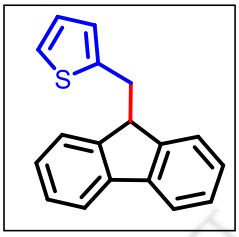
9-(4-(trifluoromethyl)benzyl)-*9H*-fluorene (2.3l):[19] White solid, 63% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.69 (d, *J* = 7.5 Hz, 2H), 7.48 (d, *J* = 7.7 Hz, 2H), 7.32 (t, *J* = 7.3 Hz, 2H), 7.22 – 7.14 (m, 6H), 4.18 (t, *J* = 7.3 Hz, 1H), 3.14 (d, *J* = 7.3 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 146.3, 143.8, 141.0, 130.0, 128.8 (q, *J* = 31.6 Hz), 127.5, 127.2, 127.0, 125.4, 125.2 (q, *J* = 4.5 Hz), 124.8, 124.6 (q, *J* = 270 Hz), 48.4, 39.8.



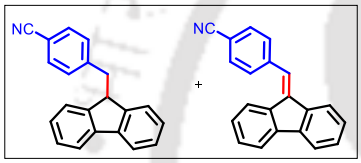
2-((*9H*-fluoren-9-yl)methyl)pyridine (2.3m):[18] White solid, 92% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 8.70-8.68 (m, 1H), 7.76 (d, *J* = 7.6 Hz, 2H), 7.62 (td, *J* = 7.6, 1.8 Hz, 1H), 7.35 (t, *J* = 7.5 Hz, 2H), 7.25 – 7.18 (m, 3H), 7.07 (d, *J* = 7.5 Hz, 2H), 7.03 (d, *J* = 8 Hz, 1H), 4.63 (t, *J* = 7.7 Hz, 1H), 3.23 (d, *J* = 7.7 Hz, 2H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 160.0, 149.7, 147.2, 140.9, 136.4, 127.2, 126.9, 124.8, 124.5, 121.8, 120.0, 47.3, 42.7.



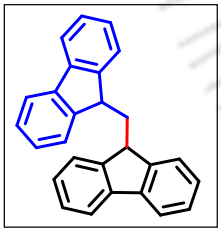
2-((*9H*-fluoren-9-yl)methyl)thiophene (2.3n):[18] Yellow solid, 68% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.73 (d, *J* = 7.6 Hz, 2H), 7.35 (t, *J* = 7.3 Hz, 2H), 7.29 – 7.23 (m, 4H), 7.12 (d, *J* = 4.0 Hz, 1H), 6.89 – 6.86 (m, 1H), 6.71 (s, 1H), 4.23 (t, *J* = 8.0 Hz, 1H), 3.39 (d, *J* = 8.0 Hz, 2H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 146.3, 142.2, 141.1, 127.4, 126.9, 126.7, 126.1, 124.8, 123.9, 120.0, 49.1, 34.1.



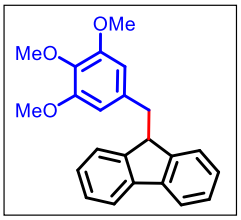
4-((*9H*-fluoren-9-yl)methyl)benzonitrile(2.3o): [21] Yellow solid, 35% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.75 –7.66 (m, 36H), 7.55 (s, 5H), 7.48 (d, *J* = 7.9 Hz, 2H), 7.40 – 7.32 (m, 22H), 7.25 – 7.19 (m,5 H), 7.17 (d, *J* = 7.4 Hz, 2H), 7.06 (t, *J* = 7.6 Hz, 5H), 4.23 (t, *J* = 7.0 Hz, 1H), 3.22 (d, *J* = 7.0 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 145.9, 145.0, 142.0, 141.8, 141.0, 139.6, 139.0, 138.6, 136.0, 132.4, 132.0, 130.4, 130.2, 129.5, 129.1, 127.6, 127.4, 127.0, 126.9, 124.7, 124.4, 124.4, 120.6, 120.2, 119.9, 119.1, 118.9, 111.6, 110.3, 48.2, 39.9.



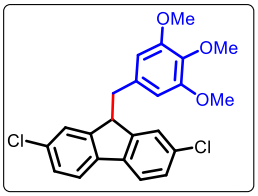
Di (*9H*-fluoren-9-yl)methane (2.3p):[22] White solid, 63% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*)** δ 7.82 (d, *J* = 7.6 Hz, 4H), 7.55 (d, *J* = 7.5 Hz, 4H), 7.40 (t, *J* = 7.5 Hz, 4H), 7.29 (t, *J* = 7.2 Hz, 4H), 4.40 (t, *J* = 7.6 Hz, 2H), 2.24 (t, *J* = 7.6 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 147.6, 141.1, 127.4, 127.1, 125.1, 120.2, 46.0, 39.0.



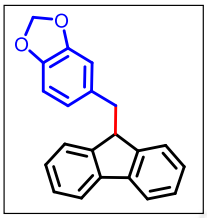
9-(3,4,5-trimethoxybenzyl)-*9H*-fluorene (2.3q): [23] White solid, 63% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.72 (d, *J* = 7.6 Hz, 2H), 7.35-7.32 (m, 2H), 7.26 – 7.22 (m, 4H), 6.35 (s, 2H), 4.20 (t, *J* = 7.3 Hz, 1H), 3.84 (s, 3H), 3.74 (s, 6H), 3.07 (d, *J* = 7.3 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 152.9, 146.6, 141.0, 136.4, 135.2, 127.2, 126.7, 125.0, 120.0, 106.4, 61.1, 56.1, 48.7, 40.3.



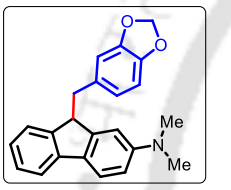
2,7-dichloro-9-(3,4,5-trimethoxybenzyl)-*9H*-fluorene(2.3r): White solid, 72% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.56 (d, *J* = 8.1 Hz, 2H), 7.32 (dd, *J* = 8.1, 1.5 Hz, 2H), 7.23 (s, 2H), 6.28 (s, 2H), 4.14 (t, *J* = 7.1 Hz, 1H), 3.83 (s, 3H), 3.76 (s, 6H), 3.04 (d, *J* = 7.1 Hz, 2H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 153.1, 148.1, 138.7, 137.1, 133.9, 132.8, 127.7, 125.5, 120.9, 106.8, 61.1, 56.2, 48.9, 40.1. HRMS (ESI) m/z (M+H): 415.0868, found: 415.0869.



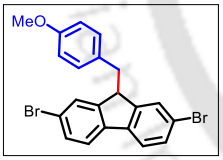
5-((*9H*-fluoren-9-yl)methyl)benzo[d][1,3]dioxole (2.3s):[24] White solid, 96% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ**7.73 (d, *J* = 7.6 Hz, 2H), 7.36-7.32 (m, 2H), 7.25 – 7.19 (m, 4H), 6.74 – 6.72 (m, 2H), 6.62 (dd, *J* = 7.9, 1.6 Hz, 1H), 5.94 (s, 2H), 4.15 (t, *J* = 7.5 Hz, 1H), 3.02 (d, *J* = 7.5 Hz, 2H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 147.7, 146.8, 146.1, 141.0, 133.7, 127.3, 126.8, 125.0, 122.7, 120.0, 109.8, 108.1, 101.0, 49.0, 40.0.



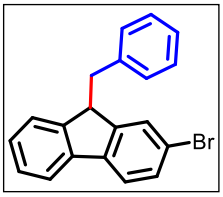
9-(benzo[d][1,3]dioxol-5-ylmethyl)-N,N-dimethyl-*9H*-fluoren-2-amine (2.3t): Brown solid, 89% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.58 (d, *J* = 6.9 Hz, 2H), 7.27 (t, *J* = 7.3 Hz, 1H), 7.16 – 7.08 (m, 2H), 6.79 (s, 1H), 6.75 (d, *J* = 7.8 Hz, 2H), 6.68 (d, *J* = 7.7 Hz, 1H), 6.54 (s, 1H), 5.94 (s, 1H), 5.93 (s, 1H), 4.07 (t, *J* = 7.5 Hz, 1H), 3.05 (dd, *J* = 13.7, 7.5 Hz, 1H), 2.96 – 2.92 (m, 7H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 148.4, 147.6, 146.1, 146.0, 141.5, 134.1, 127.2, 125.0, 124.6, 122.8, 120.5, 118.6, 112.1 110.1, 109.7 108.1, 100.9, 49.1, 41.2, 40.4. HRMS (ESI) m/z (M+H): 344.1651, found: 344.1657.



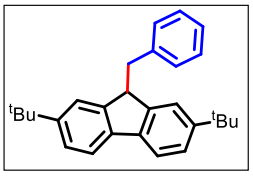
2,7-dibromo-9-(4-methoxybenzyl)-*9H*-fluorene(2.3u): Yellow solid, 82% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.52 (d, *J* = 8.0 Hz, 2H), 7.46 (d, *J* = 8.0 Hz, 2H), 7.29 (s, 2H), 7.05 (d, *J* = 8.5 Hz, 2H), 6.84 (d, *J* = 8.5 Hz, 2H), 4.11 (t, *J* = 7.5 Hz, 1H), 3.81 (s, 3H), 3.02 (d, *J* = 7.5 Hz, 2H). **^{13}C NMR (125 Chloroform-*d*) δ** 158.6, 148.6, 139.0, 130.7, 130.4, 130.5, 128.4, 121.3, 121.0, 114.0, 55.5, 49.1, 39.0. **HRMS (ESI) m/z $(M+K)^+$:** 480.0905, found: 480.0903.



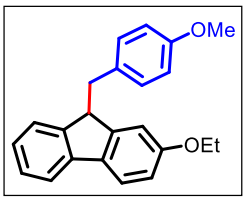
9-benzyl-2-bromo-*9H*-fluorene (2.3v):[18] White solid, 86% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.68 (d, *J* = 7.6 Hz, 1H), 7.56 (d, *J* = 8.1 Hz, 1H), 7.45 (dd, *J* = 7.8 Hz, 1.2 Hz, 1H), 7.34 – 7.17 (m, 8H), 7.18 (d, *J* = 7.2 Hz, 1H), 4.18 (t, *J* = 7.6 Hz, 1H), 3.04 – 3.01 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 148.9, 146.6, 140.0, 139.9, 139.3, 130.3, 129.6, 128.5, 128.3, 127.4, 127.2, 126.7, 125.0, 121.2, 120.5, 120.0, 48.8, 40.0.



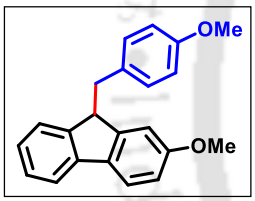
9-benzyl-2,7-di-tert-butyl-*9H*-fluorene(2.3w):[25] White solid, 86% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.60 (d, *J* = 8.0 Hz, 2H), 7.35 – 7.31 (m, 4H), 7.25 (dd, *J* = 13.2, 5.8 Hz, 3H), 7.11 (s, 2H), 4.14 (t, *J* = 7.8 Hz, 1H), 3.06 (d, *J* = 7.9 Hz, 2H), 1.28 (s, 18H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 149.5, 147.0, 140.5, 138.3, 129.9, 128.4, 126.4, 124.2, 122.0, 119.1, 49.1, 40.8, 34.9, 31.7.



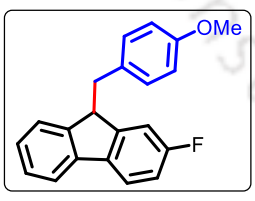
2-ethoxy-9-(4-methoxybenzyl)-*9H*-fluorene (2.3x): White solid, 94% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.61 (t, *J* = 8.1 Hz, 2H), 7.31 – 7.27 (m, 1H), 7.13 – 7.12 (m, 4H), 6.88 (d, *J* = 8.3 Hz, 1H), 6.84 (d, *J* = 8.4 Hz, 2H), 6.70 (s, 1H), 4.11 (t, *J* = 7.6 Hz, 1H), 3.97 (m, 2H), 3.80 (s, 1H), 3.07 – 2.99 (m, 2H), 1.39 (t, *J* = 6.9 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 158.5, 158.3, 148.8, 146.6, 141.0, 133.8, 132.0, 130.6, 127.18, 125.6, 124.8, 120.6, 119.1, 114.1, 113.8, 111.2, 63.8, 55.4, 49.1, 39.5, 15.0. HRMS (ESI) m/z $(M+H)^+$: 331.1698, found: 331.1698



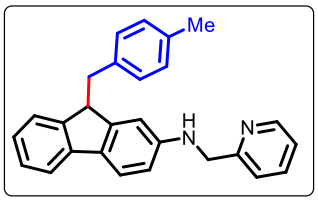
2-methoxy-9-(4-methoxybenzyl)-*9H*-fluorene (2.3y): White solid, 95% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.61 (t, *J* = 8.1 Hz, 2H), 7.31 – 7.28 (m, 1H), 7.15 – 7.12 (m, 4H), 6.88 (dd, *J* = 8.3, 2.3 Hz, 1H), 6.84 (d, *J* = 8.6 Hz, 2H), 6.68 (d, *J* = 2.1 Hz, 1H), 4.12 (t, *J* = 7.6 Hz, 1H), 3.80 (s, 3H), 3.75 (s, 3H), 3.08 (dd, *J* = 13.8, 7.6 Hz, 1H), 2.98 (dd, *J* = 13.8, 7.6 Hz, 1H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 159.2, 158.4, 148.9, 146.6, 140.9, 134.0, 132.0, 130.6, 127.2, 125.6, 124.8, 120.6, 119.1, 113.8, 113.4, 110.6, 55.5, 55.4, 49.1, 39.5. HRMS (ESI) m/z $(M+H)^+$: 317.1542, found: 317.1549.



2-fluoro-9-(4-methoxybenzyl)-*9H*-fluorene (2.3z): White solid, 81% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.66 – 7.62 (m, 2H), 7.34 – 7.31 (m, 1H), 7.22 – 7.18 (m, 2H), 7.09 (d, *J* = 8.5 Hz, 2H), 7.03 – 7.00 (m, 1H), 6.83 (d, *J* = 8.5 Hz, 3H), 4.14 (t, *J* = 7.6 Hz, 1H), 3.80 (s, 3H), 3.08 (dd, *J* = 13.8, 7.6 Hz, 1H), 2.98 (dd, *J* = 13.8, 7.6 Hz, 1H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 162.2 (d, *J* =243.0 Hz), 158.3, 149.0 (d, *J* = 8.2 Hz), 146.7 (d, *J* = 2.1 Hz), 140.0, 136.8 (d, *J* = 2.4 Hz), 131.3, 130.4, 127.2, 126.3, 124.8, 120.6 (d, *J* = 8.1 Hz), 119.5, 114.2 (d, *J* = 22.9 Hz), 113.8, 112.3 (d, *J* = 22.6 Hz), 55.3, 48.9 (d, *J* = 2.3 Hz), 39.0. **^{19}F NMR (470 MHz, $CDCl_3$) δ** -115.3. **HRMS (ESI) m/z (M+H):** 305.1342, found: 305.1346.

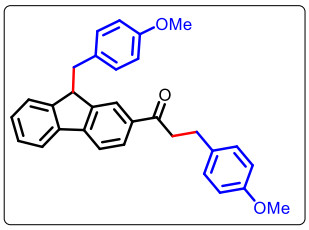


9-(4-methylbenzyl)-N-(pyridin-2-ylmethyl)-*9H*-fluoren-2-amine (2.3aa): Yellow solid, 90% Yield.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.57 (d, *J* = 4.5 Hz, 1H), 7.62 (t, *J* = 7.7 Hz, 1H), 7.54 (d, *J* = 7.5 Hz, 1H), 7.50 (d, *J* = 8.1 Hz, 1H), 7.28 – 7.23 (m, 3H), 7.17 – 7.15 (m, 1H), 7.10 – 7.04 (m, 6H), 6.64 (dd, *J* = 8.1, 1.6 Hz, 1H), 6.47 (s, 1H), 4.40 (s, 2H), 4.08 (t, *J* =

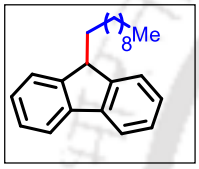


7.5 Hz, 1H), 3.01 (d, *J* = 7.5 Hz, 2H), 2.34 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 158.6, 149.3, 150.0, 147.4, 146.1, 141.6, 137.1, 136.8, 135.7, 131.3, 129.6, 129.0, 127.0, 124.8, 124.6, 122.2, 121.8, 120.7, 118.5, 112.6, 109.6, 49.5, 48.8, 40.0, 21.2. **HRMS (ESI) m/z (M+H):** 377.2018, found: 377.2019.

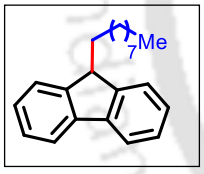
1-(9-(4-methoxybenzyl)-*9H*-fluoren-2-yl)-3-(4-methoxyphenyl)propan-1-one (2.3ab): White solid, 62% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.98 (d, *J* = 8.4 Hz, 1H), 7.76 (t, *J* = 7.8 Hz, 2H), 7.72 (s, 1H), 7.37 (t, *J* = 7.8 Hz, 1H), 7.29 (t, *J* = 7.2 Hz, 1H), 7.25 – 7.23 (m, 1H), 7.16 (d, *J* = 8.4 Hz, 2H), 7.08 (d, *J* = 8.4 Hz, 2H), 6.85 (d, *J* = 8.4 Hz, 2H), 6.81 (d, *J* = 8.4 Hz, 2H), 4.20 (t, *J* = 7.5 Hz, 1H), 3.79 (s, 3H), 3.74 (s, 3H), 3.17 (t, *J* = 7.2 Hz, 2H), 3.11 – 3.02 (m, 2H), 3.00 (t, *J* = 7.2 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 199.4, 158.4, 158.1, 148.3, 147.0, 145.7, 139.7, 135.3, 133.5, 131.5, 130.6, 129.5, 128.0, 127.8, 127.5, 125.2, 124.9, 120.9, 119.8, 114.1, 113.8, 55.4, 55.3, 49.1, 40.8, 39.1, 29.6. **HRMS (ESI) m/z $(M+H)^+$:** 449.2117, found: 449.2118.



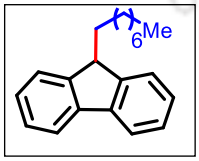
9-decyl-*9H*-fluorene (2.3ac):[18] Sticky yellow oil, 96% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.72 (d, *J* = 7.6 Hz, 2H), 7.49 (d, *J* = 7.4 Hz, 2H), 7.35 – 7.25 (m, 4H), 3.94 (t, *J* = 5.8 Hz, 1H), 1.99 – 1.96 (m, 2H), 1.29 – 1.19 (m, 16H), 0.88 – 0.84 (m, 3H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 147.8, 141.2, 126.9, 126.9, 124.5, 119.9, 47.3, 33.2, 32.1, 30.1, 29.8, 29.7, 29.6, 29.5, 25.8, 22.8, 14.3.



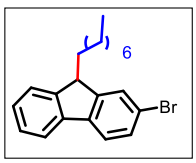
9-nonyl-*9H*-fluorene (2.3ad):[18] Sticky yellow oil, 83% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.74 (d, *J* = 7.5 Hz, 2H), 7.51 (d, *J* = 7.3 Hz, 2H), 7.38–7.33 (m, 2H), 7.31 –7.28 (m, 2H), 3.96 (t, *J* = 5.9 Hz, 1H), 2.01 – 1.96 (m, 2H), 1.29 – 1.15 (m, 14H), 0.86 (t, *J* = 6.9 Hz, 3H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 147.8, 141.2, 126.9, 126.9, 124.5, 119.9, 47.6, 33.2, 32.0, 30.1, 29.7, 29.6, 29.4, 25.9, 22.8, 14.2.



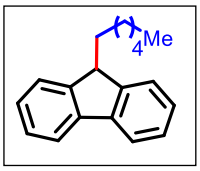
9-octyl-*9H*-fluorene (2.3ae):[19] Sticky yellow oil, 81% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.74 (d, *J* = 7.5 Hz, 2H), 7.50 (d, *J* = 7.4 Hz, 2H), 7.37 – 7.27 (m, 4H), 3.96 (t, *J* = 5.9 Hz, 1H), 2.01 – 1.95 (m, 2H), 1.27 – 1.14 (m, 12H), 0.85 (t, *J* = 6.9 Hz, 3H).**^{13}C NMR (100 MHz, $CDCl_3$) δ** 147.8, 141.2, 126.9, 126.9, 124.5, 119.9, 47.6, 33.2, 32.0, 30.1, 29.5, 29.4, 25.8, 22.8, 14.2.



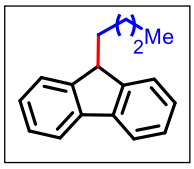
2-bromo-9-octyl-*9H*-fluorene (2.3af):[18] Sticky colourless oil, 87% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.70 (d, *J* = 7.5 Hz, 1H), 7.62 (s, 1H), 7.59 (d, *J* = 8.0 Hz, 1H), 7.48 (t, *J* = 7.0 Hz, 2H), 7.36 – 7.30 (m, 2H), 3.94 (t, *J* = 5.5 Hz, 1H), 2.02 – 1.92 (m, 2H), 1.26 – 1.12 (m, 13H), 0.86 (t, *J* = 7.0 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 149.9, 147.5, 140.3, 140.3, 130.1, 127.8, 127.4, 127.2, 124.5, 121.2, 120.8, 120.0, 47.7, 33.0, 32.0, 30.3, 29.5, 29.4, 25.7, 22.8, 14.2.



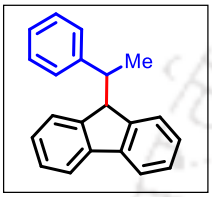
9-hexyl-*9H*-fluorene (2.3ag):[19] Sticky yellow oil, 56% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.74 (d, *J* = 7.5 Hz, 2H), 7.50 (d, *J* = 7.4 Hz, 2H), 7.38 – 7.33 (m,2H), 7.31 – 7.28 (m, 2H), 3.96 (t, *J* = 5.9 Hz, 1H), 2.01 – 1.96 (m, 2H), 1.27 – 1.15 (m, 8H), 0.83 (t, *J* = 6.8 Hz, 3H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 147.8, 141.2, 126.9, 126.9, 124.5, 119.9, 47.6, 33.2, 31.8, 29.8, 25.8, 22.8, 14.2.



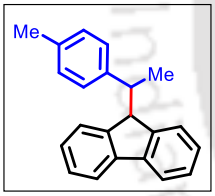
9-butyl-*9H*-fluorene (2.3ah):[19] Sticky yellow oil, 39% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.73 (d, *J* = 7.4 Hz, 2H), 7.49 (d, *J* = 7.3 Hz, 2H), 7.34 (t, *J* = 7.4 Hz, 2H), 7.29 (t, *J* = 7.3 Hz, 2H), 3.95 (t, *J* = 5.6 Hz, 1H), 2.01 – 1.97 (m, 2H), 1.28 – 1.23 (m, 2H), 1.17 – 1.12 (m, 2H), 0.81 (t, *J* = 6.8 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 147.7, 141.2, 126.9, 126.9, 124.4, 119.9, 47.6, 32.9, 27.9, 23.2, 14.1.



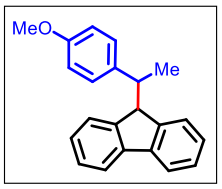
9-(1-phenylethyl)-*9H*-fluorene (2.3ai):[18] Yellow solid, 62% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.72 – 7.68 (m, 2H), 7.48 (d, *J* = 7.4 Hz, 1H), 7.38 – 7.28 (m, 8H), 7.10 (t, *J* = 7.5 Hz, 1H), 6.81 (d, *J* = 7.6 Hz, 1H), 4.28 (d, *J* = 4.5 Hz, 1H), 3.70 – 3.64 (m, 1H), 0.91 (d, *J* = 7.1 Hz, 3H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 146.6, 144.7, 144.7, 142.0, 141.5, 128.3, 128.2, 127.2, 127.2, 126.9, 126.4, 126.4, 125.8, 124.4, 119.8, 119.7, 54.3, 42.0, 14.0.



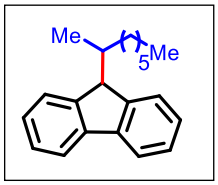
9-(1-(p-tolyl)ethyl)-*9H*-fluorene (2.3aj):[18] Yellow solid, 68% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.72 – 7.68 (m, 2H), 7.48 (d, *J* = 7.4 Hz, 1H), 7.37 – 7.27 (m, 3H), 7. 23 – 7.08 (m, 5H), 6.83 (d, *J* = 7.6 Hz, 1H), 4.26 (d, *J* = 4.3 Hz, 1H), 3.67 – 3.60 (m, 1H), 2.36 (s, 3H), 0.88 (d, *J* = 7.0 Hz, 3H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 146.8, 144.8, 141.2, 141.7, 141.5, 135.9, 129.0, 128.0, 127.1, 127.1, 126.9, 126.3, 125.8, 124.4, 119.8, 119.7, 54.4, 41.6, 21.2, 14.0.



9-(1-(4-methoxyphenyl)ethyl)-*9H*-fluorene (2.3ak):[18] Yellow solid, 71% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.72 – 7.68 (m, 2H), 7.49 (d, *J* = 7.4 Hz, 1H), 7.38 – 7.28 (m, 3H), 7.21 (d, *J* = 8.6 Hz, 2H), 7.11 (td, *J* = 7.5 Hz, 0.88 Hz, 1H), 6.89 – 6.83 (m, 3H), 4.25 (d, *J* = 4.5 Hz, 1H), 3.83 (s, 3H), 3.66 – 3.60 (m, 1H), 0.89 (d, *J* = 8.0 Hz, 3H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 158.1, 146.7, 144.8, 141.9, 141.5, 136.8, 129.1, 127.2, 127.1, 126.9, 126.3, 125.8, 124.4, 119.8, 119.7, 113.6, 55.4, 54.5, 41.2, 14.3.

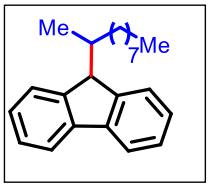


9-(octan-2-yl)-*9H*-fluorene (2.3al):[18] Sticky yellow oil, 64% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.75 – 7.72 (m, 2H), 7.52 – 7.49 (m, 2H), 7.35 (t, *J* = 7.6 Hz, 4H), 7.28 (q, *J* = 7.0 Hz, 1H), 3.99 (brs, 1H), 2.39 – 2.35 (m, 1H), 1.47 – 1.27 (m, 10H), 0.88 (t, *J* = 6.3 Hz, 3H), 0.60 (d, *J* = 6.8 Hz, 3H). **^{13}C NMR**

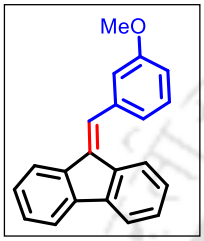


(100 MHz, $CDCl_3$) δ 147.2, 145.9, 142.0, 141.6, 126.9, 126.9, 126.9, 126.7, 125.3, 124.5, 119.8, 119.7, 52.6, 37.3, 34.6, 32.0, 29.6, 28.1, 22.8, 15.8, 14.3.

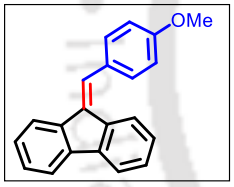
9-(decan-2-yl)-*9H*-fluorene (**2.3am**): Sticky yellow oil, 69% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.68 – 7.65 (m, 2H), 7.44 – 741 (m, 2H), 7.30 – 7.26 (m, 2H), 7.23 – 7.17 (m, 2H), 3.91 (d, *J* = 2.6 Hz, 1H), 2.32 – 2.25 (m, 1H), 1.40 – 1.19 (m, 14H), 0.82 (t, *J* = 6.6 Hz, 3H), 0.52 (d, *J* = 6.8 Hz, 3H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 146.1, 144.8, 140.9, 140.5, 125.8, 125.7, 125.7, 125.5, 124.1, 123.3, 118.6, 118.5, 51.4, 36.1, 33.5, 30.9, 28.7, 28.6, 28.3, 26.9, 21.7, 14.7, 13.1. HRMS (ESI) m/z $(M+)^+$: 306.2348, found: 306.2322.



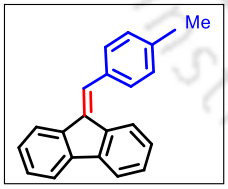
9-(3-methoxybenzylidene)-*9H*-fluorene (2.4a):[26] Yellow solid, 83% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.76 (d, *J* = 7.2 Hz, 1H), 7.70 (d, *J* = 8.2 Hz, 2H), 7.65 (s, 1H), 7.60 (d, *J* = 7.8 Hz, 1H), 7.40 – 7.28 (m, 4H), 7.16 (d, *J* = 8.6 Hz, 1H), 7.11 (s, 1H), 7.08 – 7.04 (m, 1H), 6.94 – 6.92 (m, 1H), 3.82 (s, 3H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 159.8, 141.4, 139.5, 139.3, 138.3, 136.7, 136.6, 129.7, 128.7, 128.4, 127.2, 127.1, 126.8, 124.7, 121.8, 120.4, 119.8, 119.7, 114.3, 114.2, 55.4.



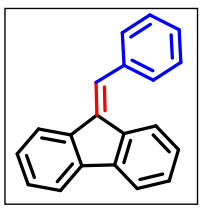
9-(4-methoxybenzylidene)-*9H*-fluorene (2.4b):[21] Yellow solid, 75% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.77 (d, *J* = 7.4 Hz, 1H), 7.73 – 7.69 (m, 3H), 7.65 (s, 1H), 7.55 (d, *J* = 8.5 Hz, 2H), 7.39 – 7.28 (m, 3H), 7.09 (t, *J* = 7.5 Hz, 1H), 6.98 (d, *J* = 8.5 Hz, 2H), 3.88 (s, 3H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 159.6, 141.1, 139.7, 138.9, 136.6, 135.5, 130.9, 129.1, 128.3, 127.9, 127.4, 126.9, 126.6, 124.2, 120.1, 119.7, 119.6, 113.9, 55.4.



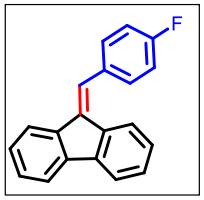
9-(4-methylbenzylidene)-*9H*-fluorene (2.4c):[21] Yellow solid, 82% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.81 (d, *J* = 7.4 Hz, 1H), 7.75 – 7.74 (m, 2H), 7.70 (s, 1H), 7.68 (d, *J* = 7.8 Hz, 1H), 7.52 (d, *J* = 7.8 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 1H), 7.37 – 7.33 (m, 2H), 7.29 (d, *J* = 7.9 Hz, 2H), 7.10 (t, *J* = 7.6 Hz, 1H), 2.47 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 141.2, 139.6, 139.1, 138.0, 136.6, 135.9, 133.8, 129.3, 129.2, 128.4, 128.0, 127.6, 126.9, 126.6, 124.4, 120.2, 119.7, 119.6, 21.5.



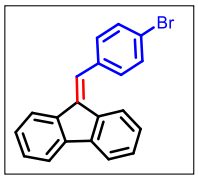
9-benzylidene-*9H*-fluorene (2.4d):[27] Yellow solid, 52% Yield.**^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.81 (d, *J* = 7.28 Hz, 1H), 7.73 – 7.70 (m, 3H), 7.60 – 7.56 (m, 3H), 7.48 – 7.44 (m, 2H), 7.41 – 7.29 (m, 4H), 7.05 (td, *J* = 7.4, 1.0 Hz, 1H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 141.2, 139.5, 139.2, 136.9, 136.6, 136.5, 129.3, 128.5, 128.2, 128.0, 127.3, 127.0, 126.7, 124.4, 120.2, 119.7, 119.6.



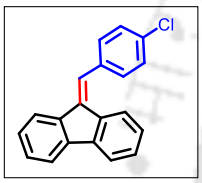
9-(4-fluorobenzylidene)-*9H*-fluorene (2.4e):[21] Yellow solid, 59% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.76 (d, *J* = 7.6 Hz, 1H), 7.71 (d, *J* = 7.5 Hz, 2H), 7.61 (s, 1H), 7.55 – 7.53 (m, 2H), 7.50 (d, *J* = 7.8 Hz, 1H), 7.37 (t, *J* = 7.4 Hz, 1H), 7.32 (q, *J* = 6.3 Hz, 2H), 7.14 (t, *J* = 8.6 Hz, 2H), 7.06 (t, *J* = 7.6 Hz, 1H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 162.6 (d, *J* = 246 Hz), 141.4, 139.4, 139.3, 136.8, 136.5, 133.0 (d, *J* = 3.0 Hz), 131.2 (d, *J* = 7.5 Hz), 128.8, 128.4, 127.2, 126.8, 126.1, 124.4, 120.3, 119.9, 119.8, 115.7 (d, *J* = 21.0 Hz).



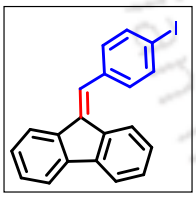
9-(4-bromobenzylidene)-*9H*-fluorene (2.4f):[21] Yellow solid, 75% Yield.**^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.76 (d, *J* = 7.4 Hz, 1H), 7.71 (d, *J* = 7.2 Hz, 2H), 7.60 – 7.56 (m, 3H), 7.52 (d, *J* = 7.8 Hz, 1H), 7.47 – 7.45 (m, 2H), 7.38 (td, *J* = 7.4, 1.2 Hz, 1H), 7.35 – 7.30 (m, 2H), 7.08 (td, *J* = 7.5, 1.2 Hz, 1H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 141.4, 139.3 (2C), 137.1, 136.3, 135.8, 131.8, 131.0, 128.8, 128.5, 127.1, 126.8, 125.6, 124.3, 122.1, 120.1, 119.9, 119.7.



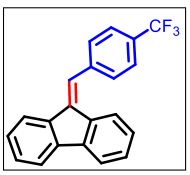
9-(4-chlorobenzylidene)-*9H*-fluorene (2.4g):[21] Yellow solid, 60% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.79 (d, *J* = 7.6 Hz, 1H), 7.74 (d, *J* = 7.5 Hz, 2H), 7.62 (s, 1H), 7.56 – 7.54 (m, 3H), 7.46 – (m, 2H), 7.43 – 7.40 (dt, *J* = 7.74 Hz, *J* = 1.0 Hz, 1H), 7.38 – 7.34 (m, 2H), 7.07 (td, *J* = 7.8 Hz, 1.1 Hz, 1H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 141.4, 139.3, 139.2, 137.1, 136.3, 135.3, 133.9, 130.7, 128.8, 128.5, 127.1, 126.8, 125.7, 124.3, 120.3, 119.9, 119.7.



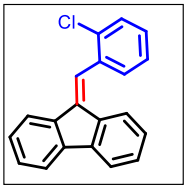
9-(4-iodobenzylidene)-*9H*-fluorene (2.4h):[28] Yellow solid, 61% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.79 (d, *J* = 8.2 Hz, 2H), 7.76 (d, *J* = 7.6 Hz, 1H), 7.71 (d, *J* = 7.5 Hz, 2H), 7.55 – 7.53 (m, 2H), 7.38 (t, J = 7.8 Hz, 1H), 7.33 (t, *J* = 8.1 Hz, 4H), 7.09 –7.06 (m, 1H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 141.4, 139.3, 139.2, 137.7, 137.0, 136.4, 136.3, 131.2, 128.8, 128.5, 127.1, 126.8, 125.8, 124.4, 120.3, 119.9, 119.7, 93.7.



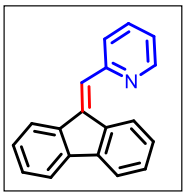
9-(4-(trifluoromethyl)benzylidene)-*9H*-fluorene (2.4i):[21] Yellow solid, 59% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.77 (d, *J* = 7.6 Hz, 1H), 7.75 – 7.71 (m, 6H), 7.62 (s, 1H), 7.46 (d, *J* = 7.8 Hz, 1H), 7.40 (td, *J* = 7.4, 1.1 Hz, 1H), 7.38 – 7.35 (m, 2H), 7.06 (td, *J* = 7.6, 1.1 Hz, 1H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 141.5, 140.7, 139.4, 139.1, 137.9, 136.1, 129.9 (d, *J* = 40.5 Hz), 129.6, 129.1, 128.7, 125.5 (q, *J* = 3.5 Hz), 125.0, 124.4, 124.2 (q, *J* = 269.0 Hz), 120.4, 119.9, 119.7.



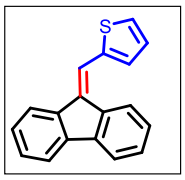
9-(2-chlorobenzylidene)-*9H*-fluorene (2.4j):[21] Yellow oil, 55% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.82 (d, *J* = 7.5 Hz, 1H), 7.71 – 7.65 (m, 3H), 7.60 (s, 1H), 7.51 (d, *J* = 7.6 Hz, 1H), 7.39 – 7.28 (m, 6H), 7.03 (t, *J* = 7.5 Hz, 1H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 141.6, 139.6, 139.3, 137.7, 136.5, 135.6, 134.2, 131.6, 129.9, 129.6, 128.9, 128.7, 127.3, 126.9, 126.7, 124.5, 124.0, 120.8, 119.9, 119.8.



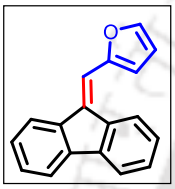
2-((*9H*-fluoren-9-ylidene)methyl)pyridine (2.4k):[21] Yellow solid, 36% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 8.81 (d, *J* = 4.8 Hz, 1H), 8.32 (d, *J* = 7.8 Hz, 1H), 7.82 – 7.79 (m, 1H), 7.77 – 7.75 (m, 1H), 7.71 – 7.69 (m, 2H), 7.65 (d, *J* = 7.7 Hz, 1H), 7.60 (s, 1H), 7.42 – 7.27 (m, 4H), 7.17 (td, *J* = 7.7, 1.1 Hz, 1H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 155.8, 149.8, 141.9, 140.0, 139.8, 138.9, 136.4, 136.4, 129.4, 128.8, 127.2, 127.2, 126.4, 125.8, 125.8, 122.6, 120.6, 119.7, 119.7.



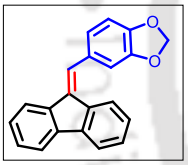
2-((*9H*-fluoren-9-ylidene)methyl)thiophene (2.4l):[21] Yellow solid, 70% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 8.11 (d, *J* = 7.7 Hz, 1H), 7.72 (q, *J* = 7.4 Hz, 3H), 7.61 (s, 1H), 7.47 – 7.44 (m, 2H), 7.38 – 7.29 (m, 3H), 7.21 – 7.13 (m, 2H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 141.4, 139.7, 139.2, 139.1, 136.7, 136.3, 129.4, 128.9, 128.4, 127.7, 127.5, 127.1, 127.0, 124.5, 120.3, 120.0, 119.8, 119.1.



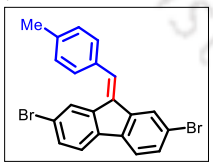
2-((*9H*-fluoren-9-ylidene)methyl)furan (2.4m):[21] Yellow solid, 68% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 8.76 (d, *J* = 7.3 Hz, 1H), 7.74 – 7.67 (m, 4H), 7.40 – 7.28 (m, 5H), 6.75 (d, *J* = 3.4 Hz, 1H), 6.57 (dd, *J* = 3.4, 1.8 Hz, 1H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 152.2, 143.9, 141.1, 140.3, 139.0, 136.2, 132.7, 128.5, 127.9, 127.1, 126.8, 125.7, 119.9, 119.6, 119.6, 115.6, 112.7, 112.5.



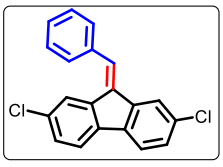
5-((*9H*-fluoren-9-ylidene)methyl)benzo[d][1,3]dioxole (2.4n):[21] Yellow solid, 52% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.75 (d, *J* = 7.6 Hz, 1H), 7.72 – 7.70 (m, 3H), 7.58 (s, 1H), 7.36 (t, *J* = 7.4 Hz, 1H), 7.31–7.29 (m, 2H), 7.11 –7.07 (m, 2H), 6.89 (d, *J* = 7.9 Hz, 1H), 6.03 (s, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 147.9, 147.7, 141.3, 139.7, 139.2, 136.5, 136.0, 130.7, 128.6, 128.2, 127.3, 127.3, 126.8, 124.5, 123.6, 120.2, 119.9, 119.7, 109.7, 108.6, 101.4.



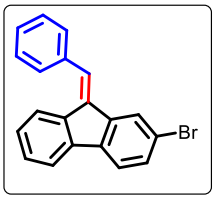
2,7-dibromo-9-(4-methylbenzylidene)-*9H*-fluorene (2.4o):[29] Yellow solid, 77% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.86 – 7.85 (m, 1H), 7.81 (d, *J* = 1.6 Hz, 1H), 7.65 (s, 1H), 7.53 – 7.51 (m, 2H), 7.48 – 7.44 (m, 3H), 7.42 (dd, *J* = 8.1, 1.7 Hz, 1H), 7.28 (d, *J* = 7.8 Hz, 2H), 2.45 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 141.5, 139.2, 139.2, 138.3, 137.0, 134.0, 132.8, 131.5, 131.2, 130.5, 129.6, 129.4, 127.5, 123.7, 121.3, 121.1, 121.0, 120.9, 21.6.



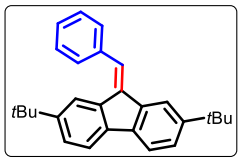
9-benzylidene-2,7-dichloro-*9H*-fluorene (2.4p):[30] Yellow solid, 65% Yield, **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.73 (d, *J* = 1.5 Hz, 1H), 7.70 (s, 1H), 7.59 – 7.55 (m, 4H), 7.51 – 7.43 (m, 4H), 7.34 (dd, *J* = 8.1, 1.8 Hz, 1H), 7.28 (dd, *J* = 8.1, 1.8 Hz, 1H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 141.1, 138.8, 138.0, 136.7, 135.9, 134.8, 133.3, 132.7, 130.0, 129.3, 128.9, 128.9, 128.8, 128.5, 124.7, 120.9, 120.7.



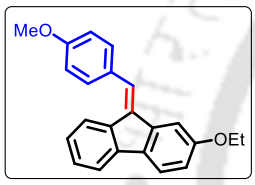
(E)-9-benzylidene-2-bromo-*9H*-fluorene (2.4q):[31] Yellow solid, 80% Yield, **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.90 (d, *J* = 1.8 Hz, 1H), 7.68 – 7.66 (m, 2H), 7.58 – 7.55 (m, 4H), 7.50 – 7.48 (m, 3H), 7.42 – 7.40 (m, 1H), 7.31 (t, *J* = 7.4 Hz, 1H), 7.08 (t, *J* = 7.6 Hz, 1H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 141.5, 140.4, 138.1, 136.5, 136.4, 135.6, 131.1, 129.3, 128.9, 128.7, 128.7, 128.5, 127.2, 124.5, 123.7, 121.0, 119.9.



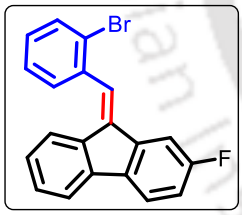
9-benzylidene-2,7-di-tert-butyl-*9H*-fluorene (2.4r):[30] Yellow solid, 81% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.79 (s, 1H), 7.68 (s, 1H), 7.60 – 7.56 (m, 4H), 7.52 (s, 1H), 7.46 (t, *J* = 7.2 Hz, 2H), 7.40 – 7.37 (m, 2H), 7.30 (d, *J* = 7.8 Hz, 1H), 1.41 (s, 9H), 1.15 (s, 9H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 149.9, 149.4, 139.6, 138.8, 137.5, 137.5, 137.1, 137.0, 129.4, 128.5, 128.0, 126.1, 125.7, 125.7, 121.9, 119.1, 119.0, 117.1, 35.1, 34.9, 31.7, 31.4.



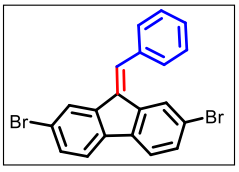
(E)-2-ethoxy-9-(4-methoxybenzylidene)-*9H*-fluorene (2.4s): White solid, 72% Yield,[1]H NMR (500 MHz, Chloroform-*d*) δ 7.71 (d, *J* = 7.5 Hz, 1H), 7.61 – 7.54 (m, 5H), 7.31 (t, *J* = 7.5 Hz, 1H), 7.26 – 7.22 (m, 2H), 6.99 (d, *J* = 8.5 Hz, 2H), 6.86 (dd, *J* = 8.1, 2.0 Hz, 1H), 3.89 – 3.85 (m, 5H), 1.33 (t, *J* = 6.5 Hz, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 159.7, 158.3, 139.6, 139.3, 138.3, 135.7, 134.4, 130.9, 129.2, 128.1, 127.4, 125.9, 120.5, 120.0, 118.9, 115.5, 114.1, 110.3, 63.6, 55.5, 15.0. HRMS (ESI) m/z (M+H): 329.1542, found: 329.1547.



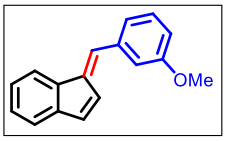
(E)-9-(2-bromobenzylidene)-2-fluoro-*9H*-fluorene (2.4t): [32]Yellow solid, 63% Yield **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.63 (d, *J* = 7.2 Hz, 2H), 7.49 – 7.44 (m, 5H), 7.32 – 7.30 (m, 1H), 7.27 – 7.25 (m, 2H), 7.16 (td, *J* = 8.5, 2.3 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 192.6, 163.6 (d, *J* = 247.5 Hz), 144.0, 140.2 (d, *J* = 3.0 Hz), 136.4 (d, *J* = 7.2 Hz), 135.2, 134.4 (d, *J* = 2.3 Hz), 128.8, 124.7, 121.7 (d, *J* = 8.0 Hz), 120.9 (d, *J* = 23.1 Hz), 120.2, 112.0 (d, *J* = 23.3 Hz). ^{19}F NMR (470 MHz, $CDCl_3$) δ -111.7.



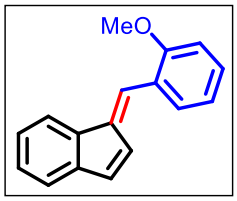
9-benzylidene-2,7-dibromo-*9H*-fluorene (2.4u):[30] Yellow solid, 70% Yield. **^{1}H NMR (500 MHz, Chloroform-d) δ** 7.87 (s, 1H), 7.67 (d, *J* = 7.6 Hz, 2H), 7.48 (m, 9H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 141.2, 139.2, 138.1, 137.1, 135.8, 134.6, 131.6, 131.3, 130.1, 129.3, 129.0, 128.9, 127.5, 123.8, 121.4, 121.1, 121.0, 120.9.



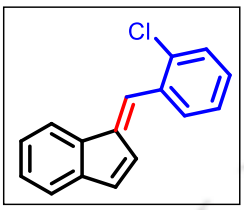
(E)-1-(3-methoxybenzylidene)-1H-indene (2.6a):[33] Yellow solid, 84% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.68 (d, *J* = 7.2 Hz, 1H), 7.46 (s, 1H), 7.34 – 7.30 (m, 2H), 7.26 – 7.18 (m, 3H), 7.13 (s, 1H), 7.03 – 7.00 (m, 2H), 6.90 (d, *J* = 8.2 Hz, 1H), 3.85 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 159.8, 142.2, 140.4, 138.4, 137.5, 134.7, 129.8, 128.7, 127.7, 126.2, 125.3, 123.0, 121.1, 119.3, 115.5, 114.2, 55.4.



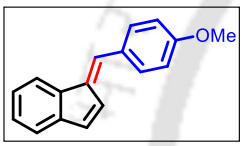
(E)-1-(2-methoxybenzylidene)-1H-indene (2.6b):[34] Yellow solid, 82% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.72 (s, 1H), 7.67 (d, *J* = 7.1 Hz, 1H), 7.50 (d, *J* = 7.5 Hz, 1H), 7.26 – 7.22 (m, 2H), 7.17 – 7.12 (m, 2H), 6.94 (t, *J* = 7.5 Hz, 1H), 6.91 – 6.87 (m, 2H), 6.84 (d, *J* = 8.3 Hz, 1H), 3.81 (s, 3H).**^{13}C NMR (150 MHz, $CDCl_3$) δ** 158.3, 142.3, 140.0, 137.5, 134.0, 132.1, 130.0, 127.4, 126.6, 126.2, 125.1, 124.6, 120.9, 120.7, 119.6, 110.7, 55.7.



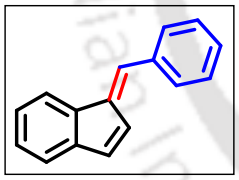
(E)-1-(2-chlorobenzylidene)-1H-indene (2.6c):[35] Yellow solid, 65% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.75 (d, *J* = 7.2 Hz, 1H), 7.70 (s, 1H), 7.60 (d, *J* = 7.5 Hz, 1H), 7.45 (d, *J* = 8.2 Hz, 1H), 7.33 – 7.29 (m, 2H), 7.28 (d, *J* = 7.32 Hz, 1H), 7.25 –7.22 (m, 2H), 7.01 (d, J = 5.76 Hz, 1H), 6.82 (d, *J* = 5.7 Hz, 1H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 142.6, 141.8, 137.1, 135.3, 135.3, 134.9, 132.6, 129.8, 129.5, 128.1, 126.9, 126.1, 125.5, 125.3, 121.2, 119.8.



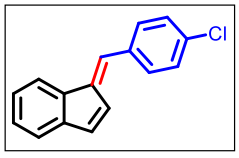
(E)-1-(4-methoxybenzylidene)-1H-indene (2.6d):[35] Yellow solid, 85% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.68 (d, *J* = 7.2 Hz, 1H), 7.57 (d, *J* = 8.7 Hz, 2H), 7.44 (s, 1H), 7.32 (d, *J* = 7.0 Hz, 1H), 7.24 – 7.19 (m, 2H), 7.05 (d, *J* = 5.76 Hz, 1H), 7.00 (d, *J* = 5.76 Hz, 1H), 6.95 (d, *J* = 8.58 Hz, 2H), 3.85 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 160.1, 141.9, 138.3, 137.8, 133.9, 131.9, 129.8, 128.7, 127.2, 126.1, 125.1, 121.0, 119.0, 114.4, 55.5.



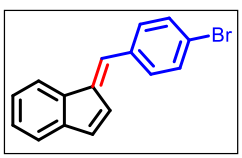
(E)-1-benzylidene-1H-indene (2.6e):[35] Yellow solid, 78% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.70 (d, *J* = 6.6 Hz, 1H), 7.61 (d, *J* = 7.5 Hz, 2H), 7.50 (s, 1H), 7.43 (t, *J* = 7.6 Hz, 2H), 7.33 –7.30 (m, 2H), 7.25 – 7.20 (m, 2H), 7.04 – 7.00 (m, 2H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 142.2, 140.3, 137.6, 137.1, 134.7, 130.4, 128.9, 128.8, 128.5, 127.7, 126.3, 125.3, 121.1, 119.3.



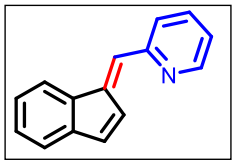
(E)-1-(4-chlorobenzylidene)-1H-indene (2.6f):[35] Yellow solid, 66% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.65 (d, *J* = 7.2 Hz, 1H), 7.50 (d, *J* = 8.1 Hz, 2H), 7.39 – 7.37 (m, 3H), 7.30 (d, *J* = 6.7 Hz, 1H), 7.26 – 7.19 (m, 2H), 7.01 (d, *J* = 5.5 Hz, 1H), 6.94 (d, *J* = 5.5 Hz, 1H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 142.2, 140.7, 137.4, 135.5, 135.2, 134.5, 131.5, 129.1, 127.9, 127.3, 125.8, 125.5, 121.2, 119.3.



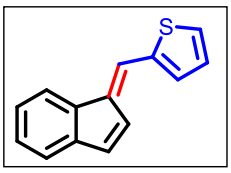
(E)-1-(4-bromobenzylidene)-1H-indene (2.6g):[36] Yellow solid, 61% Yield. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 7.76 (d, *J* = 7.4 Hz, 1H), 7.71 (d, *J* = 7.2 Hz, 2H), 7.60 – 7.56 (m, 2H), 7.52 (d, *J* = 7.8 Hz, 1H), 7.47 – 7.45 (m, 1H), 7.38 (td, *J* = 7.4, 1.2 Hz, 2H), 7.35 – 7.30 (m, 1H), 7.08 (td, *J* = 7.5, 1.2 Hz, 1H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 142.2, 140.8, 137.4, 136.0, 135.3, 132.0, 131.7, 127.9, 127.3, 125.8, 125.5, 122.8, 121.2, 119.3.



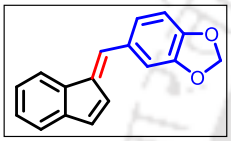
(E)-2-((1H-inden-1-ylidene)methyl)pyridine (2.6h):[24] Yellow solid, 75% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 8.71 (d, *J* = 4.56 Hz, 1H), 7.70 – 7.66 (m, 2H), 7.64 (d, *J* = 6.4 Hz, 1H), 7.50 (d, *J* = 7.8 Hz, 1H), 7.36 (s, 1H), 7.28 (d, *J* = 7.4 Hz, 1H), 7.25 – 7.23 (m, 1H), 7.20 (d, *J* = 7.5 Hz, 1H), 7.18 – 7.16 (m, 1H), 7.02 (d, *J* = 5.9 Hz, 1H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 155.9, 150.2, 142.9, 142.7, 137.8, 136.5, 135.9, 128.3, 127.6, 126.2, 126.0, 125.4, 122.5, 121.2, 119.6.



(E)-2-((1H-inden-1-ylidene)methyl)thiophene (2.6i):[35] Yellow solid, 68% Yield. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.62 (d, *J* = 7.0 Hz, 1H), 7.52 (s, 1H), 7.43 (d, *J* = 5.04 Hz, 1H), 7.34 – 7.28 (m, 2H), 7.22 – 7.17 (m, 3H), 7.08 – 7.06 (m, 1H), 6.99 (d, *J* = 5.7 Hz, 1H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 142.0, 140.8, 137.7, 137.4, 134.2, 131.8, 129.3, 127.8, 127.4, 125.7, 125.3, 121.3, 121.1, 119.1.



(E)-5-((1H-inden-1-ylidene)methyl)benzo[d][1,3]dioxole (2.6j):[24] Yellow solid, 63% Yield. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.66 (d, *J* = 6.9 Hz, 1H), 7.39 (s, 1H), 7.31 (d, *J* = 6.8 Hz, 1H), 7.24 – 7.18 (m, 2H), 7.15 (s, 1H), 7.09 (d, *J* = 7.9 Hz, 1H), 7.03 – 7.00 (m, 2H), 6.87 (d, *J* = 8.0 Hz, 1H), 6.01 (s, 2H). **^{13}C NMR (100 MHz, $CDCl_3$) δ** 148.3, 148.2, 141.9, 138.7, 137.7, 134.2, 131.3, 128.7, 127.4, 125.9, 125.4, 125.2, 121.1, 119.1, 109.9, 108.8, 101.5.



2.8. References:

[1] a) R. H. Crabtree, *Chem. Rev*. **2017**, *117*, 9228−9246; b) C. Gunanathan and D. Milstein, *Chem. Rev*. **2014**, *114*, 12024−12087.

[2] a) B. Blank and R. Kempe, *J. Am. Chem. Soc*. **2010**, *132*, 924–925; b) S. Thiyagarajan and C. Gunanathan, *J. Am. Chem. Soc*. **2019**, *141*, 3822−3827.

[3] a) A. Mondal, R. Sharma, D. Pal and D. Srimani, *Eur. J. Org. Chem*. **2021**,*2021*, 3690–3720; b) A. Mukherjee and D. Milstein, *ACS Catal*. **2018**, *8*, 11435−11469.

[4] a) T. Irrgang, R. Kempe, *Chem. Rev*. **2019**, *119*, 2524–254; b) M. Peña-López, P. Piehl, S. Elangovan, H. Neumann and M. Beller, *Angew. Chem. Int. Ed*. **2016**, *55*, 14967–14971.

[5] a) V. Yadav, V. G. Landge, M. Subaramanian, E. Balaraman, *ACS Catal*. **2020**, 1*0*, 947−954; b) A. Jana, C. B. Reddy, B. Maji, *ACS Catal*. **2018**, *8*, 9226−9231; c) S. Chakraborty, U. K. Das, Y. Ben-David, D. Milstein, *J. Am. Chem. Soc*. **2017**, *139*, 11710−11713.

[6] G. Zhang, T. Irrgang, T.Dietel, Fabian Kallmeier, Rhett Kempe, *Angew. Chem. Int. Ed*.**2018**, *57*, 9131 –9135.

[7] a) M. K. Barman, S. Waiba, B. Maji, *Angew. Chem. Int. Ed*. **2018**, *57*, 9126 –9130; b) A. Jana, A. Kumar, B. Maji, *Chem. Commun*. **2021**, *57*, 3026–3029.

[8] a) S. J. Liu, K. Zhang, J. Lu, J. Zhang, H.-L. Yip, F. Huang, Y. Cao, *J. Am. Chem. Soc*. **2013**, *135*, 15326–15329; b) A. C. Grimsdale, K. L. Chan, R. E. Martin, P. G. Jokisz, A. B. Holmes, *Chem. Rev*. **2009**, *109*, 897–1091.

[9] a) G. Rieveschl, F. E. Ray, *Chem. Rev*. **1938**, *23*, 287; b) S. W. Thomas III, G. D. Joly and T. M. Swager, *Chem. Rev*. **2007**, *107*, 1339.

[10] a) G. Saikia, P. K. Iyer, *J. Org. Chem*. **2010**, *75*, 2714; b) M. Ranger and M. Leclerc, *Chem. Commun*. **1997**, 1597–1598.

[11] a) J. Chen, Y. Li, S. Li, J. Liu, F. Zheng, Z. Zhang and Q. Xu, *Green Chem*. **2017**, *19*, 623–628; b) M. A. Shaikh, S. G. Agalave, A. S. Ubale, B. Gnanaprakasam, *J. Org. Chem*. **2020**, *85*, 2277–2290.

[12] a) G. Kumar, R. Agarwal, S. Swaminathan, *Chem.Commun*. **2012**, *48*, 2412–2414; b) S. J. Gould C. R. Melville, *Bioorg. Med. Chem. Lett*. **1995**, *5*, 51–54.

[13] a) S. Beaupré, P.-L. T. Boudreault and M. Leclerc, *Adv. Mater*. **2010**, *22*, E6–E27; b) A. Shimizu and Y. Tobe, *Angew. Chem., Int. Ed*. **2011**, *50*, 6906–6910.

[14] M. Banerjee, S. J. Emond, S. V. Lindeman, R. Rathore, *J. Org. Chem*. **2007**, *72*, 8054–8061.

[15] Y. Ooyama, R. Sagisaka, T. Enoki, N. Tsunoji and J. Ohshita, *New J. Chem*. **2018**, *42*, 13339–13350.

[16] a) N. Chernyak and V. Gevorgyan, *J. Am. Chem. Soc*. **2008**, *130*, 5636–5637; b) J. Zhao, N. Asao, Y. Yamamoto and T. Jin, *J. Am. Chem. Soc*. **2014**, *136*, 9540–9543.

[17] a) K. Das, A. Mondal, D. Srimani, *Chem. Commun*. **2018**, *54*, 10582−10585; (b) K. Das, A. Mondal and D. Srimani, *J. Org. Chem*. **2018**, *83*, 9553−9560.

[18] J. Chen, Y. Li, S. Li, J. Liu, F. Zheng, Z. Zhang, Q. Xu, *Green Chem.* **2017**, *19*, 623−628.

[19] M. A. Shaikh, S. G. Agalave, A. S. Ubale, B. Gnanaprakasam, *J. Org. Chem.* **2020**, *85*, 2277−2290.

[20] J-T. Fan, Xin-H. Fan, Cai-Y. Gao, Z. Wang, Lian-M. Yang, *RSC Adv*. **2019**, *9*, 35913–35916.

[21] Yu-C. Ma, Jin-Y. Luo, Shi-C. Zhang, Shu-H. Lu, Guang-F. Du, *Org. Biomol. Chem*. **2021**, *19*, 3717−3721.

[22] C. A. Fleckenstein, H. Plenio, *Organometallics*, **2008**, *27*, 3924–3932.

[23] C. A. Fleckenstein, R. Kadyrov, H. Plenio, *Org. Process Res. Dev*. **2008**, *12*, 475–479.

[24] R. K. Mohamed, S. Mondal, K. Jorner, T. F. Delgado, V. V. Lobodin, H. OttossonAlabugin, V. Igor- *J. Am. Chem. Soc*. **2015**, *137*, 15441−15450.

[25] A. Alberti, G.F. Pedulli, R. Leardin, A. Tundo, G. Zanardi, *Tetrahedron*, **1986**, *42*, 2533 – 2538.

[26] C. Do, J. Hatfield, S. Patel, D. Vasudevan, C. Tirla, N. S. Mills, *J. Org. Chem.* **2011**, *76*, 181–187.

[27] H. E. Ho, N. Asao, Y. Yamamoto, T. Jin, *Org. Lett.* **2014**, *16*, 4670−4673.

[28] M. T. Colvin, A. L. Smeigh, E. M. Giacobbe, S. M. M. Conron, A. B. Ricks, M. R. Wasielewski, *J. Phys. Chem. A.* **2011**, *115*, 7538–7549.

[29] G. A. Corrente, E. Fabiano, F. Manni, G. Chidichimo, G. Gigli, A. Beneduci, A.-L. Capodilupo, *Chem. Mater*. **2018**, *30*, 5610−5620.

[30] L. Yang, I. D. Gridnev, M. Terada Jin, T. *Org. Lett.* **2020**, *22*, 8920−8924.

[31] A. S. Ubale, M. B. Chaudhari, M. A. Shaikh and B. Gnanaprakasam, *J. Org. Chem.* **2020**, *85*, 10488–10503.

[32] E. H. Weyand, S. Amin, K. Huie, E. Boger, E. Neuber, S. S. Hecht, E. LaVoie, J. *Chem.-Biol. Interactions*,**1989**, *71*, 279 - 290.

[33] G. Kresze, H-G. Henkel, H. Goetz, **1964**, doi.org/10.1002/jlac.19646740104.

[34] M. Zheng, L. Wang, J. Shao, i. Zhong, *Synth. Commun.* **1997**, *27*, 1751–1755.

[35] R. Yi, J. Chen, X. Wang, Z. Liang, X. Xu. *Eur. J. Org. Chem.* **2018**, 1347–1351.

[36] K. Kondo, H. Goda, K. Takemoto, H. Aso, T. Sasaki, K. Kawakami, H. Yoshida, Yoshida, K. *J. Mater. Chem.* **1992**, *2*, 1097–1102.

[37] B. Chatterjee, C. Gunanathan, *Org. Lett.* **2015**, *17*, 4794−4797.

2.9. Selective ^{1}H & ^{13}C copies of synthesised compounds:

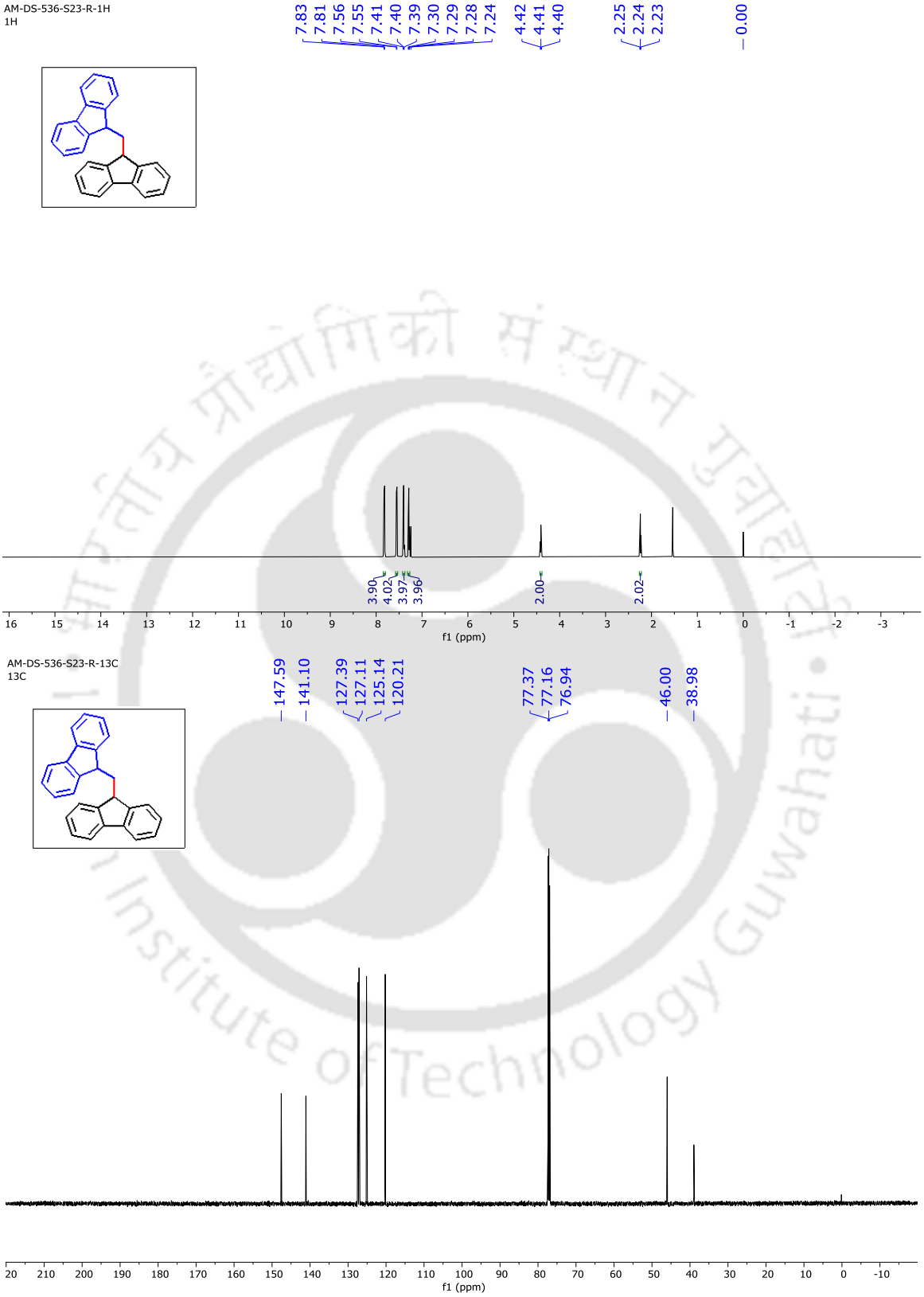


Figure 2.4.^{1}H (600 MHz) and $^{13}C\{^{1}H\}$ (150 MHz) NMR Spectrum of di(9H-fluoren-9-yl)methane **(2.3p)** in $CDCl_3$.

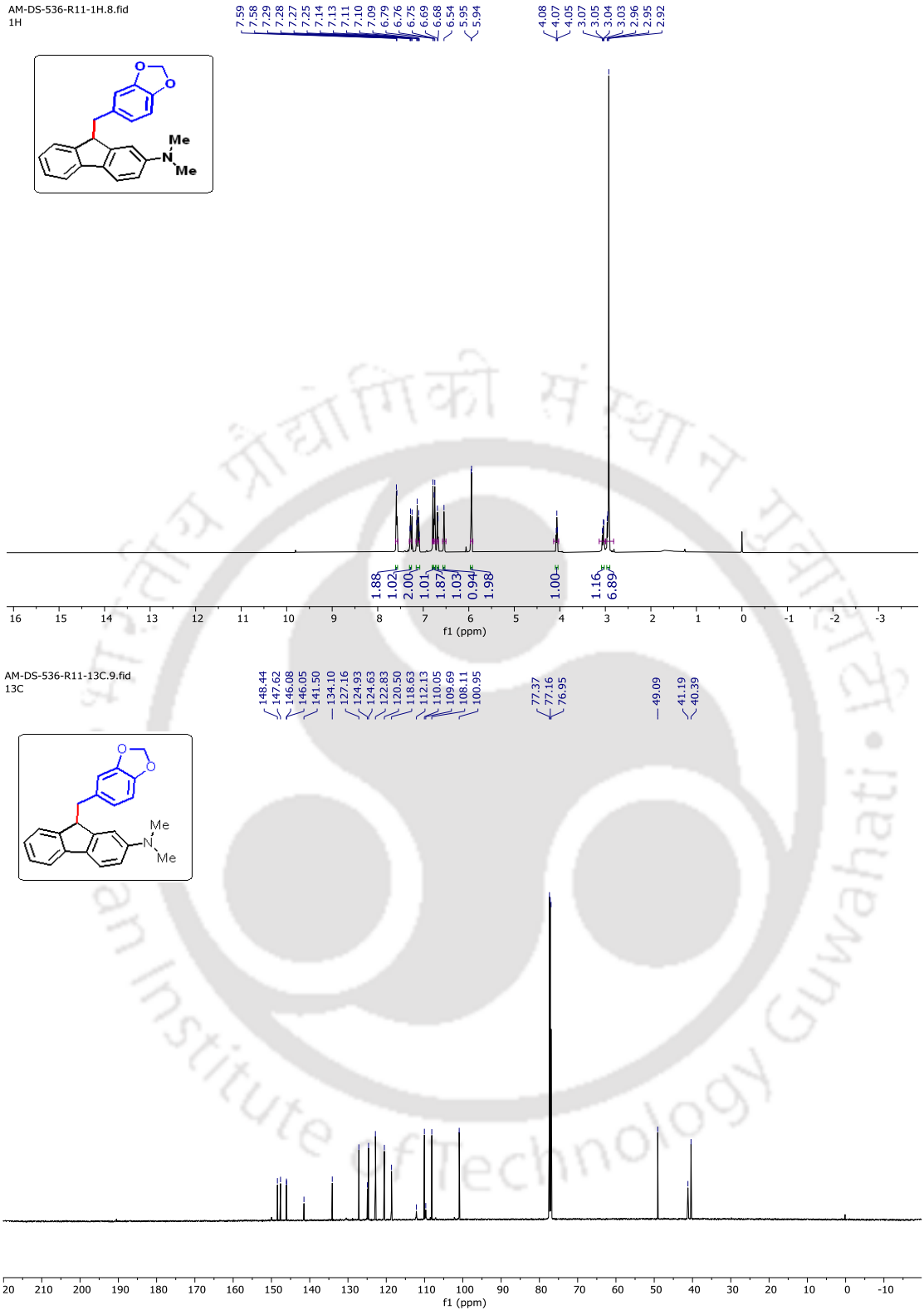


Figure 2.5. ^{1}H (600 MHz) and $^{13}C\{^{1}H\}$ (150 MHz) NMR Spectrum of 9-(benzo[d][1,3]dioxol-5-ylmethyl)-N,N-dimethyl-9H-fluoren-2-amine **(2.3t)** in $CDCl_3$.

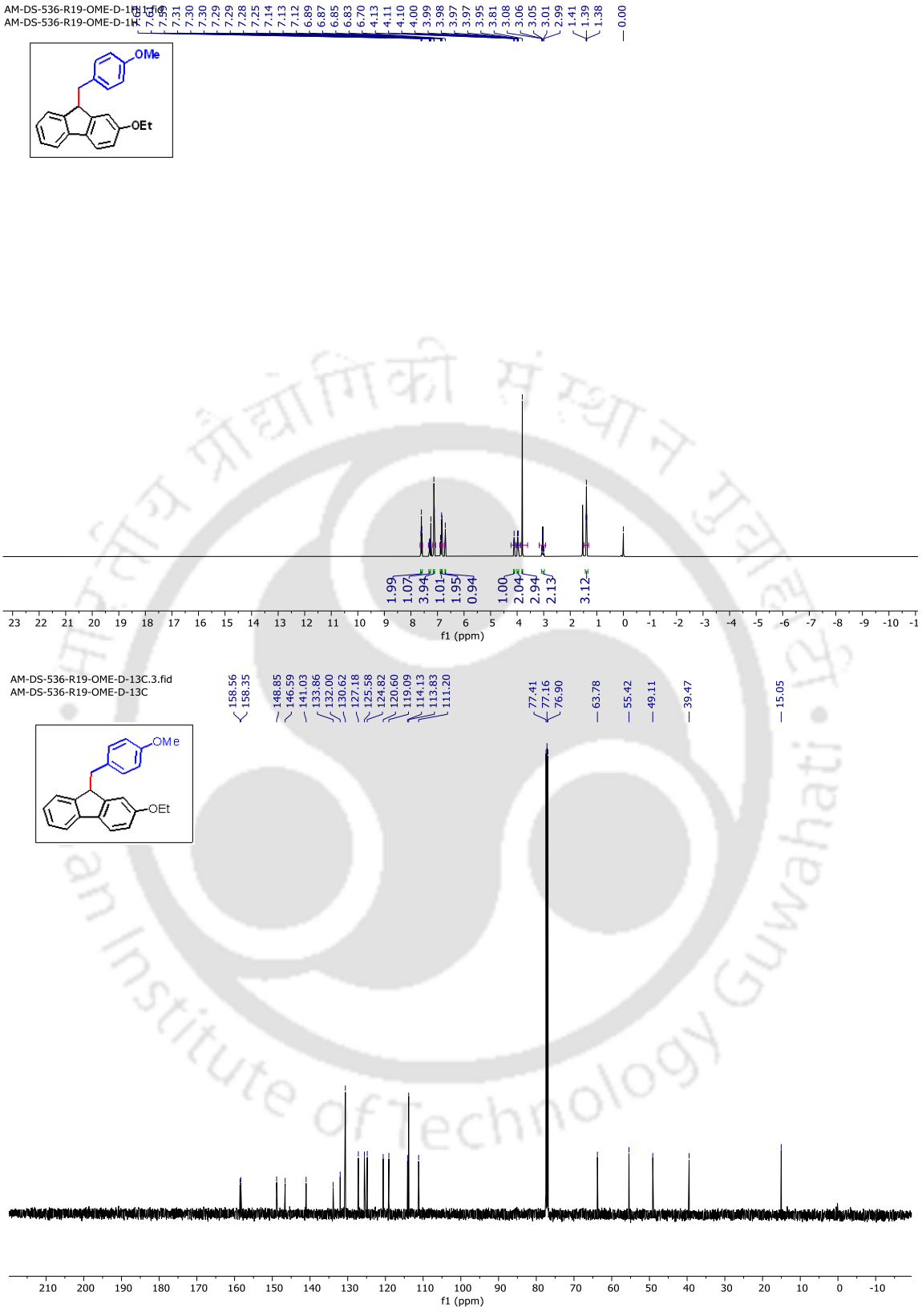


Figure 2.6. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of 2-ethoxy-9-(4-methoxybenzyl)-9H-fluorene **(2.3x)** in $CDCl_3$.

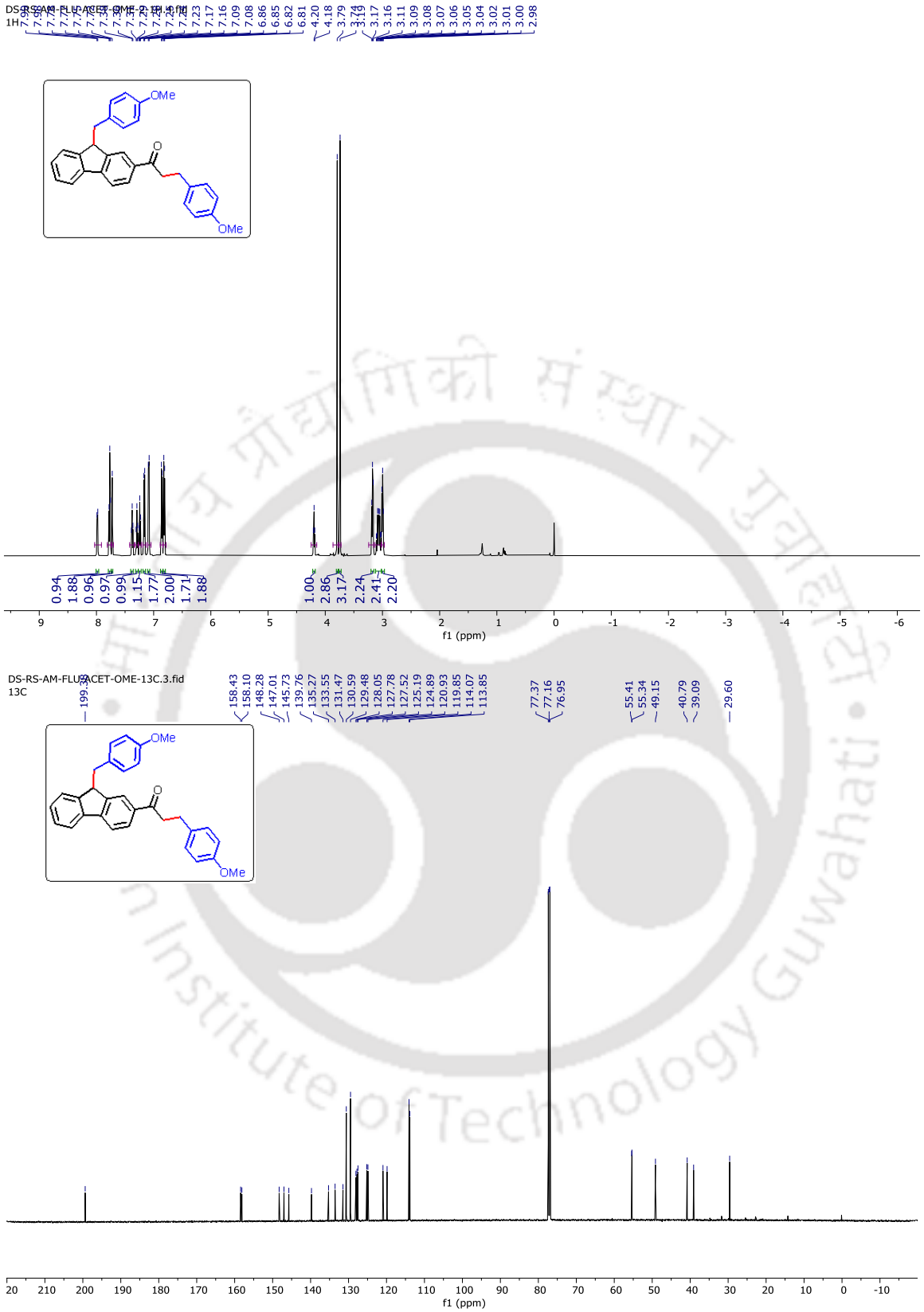


Figure 2.7.^{1}H (600 MHz) and^{13}C{^{1}H} (150 MHz) NMR Spectrum of 1-(9-(4-methoxybenzyl)-9H-fluoren-2-yl)-3-(4-methoxyphenyl)propan-1-one **(2.3ab)** in $CDCl_3$.

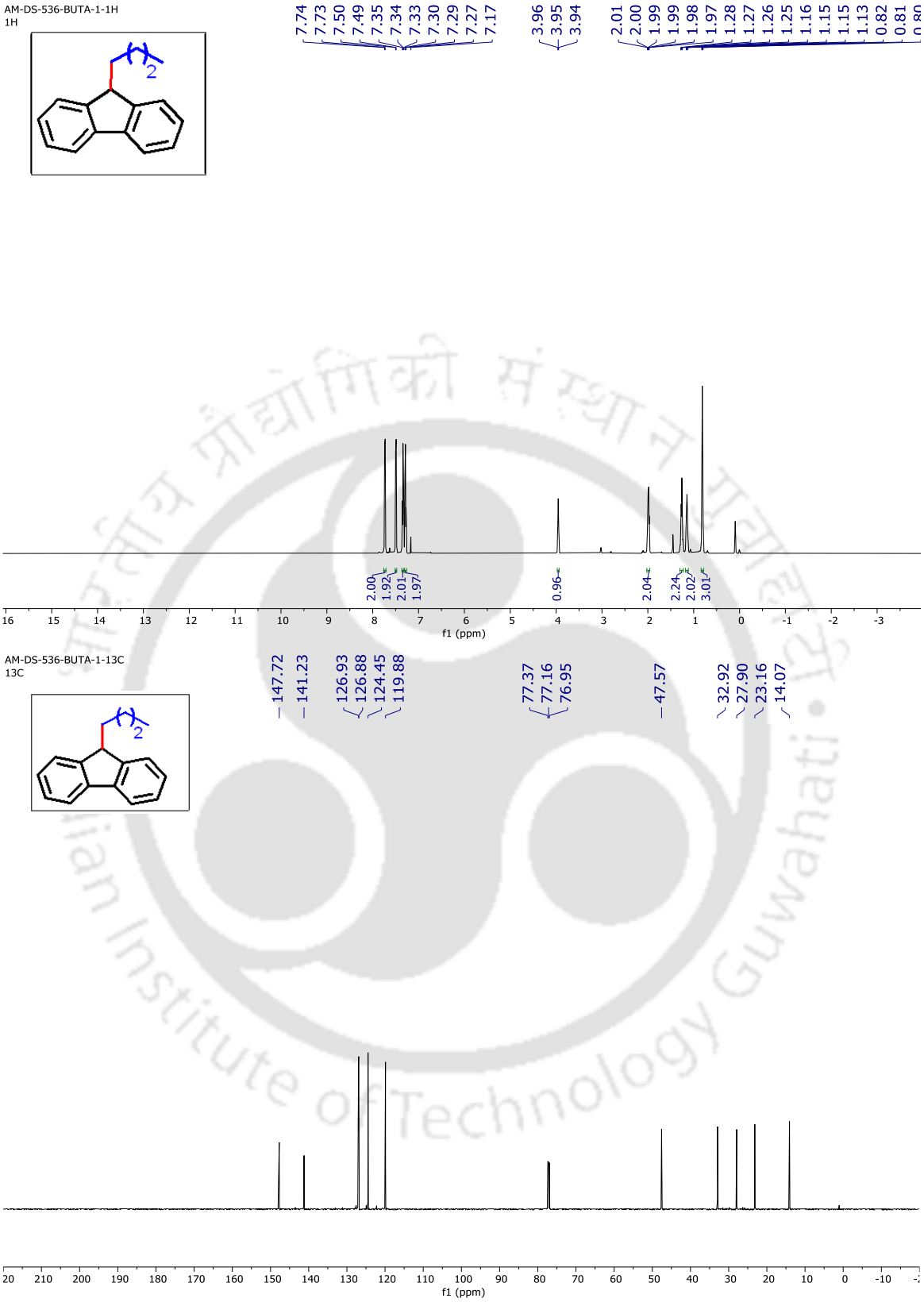


Figure 2.8. ^{1}H (600 MHz) and $^{13}C\{^{1}H\}$ (150 MHz) NMR Spectrum of 9-butyl-9H-fluorene **(2.3ah)** in $CDCl_3$.

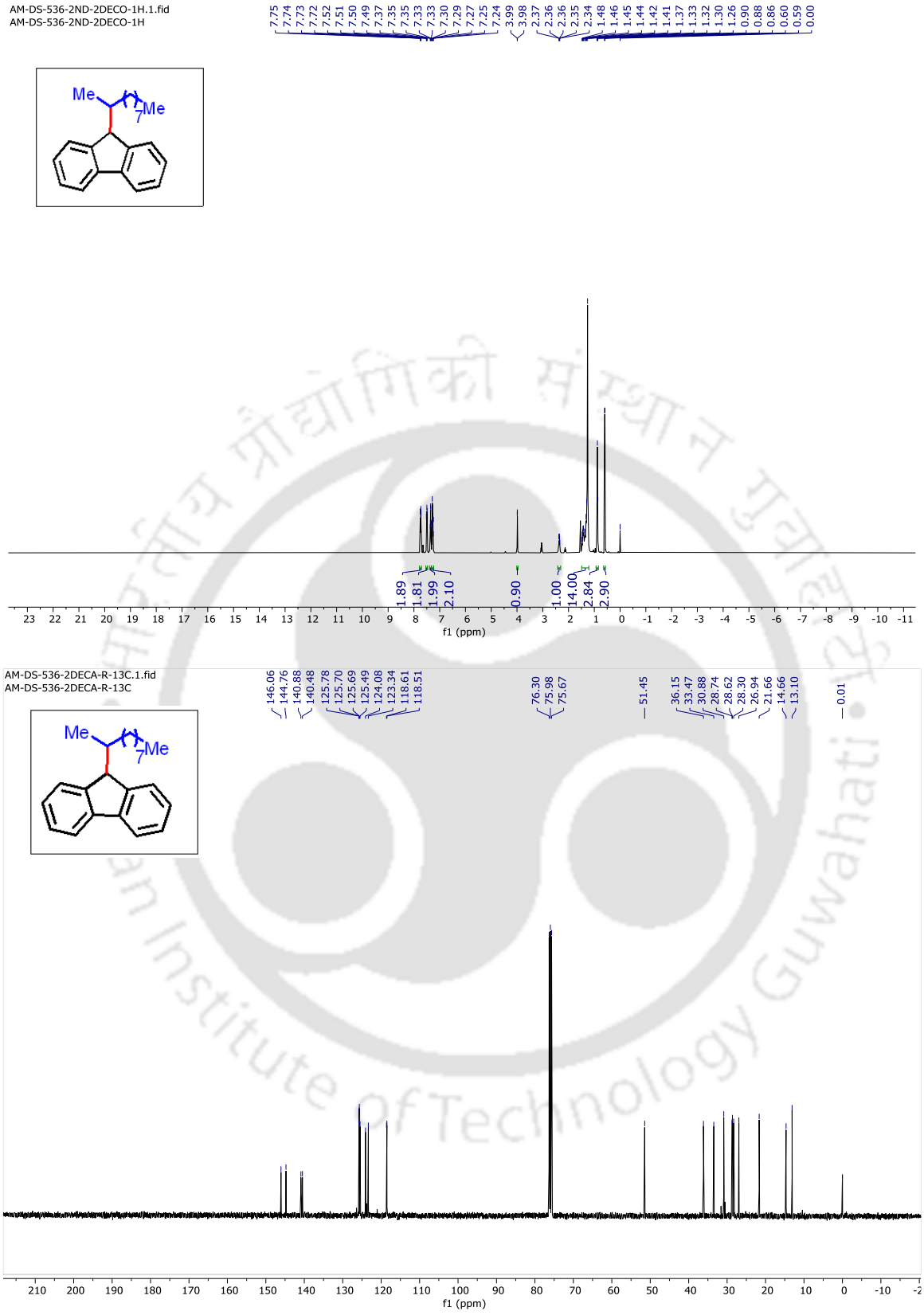


Figure 2.9.^{1}H (400 MHz) and^{13}C{^{1}H} (100 MHz) NMR Spectrum of 9-(decan-2-yl)-9H-fluorene **(2.3am)** in $CDCl_3$.

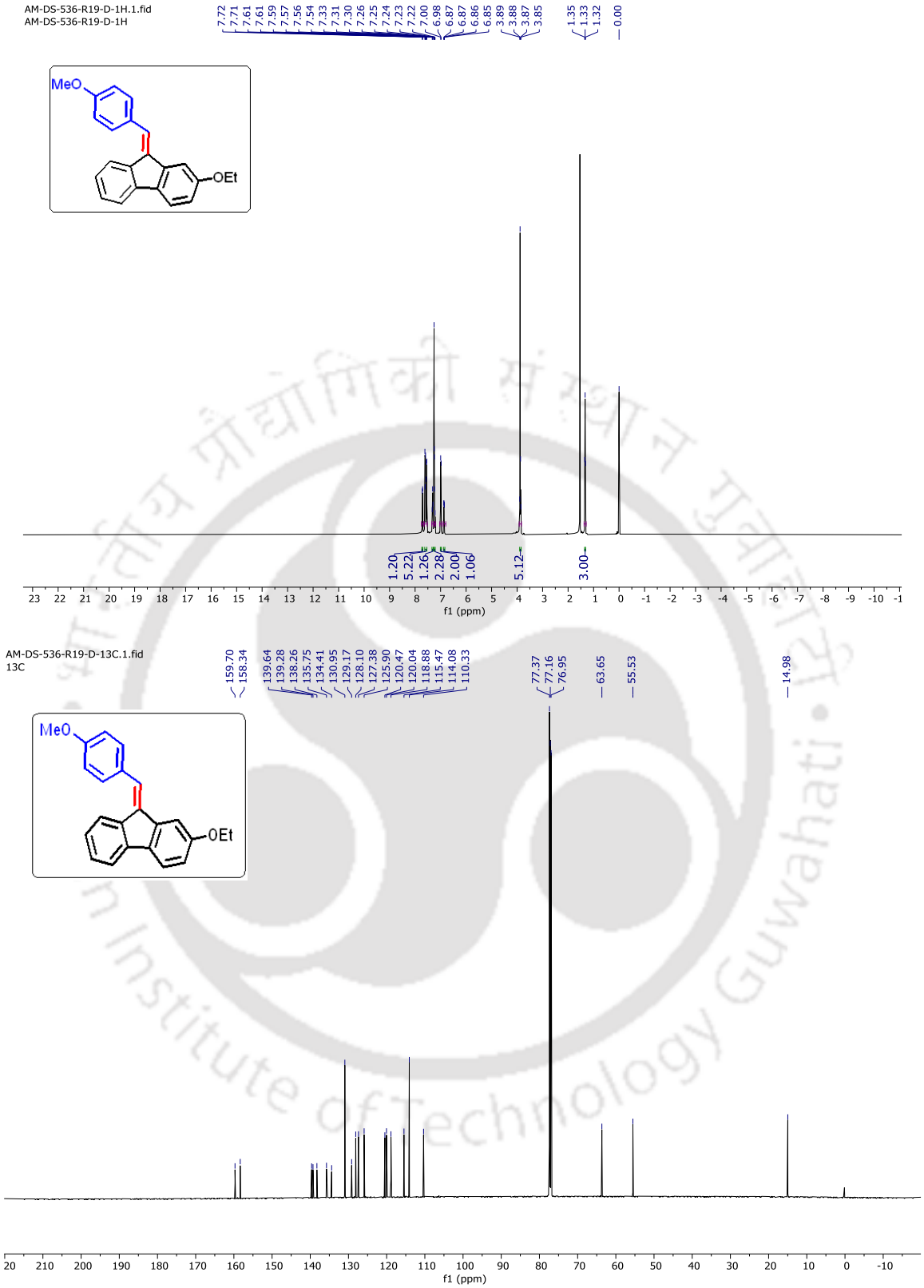


Figure 2.10.^{1}H (500 MHz) and^{13}C{^{1}H} (125 MHz) NMR Spectrum of (E)-2-ethoxy-9-(4-methoxybenzylidene)-9H-fluorene **(2.4s)** in $CDCl_3$.

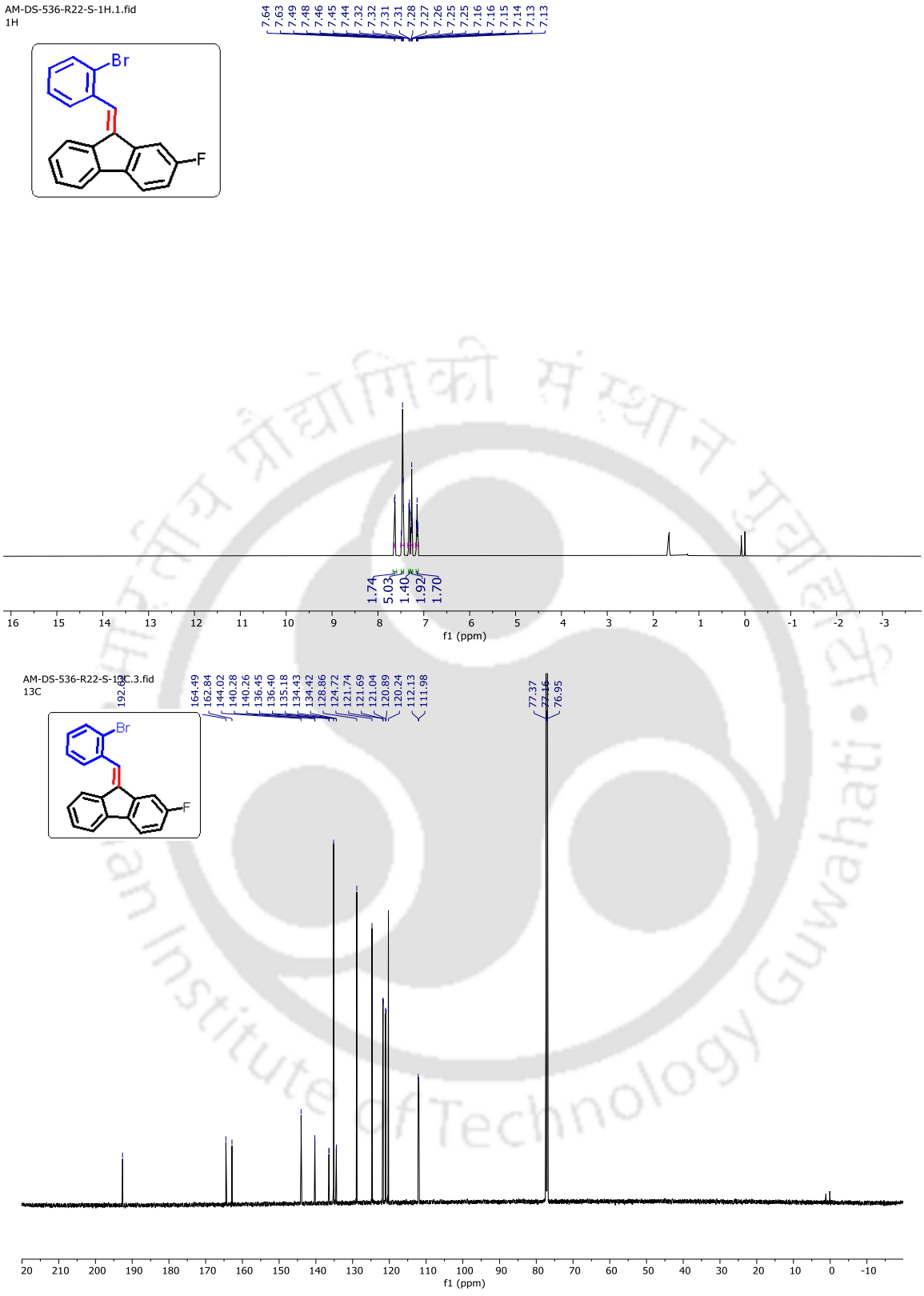


Figure 2.11. ^{1}H (600 MHz) and $^{13}C\{^{1}H\}$ (150 MHz) NMR Spectrum of (E)-9-(2-bromobenzylidene)-2-fluoro-9H-fluorene **(2.4t)** in $CDCl_3$.

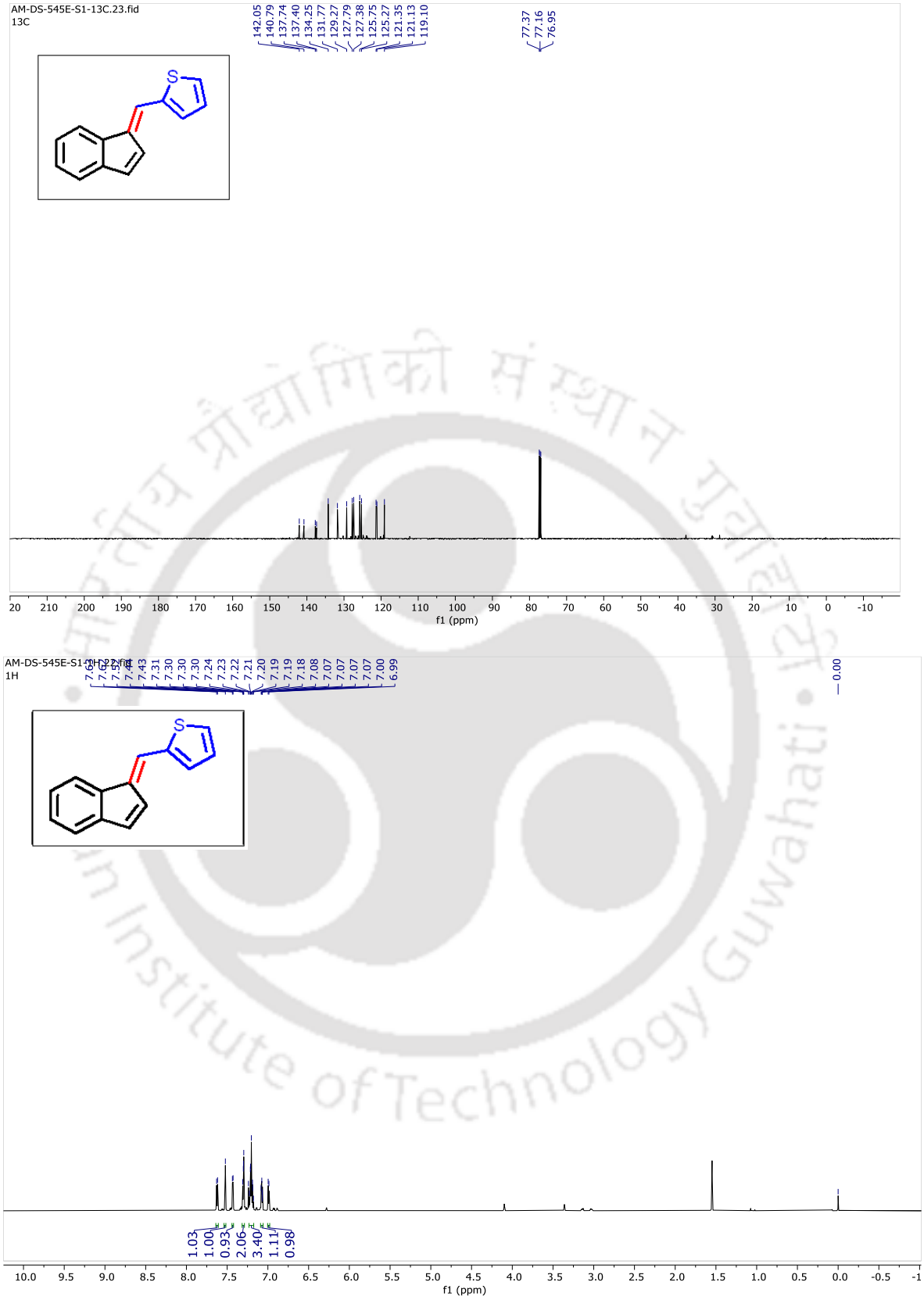


Figure 2.12.^{1}H (600 MHz) and^{13}C{^{1}H} (150 MHz) NMR Spectrum of (E)-2-((1H-inden-1-ylidene)methyl)thiophene **(2.6i)** in $CDCl_3$.

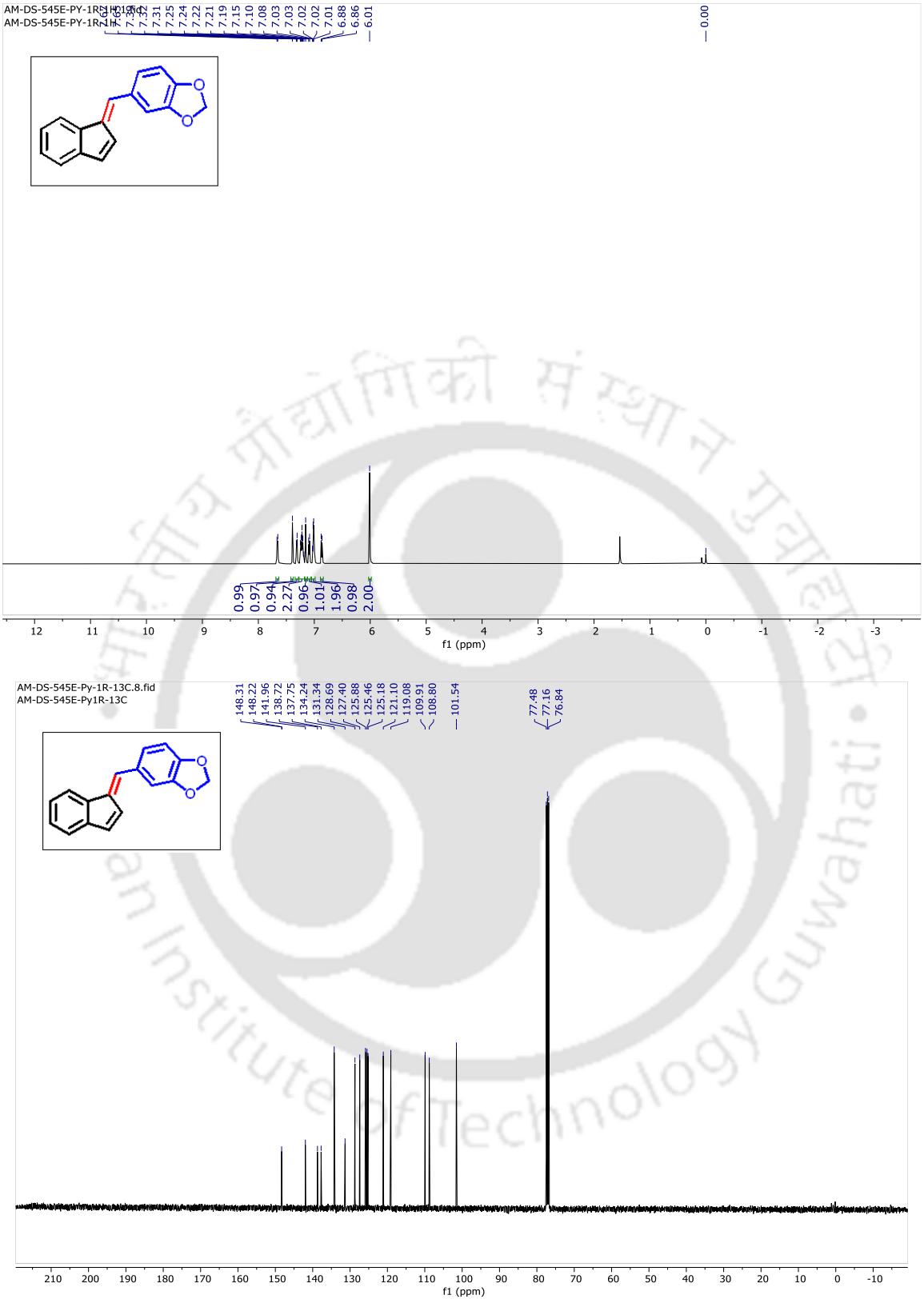
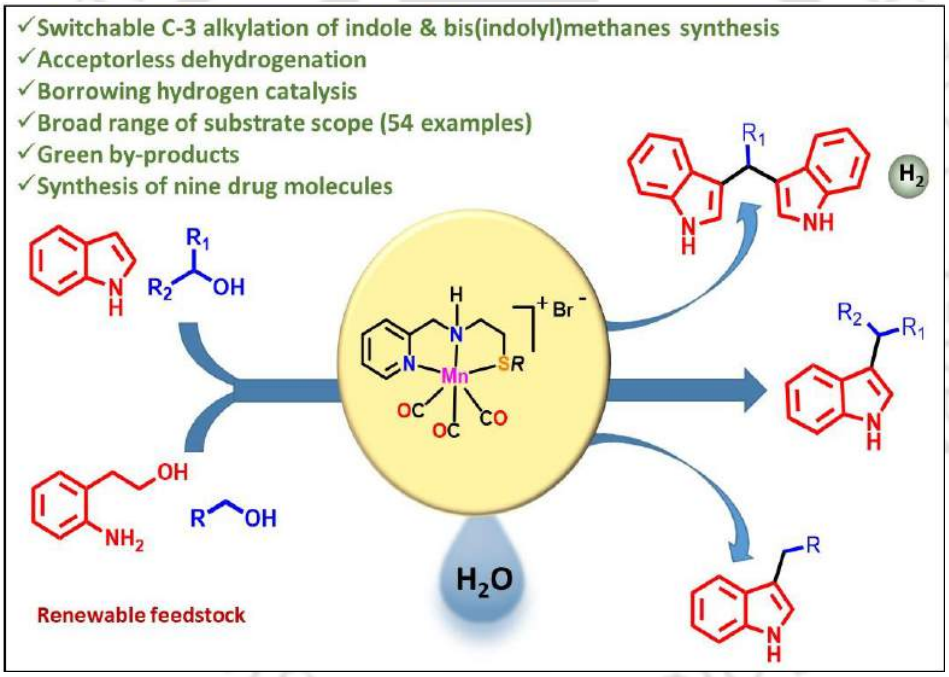


Figure 2.13. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of (E)-5-((1H-inden-1-ylidene)methyl) benzo[d][1,3]dioxole**(2.6j)** in $CDCl_3$.

CHAPTER 3

Well-defined NNS-Mn(I) Complex Catalysed Selective Synthesis of C-3 Alkylated Indoles and Bisindolylmethanes from Same Set of Starting Materials



A. Mondal, R. Sharma, D. Pal, B. Dutta, D. Srimani, *J. Org. Chem.* 2022, *87*, 6, 3989–4000.

3.1. Introduction: Indole is one of the most ubiquitous structural scaffolds in bio-active natural and unnatural compounds.[1] Functionalized indoles epitomize a vital chemical motif in medicinal chemistry and agrochemistry.[2] Numerous drugs like bufotenine, heteroauxin, serotonin, tryptophan, and melatonin contain this basic structural unit.[3] Not only C-3 alkylated indoles but also bis(indolyl)methanes (BIMs) are important for their anti-bacterial,[4] anti-tumour,[5] and anti-fungal activities.[6] Thus, the synthesis and selective functionalization of indoles have attracted considerable attention.[7] However, the classical approach relies on the use of prefunctionalized toxic reagents and harsh reaction conditions.[8] This creates substantial unwanted by-products that decrease the atom economy and sustainability.

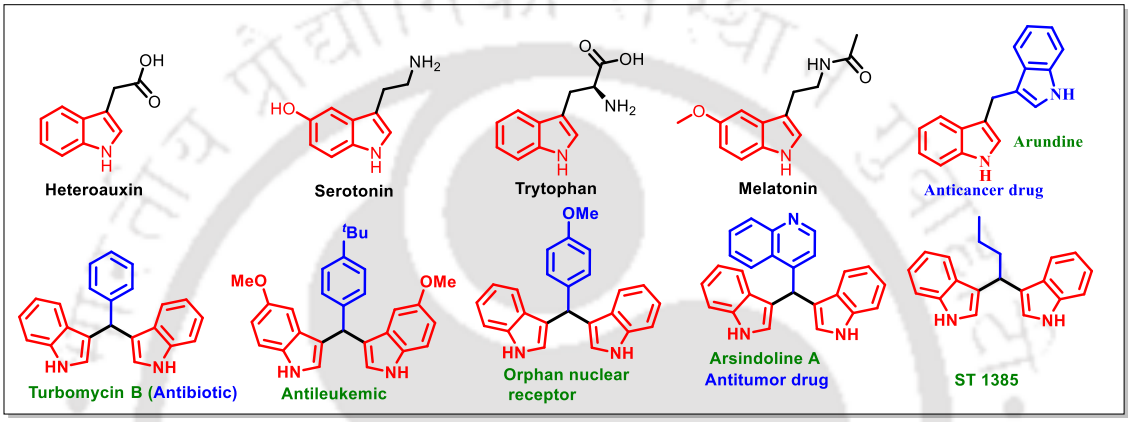


Figure 3.1. Biologically relevant molecules.

3.2. Literature reports:[10-12] The dehydrogenative construction of heterocycles and their selective functionalization with alcohols have attracted considerable attention because of their atom economic, green, and sustainable nature.[9] Catalytic synthesis and functionalization of indoles using renewable alcohols have been mostly explored utilizing noble metal catalysts.[10] Thorough literature study regarding functionalization of indole (discussed in chapter **I, Section 1.17**) reflected that only one example of Ru-catalytic system has been reported which can selectively deliver both C-3 alkylated and bis(indolyl)methanes from indole and alcohols.[10d] Therefore, utilization of base metal catalytic system for the synthesis of both products selectively would be beneficial.

3.3. Present work: This present chapter demonstrated selective synthesis of both C-3 alkylated indoles and bis(indolyl)methanes from same set of alcohols and indoles using single molecularly defined NNS-Mn(I) catalyst. Several mechanistic studies were also conducted. Diverse range of substrates including nine structurally important drug molecules like Arundine, Arsindoline A, Turbomycin B, Antileukemic, Orphan nuclear receptor etc are synthesized. Furthermore, one-pot cascade strategy for synthesizing C-3 functionalized indoles directly from 2-aminophenyl ethanol and alcohol was also highlighted.

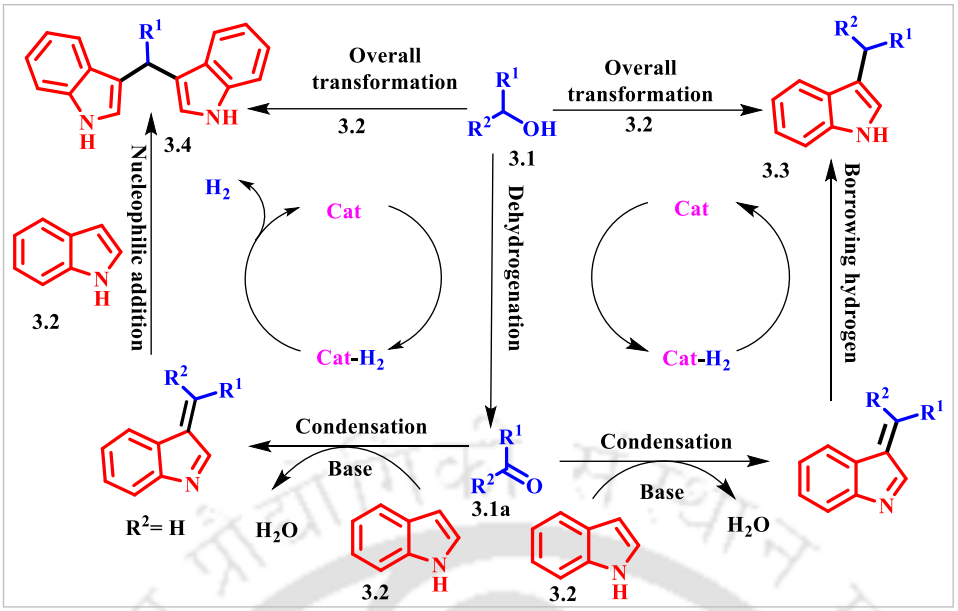
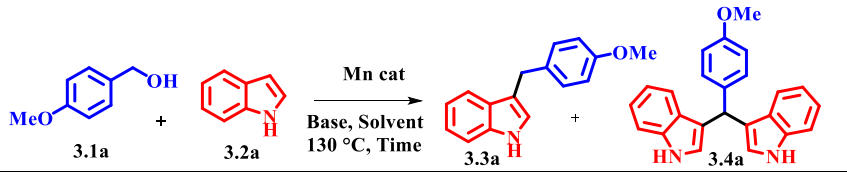


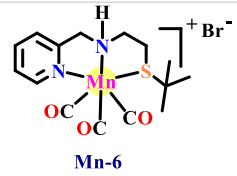
Figure 3.2. Mechanistic overview for C-3 functionalization of indole & bis(indolyl)methanes synthesis.

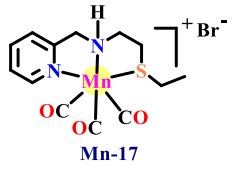
3.3.1. Reaction optimization: In the quest for this particular objective, the potential of NNS-Mn (I) complexes (Figure 2) in this selective functionalization was investigated. Initially, indole and 4-methoxybenzyl alcohol have been chosen as a model substrate to find optimal reaction conditions to synthesize selectively C-3 alkylated indoles/BIMs. Thus, when indole and alcohol were heated in a 2:1 ratio in the presence of 5 mol% of **Mn-6** with 0.25 mmol of KO^{t}Bu under argon atmosphere at 130 °C, 78% yield of BIM product (**3.4a**) was isolated after 24 h (Table **3.1**, entry **1**). Pleasingly, the yield of (**3.4a**) was further improved (94%) simply by increasing the reaction time (36 h) (Table **3.1**, entry **2**). Next, the effect of the weak bases in this reaction was studied. The weak base Na_2CO_3 failed to give any product and other bases like K_2CO_3, NaOH, KOH and CsOH.H_2O gave onlya small amount (10-30%) of the alkylated product (Table **3.1**, entry **3-7**). Moreover, reduced yield was observed when the temperature (100 °C), catalyst loading (3.5 mol%) or amount of KO^{t}Bu (0.15 mmol) were lowered (Table **3.1**, entries **8**–**10**). Notably, on increasing the amount of alcohol, keeping the other parameters constant, the C-3 alkylated product was formed in a major amount (60% yield) (Table **3.1**, entry **16**). On higher concentration of alcohol various reaction parameters also vigorously screened to get best optimal reaction conditions for C-3 alkylated indole (Table **3.1**, entry **17-28**). Gratifyingly, the yield of the C-3 alkylated product was further improved to 93% by switching the base and its amount (Table **3.1**, entry **19**). Control experiments revealed both catalyst and base are essential to activate the reaction (Table **3.1**, entries **23** & **24**).

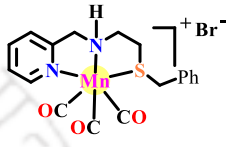
Table 3.1: Reaction optimization for selective functionalization of indole[a,b]

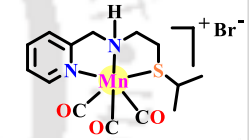


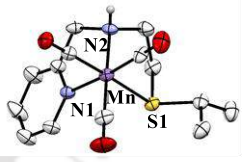
Entry	Cat	Base (mmol)	Solvent (ml)	Time (h)	Alcohol : Indole (mmol)	% Yield [b] 3.3a	3.4a
1	Mn-6	^{t}BuOK (0.25)	Toluene(2)	24	0.5 : 1	--	78
2	Mn-6	^{t}BuOK (0.25)	Toluene(2)	36	0.5 : 1	--	94
3	Mn-6	KOH (0.25)	Toluene(2)	36	0.5 : 1	10	70
4	Mn-6	NaOH (0.25)	Toluene(2)	36	0.5 : 1	--	20
5	Mn-6	Na_2CO_3 (0.25)	Toluene(2)	36	0.5 : 1	--	---
6	Mn-6	K_2CO_3 (0.25)	Toluene(2)	36	0.5 : 1	--	10
7	Mn-6	$Cs_2CO_3.H_2O$ (0.25)	Toluene(2)	36	0.5 : 1	--	30
8[c]	Mn-6	^{t}BuOK (0.25)	Toluene(2)	36	0.5 : 1	--	68
9[d]	Mn-6	^{t}BuOK (0.25)	Toluene(2)	36	0.5 : 1	--	81
10	Mn-6	^{t}BuOK (0.15)	Toluene(2)	36	0.5 : 1	--	72
11	Mn-6	^{t}BuOK (0.25)	Toluene(2)	36	0.5 : 1	--	89
12	Mn-6	^{t}BuOK (0.25)	Toluene(2)	36	0.5 : 1	--	92
13	Mn-6	^{t}BuOK (0.25)	Toluene(2)	36	0.5 : 1	--	73
14	--	^{t}BuOK (0.25)	Toluene(2)	36	0.5 : 1	--	10
15	Mn-6	-----	Toluene(2)	36	0.5 : 1	--	--
16	Mn-6	^{t}BuOK (0.25)	Toluene(2)	36	2.5 : 1	60	30
17	Mn-6	^{t}BuOK (0.25)	Neat	36	2.5 : 1	74	10
18	Mn-6	KOH (0.25)	Neat	36	2.5 : 1	82	---
19	Mn-6	KOH (0.3)	Neat	36	2.5 : 1	93	---
20	Mn-6	KOH (0.3)	Neat	36	1.5 : 1	65	20
21[f]	Mn-6	KOH (0.3)	Neat	36	2.5 : 1	70	10
29[g]	Mn-6	KOH (0.3)	Neat	36	2.5 : 1	58	15
23	....	KOH (0.3)	Neat	36	2.5 : 1	10	----
24	Mn-6	.....	Neat	36	2.5 : 1	Trace	Trace
25	Mn-17	KOH (0.3)	Neat	36	2.5 : 1	91	---
26	Mn-21	KOH (0.3)	Neat	36	2.5 : 1	67	---
27	Mn-20	KOH (0.63)	Neat	36	2.5 : 1	90	----
28	$MnBr(CO_5)$	KOH (0.3)	Neat	36	2.5 : 1	10	12









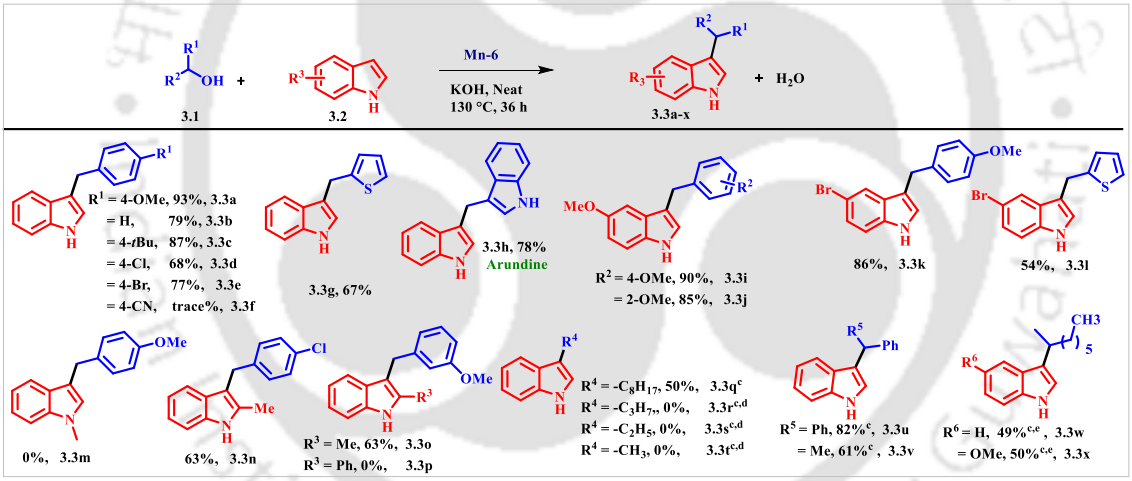


[a]**Conditions**: **3.1a** (0.5-2.5 mmol), **3.2a** (0.5-1.0 mmol), Base (0.15-0.3 mmol) Mn-catalyst (5 mol %), Under argon. [c]Catalyst loading 3.5 mol%, [d]Temperature 100 °C, [b]Isolated yield, [c,f]Catalyst loading 3.5 mol%, [d,g]Temperature 100 °C.

3.3.2. Mn(I) catalysed C-3 alkylated indole synthesis: substrate scope:[a,b]

Next, efficacy of this developed protocol for the selective C-3 functionalization of indoles with various primary alcohols was examined (**3.3.**). Under the standard reaction conditions, electron neutral benzyl alcohol and its derivatives bearing electron donating substituents at the *p*-position afforded excellent yields (78–93%) of the C-3 alkylated products (**3.3a**–**3.3c**). Of note, halide

substituents were also tested for the alkylation, and delightfully, good yields (68–77%) of the corresponding C-3 alkylated products (**3.3d** & **3.3e**) were isolated. Heteroaromatic alcohols such as thiophene methanol and indole-3-carbinol with indole were reacted smoothly under the optimized conditions, both alcohols furnished good to excellent yields (67–78%) of the desired products (**3.3g** & **3.3h**). Notably, **3.3h**, known as Arundine, is an important anti-cancer drug. Next, the scope of substituted indoles was investigated. 5-Methoxy indole and 5-bromo indole reacted well with various benzyl alcohols and heterocyclic alcohols to furnish C-3 functionalized indoles in moderate to excellent yields (54–90%). However, 4-cyano benzyl alcohol gave only a trace amount of **3.3f**. 2-Methyl indole was also successfully functionalized at the C-3 position. However, further increase of the bulkiness at 2-position of indole ceases the reaction (**3.3p**). N-methyl indole was also unable to furnish the C-3 alkylated product, which clearly indicated that the anion formed in the presence of base on the nitrogen center plays a pivotal in the reaction (**3.3m**). Pleasingly, 1-octanol was also found as a reactive coupling partner for this reactions and delivered 50% yield of the desired product (**3.3q**). However, **Mn-6** catalyst failed to activate short chain aliphatic alcohols (**3.3r-3.3t**).

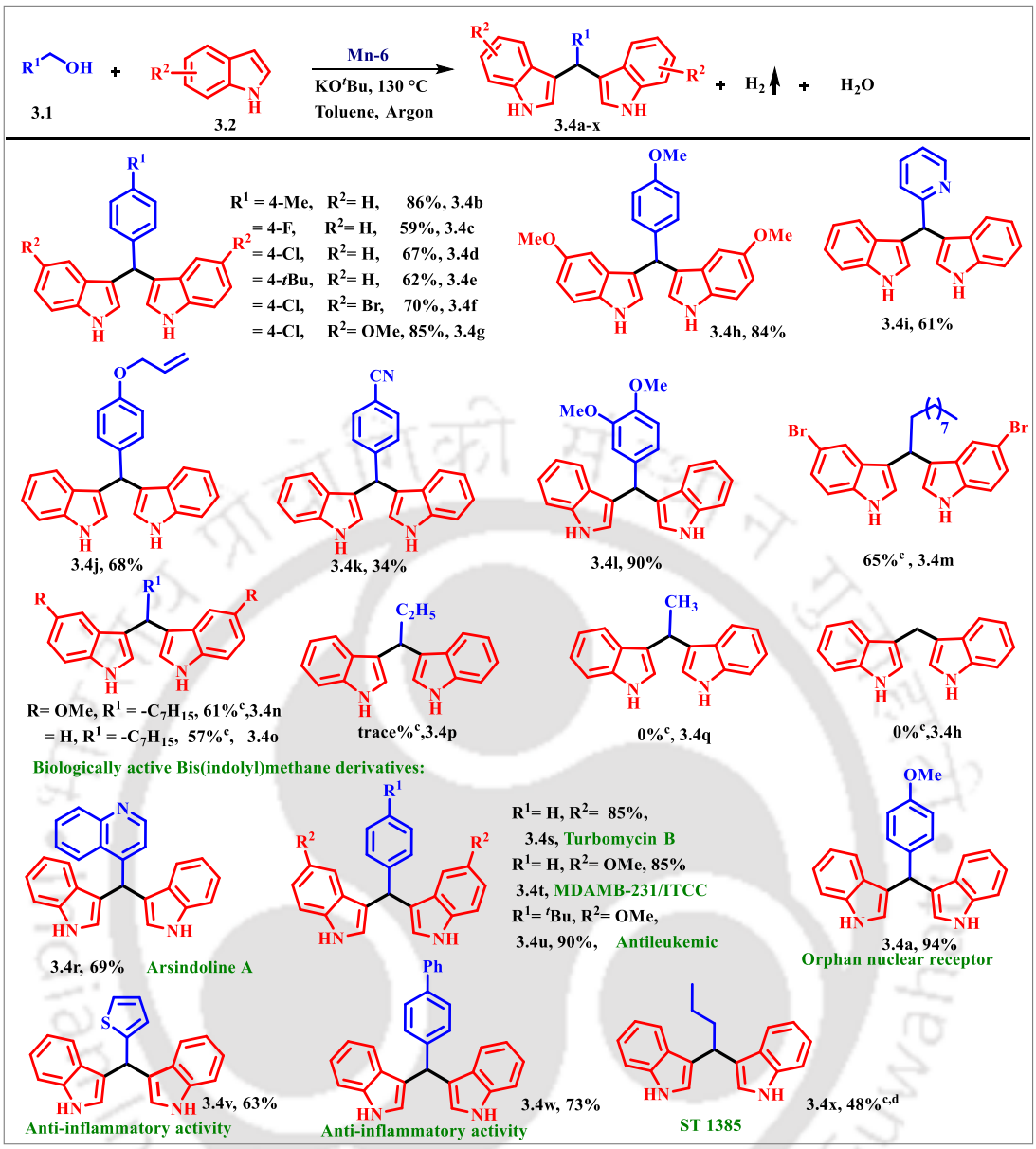


[a]**Conditions**: **3.1** (2.5 mmol), **3.2**(0.5 mmol), KOH (0.3 mmol), **Mn-6**(5 mol%), Time: 36 h at 130 °C (oil bath), [b]Isolated yield, [c]0.5 mmol KOH, [d]Sealed tube, [e]48 h.

Notable, secondary aromatic and aliphatic alcohols were also found to be effective. On slightly higher concentration of base, secondary alcohols provide moderate to excellent yields of the desired products (**3.3u-3.3x**).

3.3.3. Manganese catalysed synthesis of bis(indolyl)methane: substrate scope:[a,b]

Next, catalytic versatility of **Mn-6** catalyst toward the synthesis of BIMs was explored as they display immense importance in the pharmaceutical industry and medicinal chemistry.[3,14] Differently substituted aromatic and heteroaromatic primary alcohols responded well with various indoles to deliver respective BIM products (**3.4a**–**3.4i**) with good to excellent yields (59–94%).

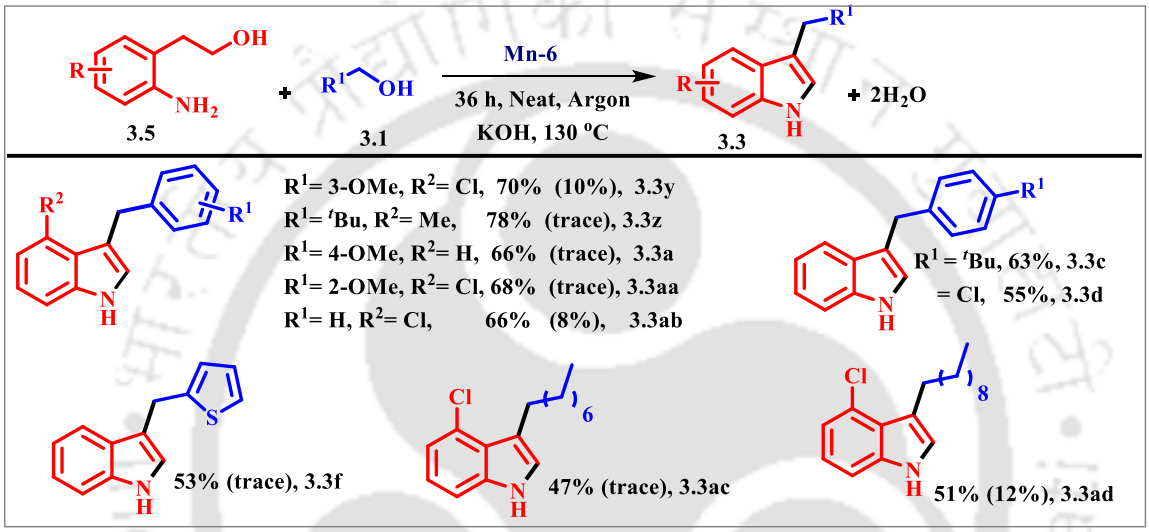


[a]**Conditions**: **3.1** (0.5 mmol), **3.2** (1.0 mmol), KO*t*Bu (0.25 mmol), **Mn-6** (5 mol%), Time: 36 h at 130 °C (oil bath), [b]Isolated yield, [c]1.5 mmol alcohol, [d]Sealed tube.

Alcohols containing unsaturated a C-C double bond or C-N triple bond at the 4-position were also well tolerated under the standard conditions (**3.4j** & **3.4k**). Pleasingly, more challenging aliphatic alcohols (**3.4m**-**3.4o**) were found effective under the optimized conditions (57–65%). The broad substrate scope in this reaction encouraged us to study further the applicability of this catalytic protocol to prepare pharmaceutically important molecules and natural products. An antitumor drug, Arsindoline A (**3.4r**, 69%) also successfully prepared using the optimized conditions. Other medicinally relevant molecules like Turbomycin B (**3.4s**), Antileukemic (**3.4u**), Orphan nuclear receptor (**3.4a**), and MDAMB-231/ITCC (**3.4t**) were also smoothly synthesized in excellent yields (63–90%). Even the shorter chain aliphatic alcohol, 1-butanol, also reacted with indole to give structurally important ST 1385 (**3.4x**) with 48% isolated yield.

3.3.4. Synthesis of C-3 functionalized indoles from 2-aminophenyl ethanol and alcohols[a,b]

Encouraged by the reactivity of catalyst **Mn-6** in selective synthesis of C-3 alkylated indole and BIMs. Therefore, it would be more fascinating if C-3 alkylated indoles were prepared in one-pot directly from renewable feedstock amino alcohol and primary alcohol using **Mn-6** catalyst. Thus, the reaction of primary alcohols and 2-aminophenyl ethanol to afford C-3 alkylated indoles were examined. This multistep sequential de(hydrogenative) process was attained at a slightly higher concentration of base and catalyst loading and **3.3y** was isolated in 70% yield.

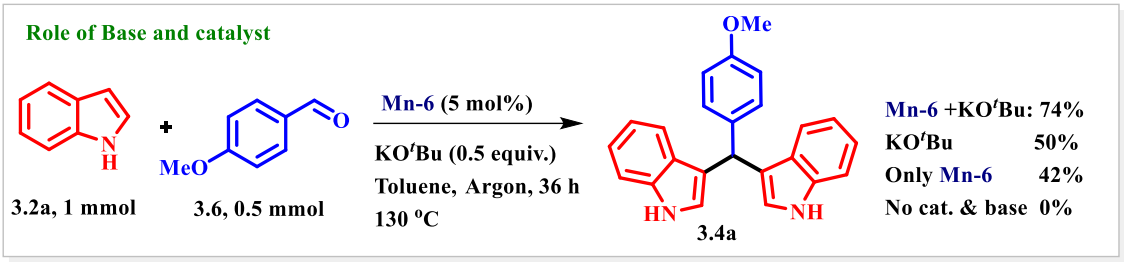


[a]**Conditions**: **3.1** (2.5 mmol), **3.5** (0.5 mmol), KOH (0.25 mmol), **Mn-6** (5 mol%), Time: 36 h at 130 °C (oil bath), [b]Isolated yield, [c]1.5 mmol alcohol, [d]Sealed tube.

Various aromatic and heteroaromatic alcohols with differently substituted amino alcohols provided good yields (53–78%) of the desired products. It is important to note that aliphatic alcohols were found inactive for this type of reaction with other 3d metals.[11a,11d] Delightfully, various C-3 functionalized indoles in one-pot were prepared in moderate yields (47– 51%) under developed protocol including octanol (**3.3ac**) and decanol (**3.3ad**).

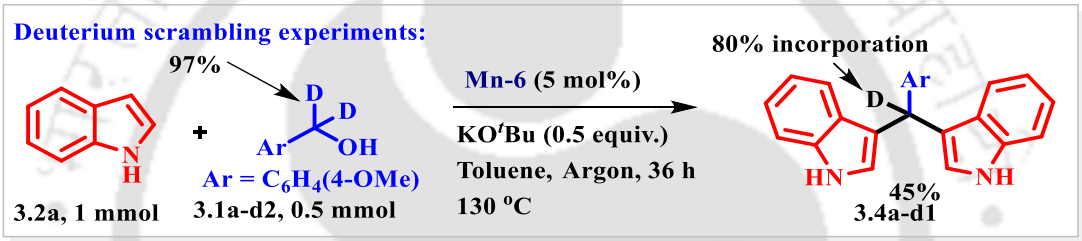
3.3.5. Mechanistic study: The successful catalytic functionalization of indoles using air and moisture stable, phosphine-free manganese catalyst encouraged us to delve into thorough mechanistic studies and reactivity patterns of the reaction by performing various control experiments and deuterium exchange studies. The condensation of indole and aldehyde was found to be assisted by the base, which was further accelerated, by the addition of the catalyst (Scheme **3.1.**). The removal of the N-H proton by the base is speculated to assist the condensation step and the catalyst increases the electrophilicity of the aldehyde through coordination. Thus, the **Mn-6**

plays a key role in the dehydrogenation of alcohol to aldehyde and also assists the condensation of indole with in situ formed aldehyde.



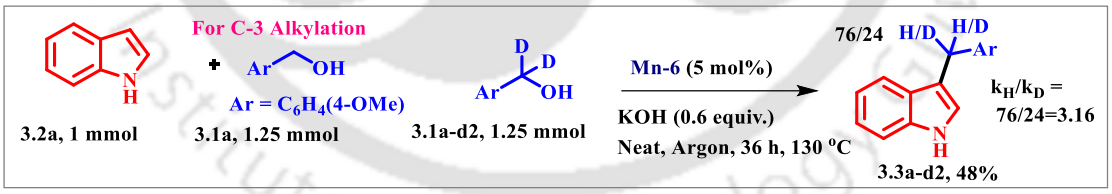
Scheme 3.1. Control experiment 1.

The reaction of indole (**3.2a**) and deuterated 4-methoxybenzyl alcohol (**3.1a-d2**) was carried out under similar reaction conditions, and 80% deuterium incorporated product (**3.4a-d1**) was detected by ^{1}H NMR spectroscopy (Scheme **3.2.**).



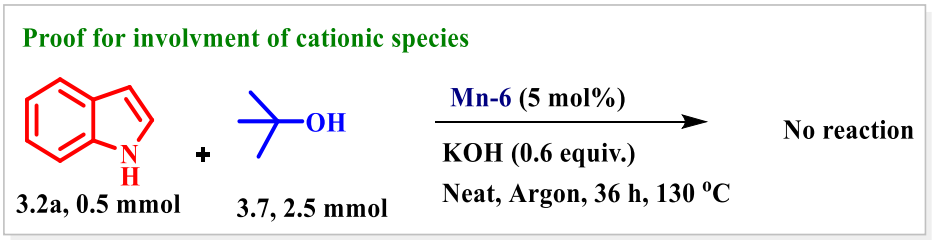
Scheme 3.2. Control experiment 2.

A competition reaction was performed utilizing **3.1a** and **3.1a-d2** in 1:1 ratio; the result indicates that the k_H/k_D = 3.16 (Scheme **3.3.**).



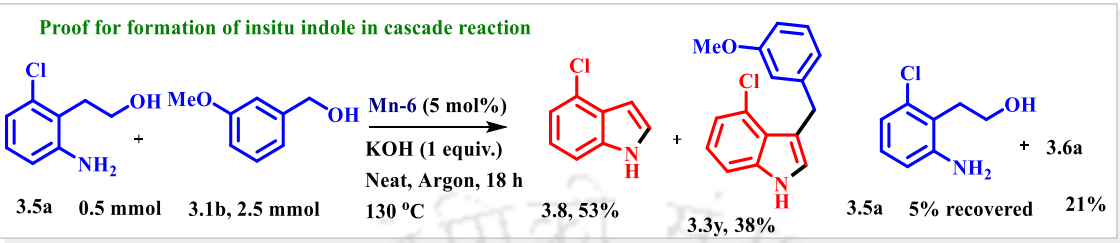
Scheme 3.3. Control experiment 3.

Tert-butanol (**3.7**) did not react with indole (**3.2a**) to form the corresponding C-3 alkylated product, which negates the involvement of carbocation, in this protocol (Scheme 3.4.).



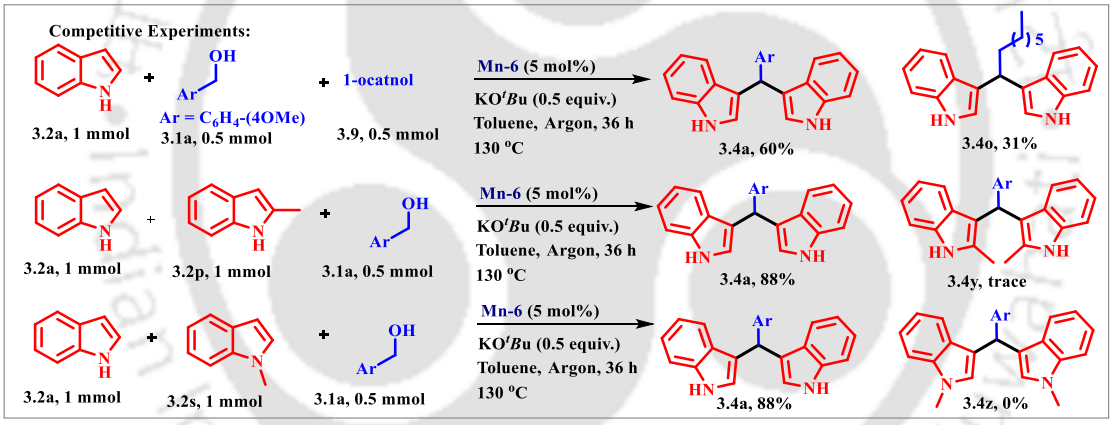
Scheme 3.4. Control experiment 4.

Additionally, the reaction of **3.5a** with 3-methoxybenzyl alcohol was carried out under the standard reaction conditions for 18 h. The result revealed that the one-pot cascade reaction for C-3 functionalization of indole goes via the in situ formation of indole (Scheme **3.5.**).



Scheme 3.5. Control experiment 5.

A competition experiment shows that primary benzyl alcohols are more reactive than aliphatic alcohols (Scheme **3.6.**). 2-substituted indoles are less reactive than unsubstituted indoles and N-substituted indoles are found to be inactive in this reaction (Scheme **3.6.**).

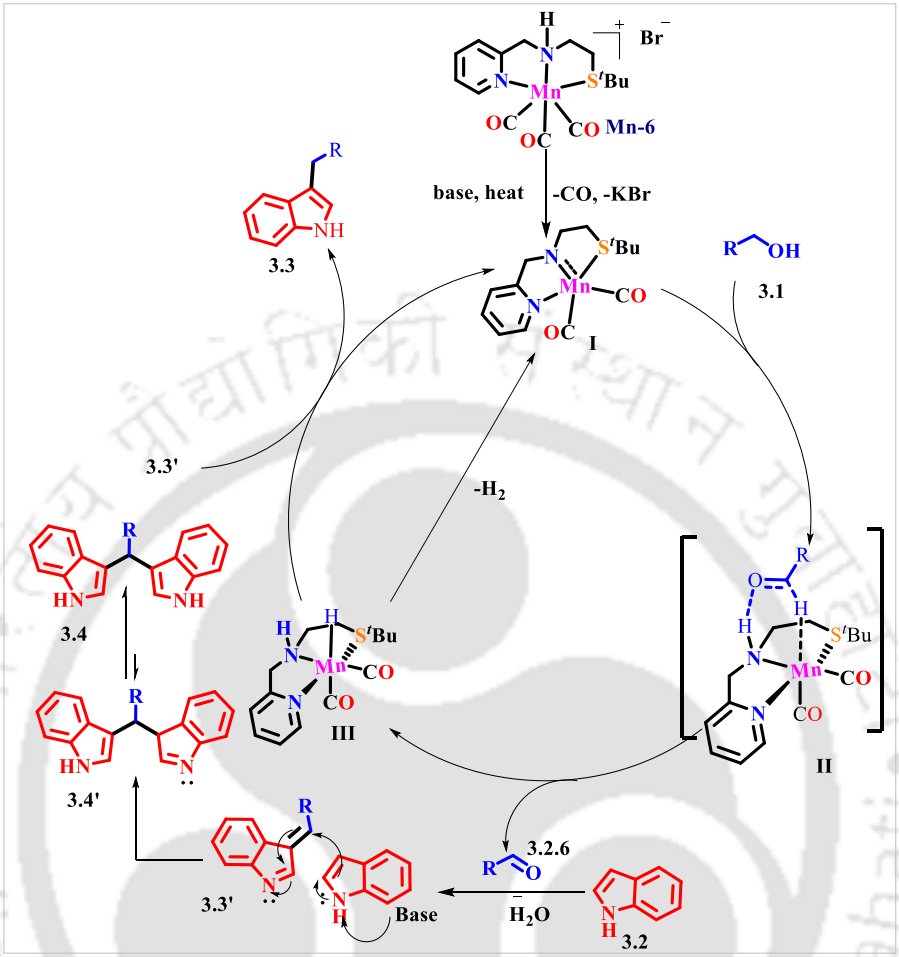


Scheme 3.6. Control experiment 6.

In addition, during the BIMs synthesis, the released H_2 has been employed to transform styrene to ethylbenzene using Wilkinson's catalyst.

3.3.6. Proposed Catalytic Cycle: Based on previous report[13c] and current control studies, a plausible mechanistic pathway was depicted in scheme 3.7. At first, the **Mn-6** is converted to catalytically active amido complex I under the reaction conditions. Complex I dehydrogenates alcohol to aldehyde via II and generates the Mn-H species III. The in situ formed aldehyde reacts with indole to form vinylogous imine 3.3′, which is then converted to the C-3 alkylated indole 3.3 via hydrogen auto-transfer with simultaneous formation of catalytically active amido complex I. On the other hand, vinylogous imine 3.3′ can also react with another molecule of indole to form

3.4′, which is then aromatized to form BIM, 3.4. In that case, Mn-H species III releases H_2 to regenerate I (scheme 3.7.).



Scheme 3.7. Plausible mechanistic cycle for selective synthesis of C-alkylated indoles and BIMs.

3.3.7. Conclusion: In conclusion, single manganese complex catalysed selective C-3 functionalization of indoles and BIMs synthesis has been highlighted simply by tuning the reaction parameters. This efficient catalytic protocol allows access to a wide range of substrates, including nine structurally important drug molecules such as Arsindoline A, Turbomycin B, Antileukemic, Orphan nuclear receptor, etc. Furthermore, the first Mn-catalysed sustainable indole synthesis and its simultaneous functionalization in one-pot are also demonstrated.

3.3.8. Experimental section:

3.3.8.1. 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 under argon atmosphere using dried glassware and standard syringe/septa techniques. DRX-400 Varian spectrometer and Bruker Avance III 600,

500 and 400 spectrometers were used to record ^{1}H and ^{13}C NMR spectra using CDCl3 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, dt = doublet of triplet, td = triplet of doublet and brs = broad singlet. X-ray crystallographic data were collected using BRUKER D8 VENTURE SC-XRD. ATR 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.

3.3.8.2. Preparation of ligands and catalysts (Mn-6, Mn-17 & Mn-21: described in chapter II (experimental section 2.4.1 & 2.4.2)

3.3.8.3. Synthesis of complexes and characterization of Mn-20: All four complexes were prepared according to previous reported literature methods.[1a,1b] Ligand [$(PyCH_2)HN(CH_2CH_2S(^{i}Pr)$] (2.0 mmol) was taken in 5 mL dry THF and was added dropwise to the orange-yellow suspension of [$MnBr(CO)_5$] (0.55 g, 2.0 mmol) in 5 mL degassed dry THF. Afterward, the suspension was refluxed for overnight under argon atmosphere. After the completion of the reaction, the reaction mixture was cooled down to the room temperature, then 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.

3.3.8.4. General experimental procedure for C-3 functionalization of indole: To an oven dried 10 mL round bottomed flask, indole **3.2** (0.059 g, 0.5 mmol), alcohols **3.1** (2.5 mmol), KOH (0.017 g, 0.3 mmol) and **Mn-6** (0.011 g, 5 mol%) were taken under argon atmosphere. Then, the resulting mixture was placed in a preheated oil bath at 130 °C and the stirring was continued for 36 h. After that, the reaction mixture was cooled to room temperature and 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 5%-10% ethyl acetate in hexane to get pure compound.

3.3.8.5. General experimental procedure for the synthesis of bisindolylmethane: To an oven dried 10 mL round bottomed flask, indole 3.2 (0.117 g, 1.0 mmol), alcohols **3.1** (0.5 mmol), $KO^{t}Bu$ (0.028 g, 0.25 mmol), **Mn-6** (0.011 g, 5 mol%) and 2 mL toluene were taken under argon atmosphere. Then the reaction mixture was kept for stirring at 130 °C. After 36 h, mixture was cooled to room temperature and 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 to get pure compound.

3.3.8.6. General experimental procedure for the synthesis of C-3 functionalized indoles from 2-aminophenyl ethanol and alcohols: To an oven dried 10 mL round bottom flask, primary alcohol (2.5 mmol), 2-aminophenyl ethanol **3.2.5** (0.5 mmol), **Mn-6** catalyst (0.018 g, 8 mol%), KOH (0.028 g, 0.5 mmol) were added under argon atmosphere. Then, the reaction mixture was kept in preheated oil bath at 130 °C for 36 h. Then, the reaction was cooled at room temperature and ethyl acetate was added, diluted the mixture and filtered through celite. The filtrate was concentrated under reduced pressure and the residue was purified by silica gel column chromatography using 5%-10% ethyl acetate as an eluting system.

3.3.8.7. Manganese catalysed dehydrogenation of alcohol: To an oven-dried 10 mL round bottomed flask, **Mn-6** (0.011 g, 5 mol%), 4-methoxy benzyl alcohol, **3.1a** (0.138 g, 1.0 mmol), toluene (2 mL) were added under argon. The reaction mixture was kept for heating at 130 °C for 20 h. Then, the reaction mixture was submitted for crude nmr analysis, result showed the formation aldehyde after the reaction.

3.3.8.8. Manganese catalysed BIM synthesis from intermediate 4-methoxy benzaldehyde (3.6) and indole (3.2a): To an oven dried 10 mL round bottomed flask, indole **3.2a** (0.117 g, 1.0 mmol), 4-methoxy benzaldehyde (**3.6**) (0.068 g, 0.5 mmol), KO^{t}Bu (0.028 g, 0.25 mmol), **Mn-6** (0.011 g, 5 mol%) and 2 mL toluene were taken under argon atmosphere. Then the reaction mixture was kept for stirring at 130 °C in preheated oil bath. After 36 h, mixture was cooled to room temperature and 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%-20% ethyl acetate in hexane as an eluting system to give the desired bisindolylmethane product **3.4a** in 0.130 g, 74% isolated yield. Later the same reaction was carried out in absence of catalyst, which delivered 3.4a in 0.088 g, 50%. In presence of only catalyst, 0.074 g, 42% of **3.4a** was isolated but when the reaction was performed in absence of both (Mn-6 and base) no product (**3.4a**) formation was observed.

3.3.8.9. Manganese catalysed alkylation of indole (3.2a) by deuterated labelled alcohol (3.1a-d2): For BIMs synthesis: To an oven dried 10 mL round bottomed flask indole, **3.2a** (0.117 g, 1.0 mmol), deuterated 4-methoxybenzyl alcohol **3.1a-d2** (0.070 g, 0.5 mmol), KO^{t}Bu (0.028 g, 0.25 mmol) and Mn-6 (0.011 g, 5 mol%) were taken, then 2 mL toluene was added under argon atmosphere. The resulting mixture was then placed into the preheated oil bath at 130 °C for 36 h under argon atmosphere. After completion the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100–200 mesh) with hexane/ethyl acetate mixture (10-25%) as eluent, 45% of **3.1a-d1** was obtained with 80%

deuterium incorporation. The percentage of deuterium incorporation was analysed using ^{1}H NMR spectroscopy which is shown in figure 3.3.

3.3.8.12. Competition reaction: For C-3 alkylation of indole: To an oven dried round bottomed flask, 4-methoxybenzyl alcohol, **3.1a** (0.173 g, 1.25 mmol), deuterated 4-methoxybenzyl alcohol, **3.1a-d2** (0.175 g, 1.25 mmol), indole, **3.2a** (0.059 g, 0.5 mmol), **Mn-6** (0.011 g, 5 mol%), KOH (0.017 g, 0.3 mmol), were added under argon. The reaction mixture was heated at 130 °C for 36 h. Then, cooling the reaction mixture, and filtered through celite, the filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100–200 mesh) with hexane/ethyl acetate mixture (2-10%) as eluent, to afford a mixture of **3.3a** and **3.3a-d2** in 48% yield.

3.3.8.12.1. Manganese catalysed alkylation reaction between indole (3.2a) and *tert*-butanol (3.7): In a typical reaction, an oven dried 10 mL round bottomed flask was charged with indole **3.2a** (0.059 g, 0.5 mmol), tert-butanol **3.7** (0.185 g, 2.5 mmol), KOH (0.017 g, 0.3 mmol) and **Mn-6** (0.011 g, 5 mol%), then the resulting mixture was placed into the preheated oil bath at 130 °C for 36 h under argon atmosphere. After completion the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum; the residue was analysed by nmr spectroscopy which indicates that no alkylated product was formed which clearly reveals that the C-3 alkylation of indole does not occur via carbocation formation.

3.3.8.12.2. Proof of in situ indole formation from 2-aminophenyl ethanol by manganese catalyst: To an oven dried 10 mL round bottomed flask 2-(2-amino-6-chlorophenyl) ethan-1-ol **3.5a** (0.086 g, 0.5 mmol), 4-methoxybenzyl alcohol, **3.1a** (0.345 g, 2.5 mmol), KOH (0.028 g, 0.5 mmol) and **Mn-6** (0.018 g, 8 mol%) were taken under argon. Then the resulting mixture was then placed into the preheated oil bath at 130 °C under argon atmosphere. Then the reaction was paused after 18 h and cooled to room temperature. After that, ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100-200 mesh) with hexane/ethyl acetate mixture (2-20%) as an eluting system and 0.040 g, 53% of **3.8**, 0.052 g, 38% **3.3y** was isolated and 0.005 g, 5% of **3.5a** was recovered.

3.3.8.13. Competitive experiments:

3.3.8.13.1. Manganese catalysed alkylation of indole (3.2a) with primary aromatic (3.1a) and aliphatic (3.9) alcohol: Indole, **3.2a** (0.117 g, 1.0 mmol), 4-methoxybenzyl alcohol **3.1a** (0.069 g, 0.5 mmol) and 1-octanol **3.9** (0.065 g, 0.5 mmol), **Mn-6** (0.011 g, 5 mol%) and ^{t}BuOK (0.028 g, 0.25 mmol) were charged in an oven dried round bottomed flask in 2 mL toluene

(2 mL) under argon. The flask was then placed in a preheated oil bath at 130 °C. After 36 h, the crude reaction mixture was diluted by ethyl acetate and filter through celite. The filtrate was concentrated under vacuum and resultant residue was purified by column chromatography using 100-200 mesh size silica with hexane / ethyl acetate as an eluent system and 0.106 g, 60% **3.4a** and 0.053 g, 31% **3.4o** were isolated.

3.3.8.13.2. Alkylation of indole (3.2a) and 2-methyl indole (3.2o) with 4-methoxy benzyl alcohol (3.1a): Indole **3.2a** (0.117 g, 1 mmol), 2-methyl indole **3.2o** (0.131 g, 1 mmol) and 4-methoxy benzylalcohol **3.1a** (0.069 g, 0.5 mmol), ^{t}BuOK (0.028 g, 0.25 mmol) and **Mn-6** (0.011 g, 5 mol%) were charged in an oven dried round bottomed flask in toluene (2 mL) under argon. The flask was then placed in a preheated oil bath at 130 °C. After 36 h, the crude reaction mixture was diluted by ethyl acetate and filter through celite. The filtrate was concentrated under vacuum and resultant residue was purified by column chromatography using 100-200 mesh size silica with hexane / ethyl acetate as an eluent, only 0.155 g, 88% **3.4a** was isolated.

3.3.8.13.3. Competition reaction between indole (3.2a) and *N*-methyl indole with alcohol (3.1a): Indole (**3.2a**) (0.117 g, 1.0 mmol), 2-methyl indole (0.131 g, **3.2s**) and 4-methoxy benzyl alcohol **3.1a** (0.069 g, 0.5 mmol) ^{t}BuOK (0.028 g, 0.25 mmol) and **Mn-6** (0.011 g, 5 mol%) were charged in an oven dried round bottomed flask in toluene (2 mL) under argon. The flask was then placed in a preheated oil bath at 130 °C. After 36 h, the crude reaction mixture was diluted by ethyl acetate and filter through celite. The filtrate was concentrated under vacuum and resultant residue was purified by column chromatography using 100-200 mesh size silica with hexane / ethyl acetate as an eluent system, 0.156 g, 88% (**3.4a**) was isolated and no product corresponding to N-methyl indole was isolated. The result indicates that the N-H proton of indole plays important role in the C-3 functionalization.

3.3.8.14. Utilization of liberated hydrogen gas: To an oven dried 10 mL round bottomed flask (A) indole **3.2a** (1.170 g, 10 mmol), 4-methoxy benzyl alcohol **3.1a** (0.690 g, 5 mmol), KO^{t}Bu (0.350 g, 3.125 mmol) and **Mn-6** (5 mol%) were added, the entire system was degassed and flushed with argon for 5 minutes (two times), then dry toluene (2 mL) was added. To another 10 mL round bottomed flask (B) $RhCl(PPh_3)_3$ (10 mol%) catalyst, styrene (1.5 mmol) were dissolved in benzene (2 mL). Both the flask (A & B) were connected through a double-headed syringe and allowed to equilibrate for 5 minutes. The mixture in the flask (A) was heated at 130 °C (oil-bath temperature), while the mixture in the flask (B) was stirred at 60 °C (oil-bath temperature). After 36 h, the organic entities present in the flask (B) were analyzed by GC, which showed a clean conversion (43%) of the styrene to ethyl benzene.

3.3.8.15. Gram scale synthesis: To an oven dried 50 mL round bottomed flask indole, **3.2a** (1.170 g, 10 mmol), 4-methoxybenzyl alcohol, **3.1a** (0.690 g, 5 mmol), KO^{t}Bu (0.350 g, 3.125 mmol) and Mn-6 (5 mol%) were taken, then toluene was added under argon atmosphere. The resulting mixture was then placed into the preheated oil bath at 130 °C for 36 h. Upon completion, the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100-200 mesh) with hexane/ethyl acetate mixture (20-30%) as eluent, and 84% of **3.4a** was obtained. Yield 84% (1.474 g).

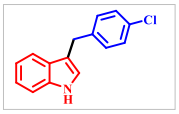
3.3.9. Spectroscopic data of synthesized compounds in this present study:

Mn-22: Yellow solid (0.874 g, 92%).**^{1}H NMR (600 MHz, CDCl$_3$) δ** 8.72 (brs, 1H), 8.17 (brs, 1H), 7.89 (brs, 1H), 7.76 (brs, 1H), 7.42 (br s, 1H), 4.85-4.65 (m, 2H), 3.34- 2.98 (m, 4H), 2.01 (brs, 1H), 1.48 (brs, 6H). **^{13}C{^{1}H} NMR (150 MHz, CDCl$_3$) δ** 219.7, 216.7, 162.4, 152.9, 139.5, 125.2, 122.9, 60.7, 55.0, 39.9, 32.1, 22.9, 21.7. IR (cm-1): 3412, 3066, 2900, 2028, 1925, 1916, 1607, 1445. HRMS (ESI) m/z: $[M]^+$Calcd for $C_{14}H_{18}MnN_2O_3S$: 349.0419; found 349.0418.

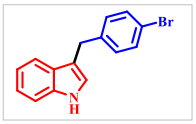
3-(4-Methoxybenzyl)-1H-indole (3.3a):[11a] White solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 93% Yield, 0.110 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.94 (s, 1H), 7.55 (d, *J* = 7.8 Hz, 1H), 7.36 (d, *J* = 8.1 Hz, 1H), 7.23 – 7.19 (m, 3H), 7.11(t, *J* = 7.4 Hz, 1H), 6.90 (brs, 1H), 6.86 (d, *J* = 8.5 Hz, 2H), 4.09 (s, 2H), 3.80 (s, 3H). **^{13}C{^{1}H} NMR (100 MHz, CDCl$_3$) δ** 157.9, 136.6, 133.4, 129.7, 127.6, 122.3, 122.1, 119.4, 119.3, 116.4, 113.9, 111.2, 55.4, 30.8.

3-Benzyl-1H-indole (3.3b):[11d] Pink solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 79% Yield, 0.083 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.89 (s, 1H), 7.51 (d, *J* = 7.9 Hz, 1H), 7.33 (d, *J* = 8.1 Hz, 1H), 7.28 – 7.25 (m, 4H), 7.18 – 7.16 (m, 2H), 7.07 (t, *J* = 7.5 Hz, 1H), 6.88 (s, 1H), 4.11 (s, 2H). **^{13}C{^{1}H} NMR (150 MHz, CDCl$_3$) δ** 141.3, 136.6, 128.8, 128.4, 127.6, 126.0, 122.4, 122.2, 119.5, 119.3, 115.9, 111.2, 31.7.

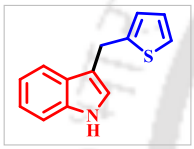
3-(4-(*Tert*-butyl)benzyl)-1H-indole (3.3c):[10f] Yellow oil. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 87% Yield, 0.0114 g. **^{1}H NMR (500 MHz, Chloroform-d) δ** 7.66 (s, 1H), 7.45 (d, *J* = 7.4 Hz, 1H), 7.20 – 7.18 (m, 3H), 7.12 -7.06 (m, 3H), 7.00 – 6.97 (m, 2H), 6.74 (s, 1H), 3.97 (s, 2H), 1.20 (s, 9H). **^{13}C{^{1}H} NMR (125 MHz, CDCl$_3$) δ** 148.8, 138.3, 136.6, 128.4, 127.7, 125.3, 122.4, 122.1, 119.4, 119.3, 116.1, 111.2, 34.5, 31.6, 31.1.

3-(4-Chlorobenzyl)-1H-indole (3.3d): [11d] Yellow oil. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 68% Yield, 0.082 g. 

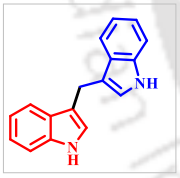
^{1}H NMR (500 MHz, Chloroform-d) δ 7.83 (s, 1H), 7.45 (d, *J* = 7.9 Hz, 1H), 7.30 (d, *J* = 8.2 Hz, 1H), 7.21 – 7.15 (m, 5H), 7.08 – 7.04 (m, 1H), 6.83 (brs, 1H), 4.04 (s, 2H). **^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ** 139.8, 136.6, 131.7, 130.1, 128.5, 127.4, 122.5, 122.3, 119.6, 119.1, 115.3, 111.3, 31.1.

3-(4-Bromobenzyl)-1H-indole (3.3e): [11d] Yellow oil. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 77% Yield, 0.110 g. 

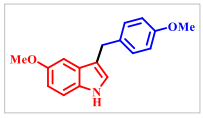
^{1}H NMR (600 MHz, Chloroform-d) δ 8.01 (s, 1H), 7.50 (d, *J* = 7.9 Hz, 1H), 7.42 – 7.38 (m Hz, 3H), 7.22 (t, *J* = 7.7 Hz, 1H), 7.18 (d, *J* = 8.4 Hz, 2H), 7.11 (t, *J* = 7.5 Hz, 1H), 6.95 (brs, 1H), 4.09 (s, 2H). **^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ** 140.2, 136.5, 131.4, 130.4, 128.3, 127.3, 122.4, 122.2, 119.5, 119.0, 115.2, 111.2, 31.1.

3-(Thiophen-2-ylmethyl)-1H-indole (3.3g):[11a] Yellow oil. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 67% Yield, 0.072 g. 

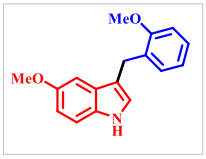
^{1}H NMR (500 MHz, Chloroform-d) δ 7.86 (s, 1H), 7.55 (d, *J* = 7.7 Hz, 1H), 7.30 (d, *J* = 8.1 Hz, 1H), 7.19 – 715 (m, 1H), 7.08 (t, *J* = 6.9 Hz, 2H), 6.97 (brs, 1H), 6.90 – 6.83 (m, 2H), 4.29 (s, 2H). **^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ** 144.8, 136.5, 127.3, 126.8, 124.8, 123.5, 122.4, 122.3, 119.6, 119.2, 115.5, 111.3, 26.1.

Di(1H-indol-3-yl) methane (3.3h):[10d] White solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 78% Yield, 0.096 g. 

^{1}H NMR (600 MHz, Chloroform-d) δ 7.85 (brs, 2H), 7.62 (d, *J* = 7.9 Hz, 2H), 7.34 (d, *J* = 8.1 Hz, 2H), 7.18 (t, *J* = 7.3 Hz 2H), 7.08 (t, *J* = 7.8 Hz, 2H), 6.90 (s, 2H), 4.23 (s, 2H). **^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ** 136.6, 127.7, 122.3, 122.0, 119.4, 119.3, 115.8, 111.2, 21.3.

5-Methoxy-3-(4-methoxybenzyl)-1H-indole (3.3i):[15] Yellow solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 90% Yield, 0.120 g. 

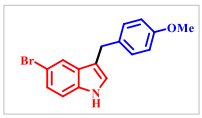
^{1}H NMR (400 MHz, Chloroform-d) δ 7.81 (brs, 1H), 7.19 – 7.15 (m, 3H), 6.95 – 6.93 (m, 1H), 6.84 – 6.79 (m, 4H), 4.00 (s, 2H), 3.78 (s, 3H), 3.75 (s, 3H). **^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ** 157.9, 153.9, 133.4, 131.8, 129.7, 127.9, 123.2, 116.0, 113.9, 112.1, 111.9, 101.3, 56.0, 55.5, 30.8.

5-Methoxy-3-(2-methoxybenzyl)-1H-indole (3.3j): Yellow solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 85% Yield, 0.114 g. 

^{1}H NMR (500 MHz, Chloroform-d) δ 7.82 (brs, 1H), 7.23 – 7.19 (m, 2H), 7.15 (d, *J* = 6.9 Hz, 1H), 7.06 (d, *J* = 2.1 Hz, 1H), 6.92 – 6.75 (m, 4H), 4.10 (s, 2H), 3.89 (s, 3H), 3.85 (s, 3H). **^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ** 157.4, 154.0,

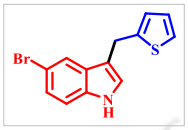
131.7, 130.1, 129.8, 128.3, 127.2, 123.4, 120.6, 115.1, 112.2, 111.8, 110.4, 101.3, 56.0, 55.5, 25.3. HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{17}H_{17}NO_2H$: 268.1338; Found 268.1389.

5-Bromo-3-(4-methoxybenzyl)-1H-indole (3.3k):[15] Yellow solid. Column chromatography



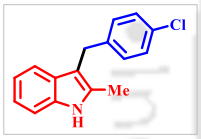
(Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 86% Yield, 0.135 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.96 (brs, 1H), 7.62 (s, 1H), 7.24 – 7.22 (m, 1H), 7.18 – 7.14 (m, 3H), 6.86 (s, 1H), 6.82 (d, *J* = 8.6 Hz, 2H), 3.98 (s, 2H), 3.77 (s, 3H). **^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ** 158.0, 135.2, 132.9, 129.6, 129.3, 125.0, 123.6, 121.8, 116.1, 114.0, 112.7, 112.6, 55.4, 30.6.

5-Bromo-3-(thiophen-2-ylmethyl)-1H-indole (3.3l):[16] Yellow solid. Column chromatography



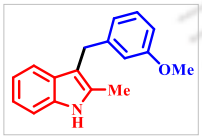
(Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 54% Yield, 0.079 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.90 (brs, 1H), 7.66 (s, 1H), 7.24 (d, *J* = 8.0 Hz, 1H), 7.16 (d, *J* = 8.6 Hz, 1H), 7.11 (d, *J* = 5.1 Hz, 1H), 6.97 (s, 1H), 6.91 – 6.89 (m, 1H), 6.84 (s, 1H), 4.22 (s, 2H). **^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ** 144.1, 135.0, 128.9, 126.9, 125.1, 124.9, 123.7, 123.6, 121.7, 115.0, 112.9, 112.7, 25.8.

3-(4-Chlorobenzyl)-2-methyl-1H-indole (3.3n):[17] Yellow solid. Column chromatography (Silica



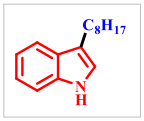
gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 63% Yield, 0.080 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.78 (brs, 1H), 7.41 (d, *J* = 7.8 Hz, 1H), 7.31 (d, *J* = 8.0 Hz, 1H), 7.25 (d, *J* = 8.4 Hz, 2H), 7.18 (d, *J* = 8.2 Hz, 3H), 7.10 (t, *J* = 6.9 Hz, 1H), 4.08 (s, 2H), 2.40 (s, 3H). **^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ** 140.2, 135.4, 131.8, 131.7, 129.7, 128.8, 128.4, 121.2, 119.5, 118.3, 110.3, 110.1, 29.6, 11.8.

3-(3-Methoxybenzyl)-2-methyl-1H-indole (3.3o):[17] Yellow solid. Column chromatography

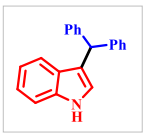


(Silica gel, 100- 200 mesh, hexane/ethyl acetate = 9:1). 63% Yield, 0.079 g. **^{1}H NMR (500 MHz, Chloroform-d) δ** 7.71 (brs, 1H), 7.39 (d, *J* = 7.8 Hz, 1H), 7.23 (d, *J* = 7.8 Hz, 1H), 7.13 (t, *J* = 7.8 Hz, 1H), 7.08 (t, *J* = 7.1 Hz, 1H), 7.01 (t, *J* = 7.1 Hz, 1H), 6.81 (d, *J* = 8.1 Hz, 1H), 6.77 (s, 1H), 6.68 (d, *J* = 8.2 Hz, 1H), 4.03 (s, 2H), 3.72 (s, 3H), 2.34 (s, 3H). **^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ** 159.8, 143.5, 135.5, 131.7, 129.3, 129.1, 121.1, 120.9, 119.4, 118.5, 114.4, 110.9, 110.6, 110.2, 55.2, 30.3, 11.9.

3-Octyl-1H-indole (3.3q):[10d] Yellow oil. Column chromatography (Silica gel, 100-200 mesh,

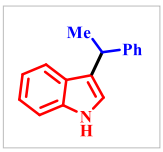


hexane only). 50% Yield, 0.058 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.90 (brs, 1H), 7.66 (d, *J* = 7.9 Hz, 1H), 7.38 (d, *J* = 8.1 Hz, 1H), 7.22 (t, *J* = 7.1 Hz, 1H), 7.15 (t, *J* = 7.5 Hz, 1H), 7.00 (s, 1H), 2.79 (t, *J* = 7.6 Hz, 2H), 1.75 (p, *J* = 7.6 Hz, 2H), 1.46 – 1.41 (m, 2H), 1.39 – 1.31 (m, 8H), 0.93 (t, *J* = 6.5 Hz, 3H). **^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ** 136.5, 127.8, 121.9, 121.1, 119.1, 117.4, 111.1, 32.1, 30.3, 29.8, 29.7, 29.5, 25.3, 22.8, 14.3.

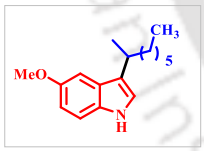


3-Benzhydryl-1H-indole (3.3u):[11d] White solid. Column chromatography (Silica gel, 100- 200 mesh, hexane/ethyl acetate = 50:1). 82% Yield, 0.116 g. ^{1}H NMR (600 MHz, Chloroform-d) δ 7.96 (brs, 1H), 7.39 (d, *J* = 8.1 Hz, 1H), 7.33 – 7.31 (m, 4H), 7.28 – 7.24 (m, 6H), 7.22 – 7.19 (m, 1H), 7.04 – 7.01 (m, 1H), 6.60 (s, 1H), 5.71 (s, 1H). ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ 144.0, 136.8, 129.1, 128.41, 127.1, 126.3, 124.2, 122.2, 120.0, 119.5, 111.2, 48.9.

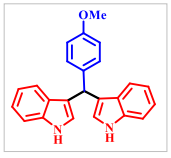
3-(1-Phenylethyl)-1H-indole (3.3v)[10d] Brown liquid. Column chromatography (Silica gel, 100-200 mesh, hexane = 100%). 61% Yield, 0.068 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.86 (brs, 1H), 7.35 (d, *J* = 8.0 Hz, 1H), 7.30 – 7.24 (m, 5H), 7.17 – 7.12 (m, 2H), 6.99 (t, *J* = 7.3 Hz, 1H), 6.95 (d, *J* = 1.2, 2H), 4.36 (q, *J* = 7.1 Hz, 1H), 1.69 (d, *J* = 7.1 Hz, 3H). **^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ** 146.9, 136.7, 128.4, 127.6, 127.0, 126.0, 122.1, 121.5, 121.2, 119.8, 119.3, 111.1, 37.1, 22.5.



3-(Octan-2-yl)-1H-indole (3.3w):[10d] Yellow oil. Column chromatography (Silica gel, 100-200 mesh, hexane only). 49% Yield, 0.056 g. ^{1}H NMR (600 MHz, Chloroform-d) δ 7.87 (brs, 1H), 7.64 (d, *J* = 7.9 Hz, 1H), 7.34 (d, *J* = 8.1 Hz, 1H), 7.17 (t, *J* = 7.4 Hz, 1H), 7.09 (t, *J* = 7.1 Hz, 1H), 6.93 (d, *J* = 1.8 Hz, 1H), 3.05 – 2.99 (m, 1H), 1.81–1.75 (m, 1H), 1.63 – 1.56 (m, 1H), 1.33 (d, *J* = 7.0 Hz, 3H), 1.32 – 1.24 (m, 8H), 0.86 (t, *J* = 6.8 Hz, 3H). **^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ** 136.6, 127.1, 123.1, 121.8, 119.9, 119.6, 119.0, 111.2, 37.8, 32.0, 31.0, 29.7, 27.8, 22.8, 21.6, 14.2.

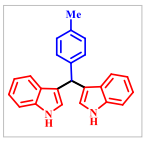


5-Methoxy-3-(octan-2-yl)-1H-indole (3.3x):[10d] Brown oil. Column chromatography (Silica gel, 100-200 mesh, hexane only). 50% Yield, 0.065 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.82 (brs, 1H), 7.27 (d, *J* = 8.7 Hz, 1H), 7.13 (s, 1H), 6.96 (s, 1H), 6.89 (d, *J* = 8.7 Hz, 1H), 3.92 (s, 3H), 3.04 – 3.00 (m, 1H), 1.82 – 1.79 (m, 1H), 1.65 – 1.61 (m, 1H), 1.38 – 1.30 (m, 11H), 0.91 (t, *J* = 6.7 Hz, 3H). **^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ** 153.7, 131.8, 127.4, 122.7, 120.8, 111.8, 111.8, 101.7, 56.1, 37.7, 32.0, 30.9, 29.7, 27.8, 22.8, 21.5, 14.2.

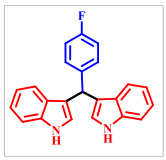


3,3'-((4-Methoxyphenyl)methylene)bis(1H-indole) (3.4a):[10d] Yellowish solid. Column chromatography (Silica gel, 100- 200 mesh, hexane/ethyl acetate = 7:3). 94% Yield, 0.166 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.83 (brs, 2H), 7.38 (d, *J* = 7.9 Hz, 2H), 7.32 (d, *J* = 8.1 Hz, 2H), 7.24 – 7.23 (m, 2H), 7.15 (t, *J* = 7.5 Hz, 2H), 6.99 (t, *J* = 7.3 Hz, 2H), 6.81 (d, *J* = 8.6 Hz, 2H), 6.60 (s, 2H), 5.82 (s, 1H), 3.76 (s, 3H). **^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ** 158.0, 136.8, 136.4, 129.7, 127.2, 123.6, 122.0, 120.2, 120.1, 119.3, 113.7, 111.1, 55.34, 39.4.

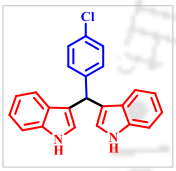
3,3'-(p-Tolylmethylene)bis(1H-indole) (3.4b):[18] Brown solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 7:3). 86% Yield, 0.145 g. **^{1}H NMR (400 MHz, Chloroform-d) δ** 7.80 (brs, 2H), 7.33 (d, *J* = 7.9 Hz, 2H), 7.26 (d, *J* = 8.1, 2H), 7.15 (d, *J* = 8.1 Hz, 2H), 7.08 (t, *J* = 7.5 Hz, 2H), 7.00 (d, *J* = 7.9 Hz, 2H), 6.92 (t, *J* = 7.6 Hz, 2H), 6.58 (s, 2H), 5.77 (s, 1H), 2.24 (s, 3H). **^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ** 141.1, 136.8, 135.6, 129.0, 128.7, 127.3, 123.7, 122.0, 120.1, 120.1, 119.3, 111.1, 39.9, 21.2.



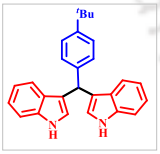
3,3'-((4-Fluorophenyl)methylene)bis(1H-indole) (3.4c):[18] Brown solid. Column chromatography (Silica gel, 100- 200 mesh, hexane/ethyl acetate = 3:2). 59% Yield, 0.100 g. **^{1}H NMR (400 MHz, Chloroform-d) δ** 7.56 (brs, 1H), 7.24 (d, *J* = 7.9 Hz, 1H), 7.17 – 7.13 (m, 4H), 7.05 (t, *J* = 7.5 Hz, 2H), 6.89 (t, *J* = 7.4 Hz, 2H), 6.82 (t, *J* = 8.7 Hz, 2H), 6.40 (d, *J* = 2.1 Hz, 2H), 5.73 (s, 1H). **^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ** 161.6 (d, *J* = 242.5 Hz), 139.8 (d, *J* = 3.1 Hz), 136.8, 130.2 (d, *J* = 7.7 Hz), 127.1, 123.7, 122.2, 112.0, 119.6, 119.4, 115.1 (d, *J* = 21.2 Hz), 111.3, 39.6. ^{19}F NMR (471 MHz, $CDCl_3$) δ -117.3.



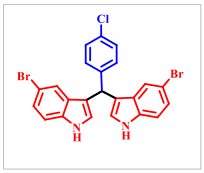
3,3'-((4-Chlorophenyl)methylene)bis(1H-indole) (3.4d):[18] Brown solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 7:3). 67% Yield, 0.114 g. **^{1}H NMR (400 MHz, Chloroform-d) δ** 7.79 (brs, 2H), 7.26 (d, *J* = 8.0 Hz, 3H), 7.18–7.14 (m, 5H), 7.09 (t, *J* = 7.6 Hz, 2H), 6.93 (t, *J* = 7.5 Hz, 2H), 6.56 (s, 2H), 5.83 (s, 1H). **^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ** 142.7, 136.8, 131.9, 130.2, 128.5, 127.0, 123.7, 122.2, 119.9, 119.5, 119.3, 111.3, 39.7.



3,3'-((4-(Tert-butyl)phenyl)methylene)bis(1H-indole) (3.4e):[10d] Brown solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 7:3). 62% Yield, 0.117 g. **^{1}H NMR (400 MHz, Chloroform-d) δ** 7.83 (brs, 2H), 7.40 (d, *J* = 7.9 Hz, 2H), 7.32 (d, *J* = 8.1 Hz, 2H), 7.28 – 7.24 (m, 4H), 7.15 (t, *J* = 7.6 Hz, 2H), 6.99 (t, *J* = 7.6 Hz, 2H), 6.65 (s, 2H), 5.85 (s, 1H), 1.29 (s, 9H). **^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ** 148.9, 141.0, 136.8, 128.4, 127.3, 125.2, 123.7, 122.0, 120.2, 120.1, 119.3, 111.1, 39.8, 34.5, 31.6.



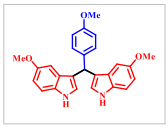
3,3'-((4-Chlorophenyl)methylene)bis(5-bromo-1H-indole)(3.4f):[19] Brown solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 3:2). 70% Yield, 0.109 g. **^{1}H NMR (400 MHz, Chloroform-d) δ** 8.01 (brs, 2H), 7.45 (s, 2H), 7.27 – 7.19 (m, 10H), 6.62 (s, 2H), 5.72 (s, 1H). **^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ** 141.8, 135.5, 132.4, 130.0, 128.7, 128.6, 125.3, 124.9, 122.3, 118.7, 113.0, 112.8, 39.5.



3,3'-((4-Chlorophenyl)methylene)bis(5-methoxy-1H-indole) (3.4g):[11f] Brown solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 3:2). 85% Yield, 0.177 g. **^{1}H NMR (400 MHz, Chloroform-d) δ** 7.84 (brs, 2H), 7.26 – 7.22 (m, 6H), 6.83 (dd, *J* = 8.7, 2.1 Hz,

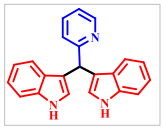
2H), 6.77 (s, 2H), 6.62 (s, 2H), 5.74 (s, 1H), 3.69 (s, 6H). **^{13}C{^{1}H} NMR (100 MHz, CDCl$_3$) δ** 153.9, 142.6, 132.0, 131.9, 130.2, 128.5, 127.5, 124.6, 118.9, 112.1, 111.9, 102.1, 56.0, 39.8.

3,3'-((4-Methoxyphenyl)methylene)bis(5-methoxy-1H-indole) (3.4h):[20] Brown solid. Column



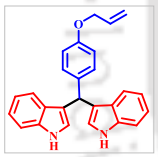
chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 3:7). 84% Yield, 0.173 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.75 (brs, 2H), 7.18 – 7.15 (m, 5H), 6.76 – 6.73 (m, 5H), 6.57 (s, 2H), 5.65 (s, 1H), 3.71 (s, 3H), 3.62 (s, 6H). **^{13}C{^{1}H} NMR (150 MHz, CDCl3) δ** 158.0, 153.8, 136.3, 132.1, 129.7, 127.7, 124.5, 119.8, 113.7, 112.0, 111.8, 102.2, 56.0, 55.4, 39.6.

3,3'-(Pyridin-2-ylmethylene)bis(1H-indole) (3.4i):[21] Brown solid. Column chromatography



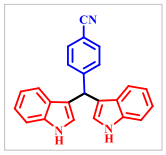
(Silica gel, 100-200 mesh, hexane/ethyl acetate = 1:1). 61% Yield, 0.100 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 8.46 (d, *J* = 4.6 Hz, 1H), 8.13 (s, 2H), 7.54 (t, *J* = 7.8 Hz, 1H), 7.30 (d, *J* = 8.0 Hz, 2H), 7.24 (d, *J* = 7.8 Hz, 2H), 7.18 (s, 1H), 7.09 – 7.05 (m, 3H), 6.92 (t, *J* = 7.8 Hz, 2H), 6.68 (s, 2H), 6.02 (s, 1H). **^{13}C{^{1}H} NMR (150 MHz, CDCl$_3$) δ** 163.3, 148.8, 137.3, 136.8, 127.1, 123.8, 123.3, 122.1, 121.7, 119.8, 119.4, 117.9, 111.3, 42.9.

3,3'-((4-(Allyloxy)phenyl)methylene)bis(1H-indole) (3.4j):[22] Pink solid. Column



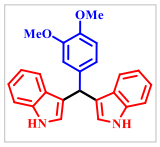
chromatography (Silica gel, 100-200 mesh, hex-ane/ethyl acetate = 5:1). 68% Yield, 0.130 g. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 7.82 (s, 2H), 7.31 (d, *J* = 8.0 Hz, 2H), 7.27 (d, *J* = 8.0 Hz, 2H), 7.17 (d, *J* = 8.6 Hz, 2H), 7.09 (t, *J* = 8.0 Hz, 2H), 6.93 (t, *J* = 7.5 Hz, 2H), 6.76 (d, *J* = 8.7 Hz, 2H), 6.57 (s, 2H), 6.01 – 5.95 (m, 1H), 5.76 (s, 1H), 5.33 (dd, *J* = 17.2, 1.5 Hz, 1H), 5.19 (dd, *J* = 10.5, 1.3 Hz, 1H), 4.43 – 4.41 (m, 2H). **^{13}C{^{1}H} NMR (150 MHz, CDCl$_3$) δ** 157.1, 136.8, 136.5, 133.7, 129.7, 127.2, 123.6, 122.0, 120.2, 120.1, 119.3, 117.7, 114.5, 111.1, 69.0, 39.5.

4-(Di(1H-indol-3-yl)methyl)benzonitrile (3.4k):[23] Brown solid. Column chromatography (Silica



gel, 100-200 mesh, hex-ane/ethyl acetate = 7:3). 34% Yield, 0.061 g. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.91 (s, 2H), 7.47 (d, *J* = 8.1 Hz, 2H), 7.36 (d, *J* = 8.0 Hz, 2H), 7.29 (d, *J* = 8.2 Hz, 2H), 7.25 (d, *J* = 8.0 Hz, 2H), 7.11 (t, *J* = 7.6 Hz, 2H), 6.94 (t, *J* = 7.6 Hz, 2H), 6.6 (d, *J* = 1.7 Hz, 2H), 5.85 (s, 1H). **^{13}C{^{1}H} NMR (150 MHz, CDCl$_3$) δ** 149.9, 136.8, 132.3, 129.6, 126.8, 123.8, 122.4, 119.7, 119.7, 119.3, 118.4, 111.4, 110.1, 40.5.

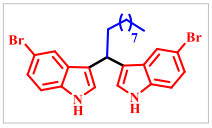
3,3'-((3,4-Dimethoxyphenyl)methylene)bis(1H-indole) (3.4l):[24] Brown solid. Column



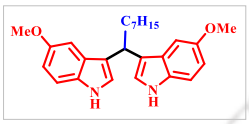
chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 3:2). 90% Yield, 0.172 g. **^{1}H NMR (500 MHz, Chloroform-d) δ** 7.88 (brs, 2H), 7.39 (d, *J* = 7.9 Hz, 2H), 7.32 (d, *J* = 8.1 Hz, 2H), 7.15 (t, *J* = 7.6 Hz, 2H), 6.99 (t, *J* = 7.5 Hz, 2H), 6.92 (s, 1H), 6.83 (d, *J* = 8.2 Hz, 1H), 6.75 (d, *J* = 8.2 Hz, 1H), 6.63 (s, 2H), 5.82 (s, 1H),

3.83 (s, 3H), 3.74 (s, 3H). **$^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ** 148.9, 147.5, 136.9, 136.9, 127.3, 123.7, 122.1, 120.8, 120.1, 120.1, 119.2, 112.5, 111.2, 111.2, 56.0, 56.0, 40.0.

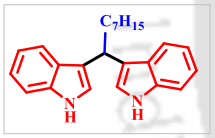
3,3'-(Decane-1,1-diyl)bis(5-bromo-1H-indole) (3.4m):[10d] Brown oil. Column chromatography (Silica gel, 100- 200 mesh, hexane/ethyl acetate = 7:3). 65% Yield, 0.172 g. **^{1}H NMR (500 MHz, Chloroform-d) δ** 7.94 (brs, 2H), 7.65 (s, 2H), 7.21–7.16 (m, 4H), 7.00 (s, 2H), 4.31 (t, *J* = 7.4 Hz, 1H), 2.16 – 2.12 (m, 2H), 1.34 – 1.26 (m, 14H), 0.86 (t, *J* = 6.8 Hz, 3H). **$^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ** 153.7, 132.0, 127.8, 122.4, 120.4, 111.8, 111.7, 102.2, 56.1, 35.7, 34.1, 32.1, 29.9, 29.4, 28.4, 22.8, 14.2.



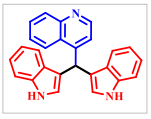
3,3'-(Octane-1,1-diyl)bis(5-methoxy-1H-indole) (3.4n):[10d] Red oil. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 3:2). 61% Yield, 0.123 g. **^{1}H NMR (500 MHz, Chloroform-d) δ** 7.79 (brs, 2H), 7.18 (d, *J* = 8.8 Hz, 2H), 7.03 (s, 2H), 6.95 (s, 2H), 6.80 (d, *J* = 8.7 Hz, 2H), 4.35 (t, *J* = 7.4 Hz, 1H), 3.76 (s, 3H), 2.18 (q, *J* = 7.5 Hz, 2H), 1.42 – 1.33 (m, 4H), 1.26 – 1.23 (m, 6H), 0.85 (t, *J* = 6.0 Hz, 3H). **$^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ** 153.7, 132.0, 127.8, 122.4, 120.4, 111.8, 111.7, 102.2, 56.1, 35.7, 34.1, 32.1, 29.9, 29.4, 28.4, 22.8, 14.2.



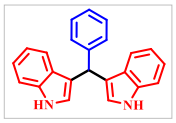
3,3'-(Octane-1,1-diyl)bis(1H-indole) (3.4o):[10d] Brown oil. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 7:3). 57% Yield, 0.098 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.93 (brs, 2H), 7.64 (d, *J* = 7.9 Hz, 2H), 7.34 (d, *J* = 8.1 Hz, 2H), 7.18 (t, *J* = 7.6 Hz, 2H), 7.07 (t, *J* = 7.5 Hz, 2H), 6.99 (d, *J* = 1.5 Hz, 2H), 4.51 (t, *J* = 7.4 Hz, 1H), 2.25 (q, *J* = 7.5 Hz, 2H), 1.47 – 1.43 (m, 2H), 1.41 – 1.35 (m, 2H), 1.32 – 1.25 (m, 6H), 0.90 (t, *J* = 7.0 Hz, 3H). **$^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) δ** 136.7, 127.3, 121.8, 121.5, 120.7, 119.8, 119.6, 111.2, 36.0, 34.1, 32.0, 29.9, 29.4, 28.5, 22.8, 14.2.



4-(Di(1H-indol-3-yl) methyl) quinoline (3.4r):[25] Oilly liquid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 1:1). 69% Yield, 0.129 g. **^{1}H NMR (500 MHz, Chloroform-d) δ** 8.65 (d, *J* = 4.5 Hz, 1H), 8.23 (brs, 2H), 8.13 (t, *J* = 8.9 Hz, 2H), 7.61 (t, *J* = 7.6 Hz, 1H), 7.38 (t, *J* = 7.9 Hz, 1H), 7.34 – 7.30 (m, 4H), 7.16 – 7.11 (m, 3H), 6.98 (t, *J* = 7.5 Hz, 2H), 6.62 (s, 1H), 6.50 (s, 2H). **$^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ** 150.15, 148.2, 136.9, 129.7, 129.3, 129.2, 127.5, 126.8, 126.8, 124.5, 124.3, 122.3, 121.1, 119.6, 119.5, 117.6, 111.4, 35.7.

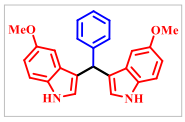


3,3'-(Phenylmethylene)bis(1H-indole) (3.4s):[10d] Brown solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 7:3). 85% Yield, 0.137 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.93 (brs, 2H), 7.42 – 7.37 (m, 6H), 7.32 – 7.28 (m, 3H), 7.24 (t, *J* = 7.8 Hz, 1H), 7.19 (t, *J* = 7.6 Hz, 2H), 7.03 (t, *J* = 7.4 Hz, 2H),

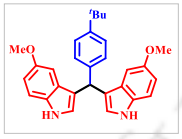


6.68 (s, 2H), 5.92 (s, 1H). **$^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) δ** 144.1, 136.7, 128.8, 128.3, 127.1, 126.2, 123.7, 121.9, 112.0, 119.6, 119.3, 111.2, 40.2.

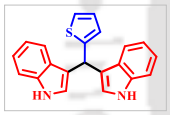
3,3'-(Phenylmethylene)bis(5-methoxy-1H-indole) (3.4t):[20] Brown solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 5:4). 85% Yield, 0.162 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.86 (brs, 2H), 7.37 (d, *J* = 7.4 Hz, 2H), 7.30 (d, *J* = 7.4 Hz, 2H), 7.27 – 7.22 (m, 3H), 6.86 – 6.82 (m, 4H), 6.68 (d, *J* = 1.3 Hz, 2H), 5.80 (s, 1H), 3.71 (s, 6H). **$^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) δ** 153.8, 144.0, 132.0, 128.9, 128.3, 127.6, 126.2, 124.6, 119.4, 112.0, 111.8, 102.1, 56.0, 40.4.



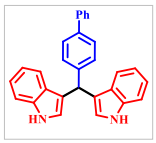
3,3'-((4-(Tert-butyl) phenyl) methylene) bis(5-methoxy-1H-indole) (3.4u):[18] Brown solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 1:1). 90% Yield, 0.197 g. **^{1}H NMR 600 MHz, Chloroform-d) δ** 7.68 (brs, 1H), 7.20 – 7.16 (m, 4H), 7.10 (d, *J* = 8.7 Hz, 2H), 6.73 – 6.71 (m, 4H), 6.56(d, *J* = 1.4 Hz, 2H), 5.65 (s, 1H), 3.71 (s, 6H), 1.21 (s, 9H). **$^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) δ** 153.7, 148.9, 140.9, 132.0, 128.4, 127.7, 125.2, 124.5, 119.7, 112.0, 111.8, 102.2, 56.0, 39.9, 34.5, 31.6.



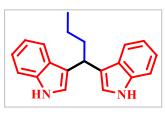
3,3'-(Thiophen-2-ylmethylene) bis(1H-indole) (3.4v):[26] Brown solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 7:3). 63% Yield, 0.103 g. **^{1}H NMR (400 MHz, Chloroform-d) δ** 7.75 (brs, 2H), 7.38 (d, *J* = 8.0 Hz, 2H), 7.24 (d, *J* = 8.2 Hz, 2H), 7.10 – 7.05 (m, 3H), 6.94 (t, *J* = 7.5 Hz, 2H), 6.84 – 6.81 (m, 2H), 6.70 (d, *J* = 2.1 Hz, 2H), 6.07 (s, 1H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 148.8, 136.7, 126.9, 126.5, 125.3, 123.7, 123.3, 122.2, 119.9, 119.8, 119.5, 111.3, 35.5.



3,3'-([1,1'-Biphenyl]-4-ylmethylene) bis(1H-indole) (3.4w):[27] Brown solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 7:3). 73% Yield, 0.150 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.98 (brs, 2H), 7.60 (d, *J* = 7.6 Hz, 2H), 7.53 (d, *J* = 8.1 Hz, 2H), 7.46 – 7.42 (m, 6H), 7.39 (d, *J* = 8.1 Hz, 2H), 7.33 (t, *J* = 7.3 Hz, 1H), 7.20 (t, *J* = 7.6 Hz, 2H), 7.04 (t, *J* = 7.5 Hz, 2H), 6.75 (d, *J* = 1.2 Hz, 2H), 5.96 (s, 1H). **$^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) δ** 143.3, 141.2, 139.0, 136.9, 129.2, 128.8, 127.2, 127.1, 127.1, 123.8, 122.1, 120.1, 119.8, 119.4, 111.2, 40.0.



3,3'-(Butane-1,1-diyl)bis(1H-indole) (3.4x):[10d] Yellow oil. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 4:1). 48% Yield, 0.069 g. **^{1}H NMR (500 MHz, Chloroform-d) δ** 7.78 (brs, 2H), 7.60 – 7.58 (m, 2H), 7.28 (d, *J* = 8.2 Hz, 2H), 7.13 (t, *J* = 7.5 Hz, 2H), 7.05 – 7.00 (m, 2H), 6.93 (brs, 2H), 4.48 (t, *J* = 7.3 Hz, 1H), 2.19 (q, *J* = 7.5 Hz, 2H), 1.43 (q, *J* = 7.5 Hz, 2H), 0.95 (t, *J* = 6.8 Hz, 3H). **$^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ** 136.7, 127.4, 121.8, 121.5, 120.7, 119.8, 119.1, 111.2, 38.3, 33.8, 21.5, 14.3.



4-Chloro-3-(4-methoxybenzyl)-1H-indole (3.3y): Yellow soild. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 70% Yield, 0.095 g. ^{1}H NMR (600 MHz, Chloroform-d) δ 7.94 (brs, 1H), 7.14 – 7.11 (m, 2H), 6.97 – 6.96 (m, 2H), 6.86 (d, *J* = 7.6 Hz, 1H), 6.74 (s, 1H), 6.68 – 6.66 (m, 2H), 4.28 (s, 2H), 3.68 (s, 3H). ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ 159.8, 143.4, 138.0, 129.3, 126.7, 124.4, 124.2, 122.7, 121.4, 120.5, 116.4, 114.9, 111.3, 110.0, 55.1, 32.6. HRMS (ESI) m/z: $[M+H]^+$Calcd for $C_{16}H_{15}ClNO$: 272.0842; Found 272.0845.

3-(4-(Tert-butyl)benzyl)-4-methyl-1H-indole (3.3z): Yellow solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 78% Yield, 0.108 g. **^{1}H NMR (500 MHz, Chloroform-d) δ** 7.85 (brs, 1H), 7.28 (d, *J* = 8.2 Hz, 2H), 7.17 – 7.12 (m, 3H), 7.04 (t, *J* = 7.6 Hz, 1H), 6.67 (d, *J* = 7.0 Hz, 1H), 6.76 (s, 1H), 4.25 (s, 2H), 2.56 (s, 3H), 1.30 (s, 9H). **^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ** 148.7, 139.0, 137.2, 131.3, 128.4, 126.3, 125.3, 123.3, 122.3, 121.1, 116.5, 109.1, 34.5, 32.9, 31.6, 20.3. HRMS (ESI) m/z: $[M+H]^+$Calcd for $C_{20}H_{23}N$: 278.1909; Found 278.1916.

4-Chloro-3-(2-methoxybenzyl)-1H-indole (3.3aa): Yellow solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 68% Yield, 0.095 g. **^{1}H NMR (600 MHz, Chloroform-d) δ** 7.85 (brs, 1H), 7.13 – 7.08 (m, 2H), 6.98 – 6.94 (m, 3H), 6.81 (d, *J* = 8.2 Hz, 1H), 6.77 (t, *J* = 7.5 Hz, 1H), 6.69 (s, 1H), 4.37 (s, 2H), 3.82 (s, 3H). **^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ** 157.4, 138.0, 130.4, 130.2, 127.2, 126.8, 124.6, 124.1, 122.5, 120.6, 120.5, 115.8, 110.4, 110.0, 55.5, 26.6. HRMS (ESI) m/z: $[M+H]^+$Calcd for $C_{16}H_{15}ClNO$: 272.0842; Found 272.0858.

3-Benzyl-4-chloro-1H-indole (3.3ab):[10a] Yellow solid. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 9:1). 66% Yield, 0.080 g. **^{1}H NMR (500 MHz, Chloroform-d) δ** 7.86 (brs, 1H), 7.22 – 7.16 (m, 4H), 7.13 – 7.09 (m, 2H), 6.97 – 6.95 (m, 2H), 6.63 (s, 1H), 4.30 (s, 2H). **^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ** 141.8, 138.1, 129.0, 128.4, 126.8, 125.9, 124.5, 124.2, 122.7, 120.7, 116.7, 110.0, 32.8.

4-Chloro-3-octyl-1H-indole (3.3ac): Yellow oil. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 20:1). 47% Yield, 0.062 g. **^{1}H NMR (500 MHz, Chloroform-d) δ** 7.97 (brs, 1H), 7.21 (dd, *J* = 6.1, 2.5 Hz, 1H), 7.05–7.02 (m 2H), 6.96 (s, 1H), 2.96 (t, *J* = 7.6 Hz, 2H), 1.73–1.67 (m, 2H), 1.40–1.38 (m, 2H), 1.33 – 1.27 (m, 8H), 0.88 (t, *J* = 6.8 Hz, 3H).**^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ** 138.1, 126.8, 124.5, 122.6, 122.4, 120.4, 118.1, 109.9, 32.08, 31.7, 29.7, 29.7, 29.5, 26.6, 22.8, 14.2. HRMS (ESI) m/z: $[M+H]^+$Calcd for $C_{16}H_{22}ClNH$: 264.1519; Found 264.1489.

4-Chloro-3-decyl-1H-indole (3.3ad): Yellow oil. Column chromatography (Silica gel, 100-200 mesh, hexane/ethyl acetate = 20:1). 51% Yield, 0.074 g. ^{1}H NMR (600 MHz, Chloroform-d) δ 8.00 (brs, 1H), 7.22 (dd, *J* = 6.2, 2.5 Hz, 1H), 7.06 –7.03 (m, 2H), 6.97 (s, 1H), 2.96 (t, *J* = 7.6 Hz, 2H), 1.72 –1.67 (m, 2H), 1.43 – 1.38 (m, 2H), 1.33 – 1.27 (m, 11H), 0.88 (t, *J* = 6.9 Hz, 3H). ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ 136.8, 125.6, 123.3, 121.4, 121.2, 119.2, 116.9, 108.7, 30.91, 30.5, 28.7, 28.6, 28.5, 28.5, 28.3, 25.4, 21.6, 13.1. HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{18}H_{26}ClNH$: 292.1832; Found 292.1844.3.

3.3.10. References:

[1] a) D. A. Horton, G. T.Bourne, M. L. Smythe, *Chem. Rev*. **2003**, *103*, 893−930; b) M. Somei, F. Yamada, *Nat. Prod. Rep.* **2004**, *21*, 278−311; c) S. B. Herzon, A. G. Myers, *J. Am. Chem. Soc*. **2005**, *127*, 5342–5344; d) R. Tjalkens, S. Safe, US Pat. 8580843, **2013**.

[2] A. Jain, K.B. Banik, *Nat. Prod. Rep*. **2005**, *22*, 73–103; b) S. A. Morris, R. J. Andersen, *Tetrahedron* **1990**, *46*, 715–720.

[3] a) J. M. Finefield, J. C. Frisvad, D. H. Sherman, R. M. J. Williams, *Nat. Prod*. **2012**, *75*, 812–833; b) M. Shiri, *Chem. Rev*. **2012**, *112*, 3508–3539.

[4] a) M. Shiri, M. A. Zolfigol, H. G. Kruger, Z. Tanbakouchian, *Chem. Rev*. **2010**, *110*, 2250–2293; b) R. Bell, S. J. Carmeli, *Nat. Prod*. **1994**, *57*, 1587; c) G. R. Humphrey, J. T. Kuethe, *Chem. Rev*. **2006**, *106*, 2875–2911.

[5] V. Jamsheena, G.Shilpa, J.Saranya, N. A. Harry, R. S. Lankalapalli, S. Priya, *Chem.-Biol. Interact.* **2016**, *247*, 11−21.

[6] a) T. Pillaiyar, M. Köse, K. Sylvester, H. Weighardt, D. Thimm, G. Borges, I. Förster, I. Kügelgen, C. E. Müller, *J. Med. Chem*. **2017**, *60*, 3636–3655; b) G. Sivaprasad, P. T. Perumal, V. R. Prabavathy, N. Mathivanan, *Bioorg. Med. Chem. Lett*. **2006**, *16*, 6302−6305.

[7] S.-L. You, Q. Cai, M. Zeng, *Chem. Soc. Rev*. **2009**, *38*, 2190 – 2201; b) M. Bandini, Eichholzer, *Angew. Chem., Int. Ed.* **2009**, *48*, 9608– 9644; c) Y.-C. Hu, D.-W. Ji, C.-Y. Zhao, H. Zheng, Q. Chen, *Angew. Chem., Int. Ed*. **2019**, 5*8*, 5438−5442; d) J. A. Leitch, Y. Bhonoah, C. G. Frost, *ACS Catal*. **2017**, *7*, 5618−5627; e) Z. Li, C.-J. Li, *J. Am. Chem. Soc*. **2005**, *127*, 6968–6969.

[8] a) G. R. Humphrey, J. T. Kuethe, *Chem. Rev.* **2006**, *106*, 2875–2911; b) S. Cacchi, G. Fabrizi, *Chem. Rev.* **2005**, *105*, 2873–2920; c) J. F. Austin, W. C. D. MacMillan, *J. Am. Chem. Soc*. **2002**, *124*, 1172-1173; d) G. Bartoli, G. Bencivenni, R. Dalpozzo, *Chem. Soc. Rev*. **2010**, *39*, 4449–4465.

[9] a) M. Maji, D. Panja, I. Borthakur, S. Kundu, *Org. Chem. Front*. **2021**, *8*, 2673 –2709; b) A. Mondal, R. Sharma, D. Pal, Srimani, *D. Eur. J. Org. Chem*. **2021**, *2021*, 3690–3720.

[10] a) S. Whitney, R. Grigg, A. Derrick, A. Keep, *Org. Lett.* **2007**, *9*, 3299–3302; b) C. Chaudhari, S. M. A. H. Siddiki, K. Kon, A. omita, Y. Tai, K. Shimizu, *Catal. Sci. Technol*. **2014**, *4*, 1064−1069; c) N. Lebrasseur, I, Larrosa, *J. Am. Chem. Soc*. **2008**, 1*30*, 2926–2927; d) N. Biswas, R. Sharma, D. Srimani, *Adv. Synth. Catal*. **2020**, *362*, 2902−2910. (e) Imm, S.; Bhan, S.; Tillack, A.; Mevius, K.; Neubert, L.; M. Beller, *Chem. Eur. J*. **2010**, *16*, 2705–2709; f) S. M. A. H. Siddiki, K. Kon, K. I. Shimizu, *Chem. - Eur. J.* **2013**, *19*, 14416−14419; g) X. Jiang, W. Tang, D. Xue, J. Xiao, C. Wang, *ACS Catal*. **2017**, *7*, 1831−1835; h) S. M. A. H. Siddiki, K. Kon, K.-i. Shimizu, *Green Chem*. **2015**, *17*, 173−177.

[11] a) G. Di Gregorio, M. Mari, F. Bartoccini, G. Piersanti, *J. Org. Chem.* **2017**, *82*, 8769–8775; b) M. B. Dambatta, K. Polidano, A. D. Northey, J. M. J. Williams, L. C. Morrill, C*hemSusChem*. **2019**, 1*2*, 2345−2349; c) C. Seck, M. D. Mbaye, S. Gaillard, J.-L. Renaud, *Adv. Synth. Catal*. **2018**, *360*, 4640−4645; d) A. K. Bains, A. Biswas, D. Adhikari, *Chem. Commun*. **2020**, *56*, 15442− 15445; e) M. Hu, Y. Jiang, N. Sun, B. Hu, Z. Shen, X. Hu, L. Jin, *New J. Chem.* **2021**, *45*, 10057–10062; f) V. Yadav, E. Balaraman, S. B. Mahaske, *Adv. Synth. Catal*. **2021**, *363*, 4430–4439; g) H. Hikawa, Y. Yokoyama, *RSC Adv*. **2013**, *3*, 1061−1064; h) H. Hikawa, H. Suzuki, I. Azumaya, *J. Org. Chem*. **2013**, *78*, 12128−12135.

[12] J. C. Borghs, V. Zubar, L. M. Azofra, J. Sklyaruk, M. Rueping, *Org. Lett*. **2020**, *22*, 4222−4227.

[13] a) K. Sarkar, K. Das, A. Kundu, D. Adhikari, B. Maji, *ACS Catal*. **2021**, *11*, 2786−2794; b) K. Das, A. Mondal, D. Srimani, J. *Org. Chem.* **2018**, *83*, 9553−9560; c) K. Das, A. Mondal, D. Pal, H. K. Srivastava, D. Srimani, *Organometallics* **2019**, *38*, 1815−1825; d) A. K. Bains, D. Dey, S. Yadav, A. Kundu, D. Adhikari, *Catal. Sci. Technol*. **2020**, *10*, 6495−6500; e) D. Srimani, G. Leitus, Y. Ben-David, D. Milstein, *Angew. Chem., Int. Ed.* **2014**, *53*, 11092–11095; f) A. K. Bains, D. A. dhikari, *Catal. Sci. Technol.* **2020**, 1*0*, 6309−6318; g) A. Mondal, R. Sharma, D. Pal, D. Srimani, *Chem. Commun.* **2021**, *57*, 10363 – 10366.

[14] a) A. Ramı´rez, S. Garcı´a-Rubio, *Curr. Med. Chem.* **2003**, *10*, 1891– 1915; b) P. J. Praveen, P. S. Parameswaran, K, Maji, *Synthesis* **2015**, *47*, 1827−1837.

[15] L. Wu, R. Jiang, J.-M. Yang, S.-Y. Wang, S.-J. Ji, *RSC Adv.* **2013**, *3*, 5459–5464.

[16] a) G.-D. Zhu, V. B. Gandhi, J. Gong, Y. Luo, X. Liu, Y. Shi, R. Guan, S. R. Magnone, V. Klinghofer, E. F. Johnson, J. Bouska, A. Shoemaker, A. Oleksijew, K. Jarvis, C. Park, R. D. Jong, T. Oltersdorf, Q. Li, S. H. Rosenberg, V. L. Giranda, *Bioorg. Med. Chem. Lett*. **2006**, *16*, 3424. 17; b) Cabrero-Antonino, J. R.; Adam, R.; Junge, K.; Beller, M. *Chem. Sci*. **2017**, *8*, 6439−6450.

[17] J. Yang, Z. Wang, F. Pan, Y. Li, W. Bao, *Org. Biomol. Chem*. **2010**, *8*, 2975.

[18] K. Griffiths, P. Kumar, G. R. Akien, N. F. Chilton, A. AbdulSada, G. J. Tizzard, S. J. Coles, G. E. Kostakis, *Chem. Commun*. **2016**, *52*, 7866−7869.

[19] S. A. R. Mulla, A. Sudalai, M. Y. Pathan, S. A. Siddique, S. M. Inamdar, S. S. Chavan, R. S. Reddy, *RSC Adv*. **2012**, *2*, 3525−3529.

[20] D. Curiel, M. Mas-Montoya, L. Usea, A. Espinosa, R. A. Orenes, P. Molina, *Org. Lett*. **2012**, *14*, 3360.

[21] X. Liu, S. Ma, P. H. Toy, *Org. Lett.* **2019**, *21*, 9212−9216.

[22] B. S. Gohain, J. A. Thakur, Au *ChemistrySelect*, **2021**, *6*, 6773 – 6780.

[23] C. Ramesh, J. Banerjee, R. Pal, B. Das, *Adv. Synth. Catal*. **2003**, *345*, 557.

[24] T. Abe, S. Nakamura, R. Yanada, T. Choshi, S.Hibino, M. Ishikura, *Org. Lett*. **2013**, *15*, 3622.

[25] A. K. Chakraborti, S. Raha, D. Kumar, P. Chopra, *Green Chem*. **2008**, *10*, 1111–1118.

[26] K. Vanderlaag, Y. Su, A.E. Frankel, H. Grage, R. Smith, S. Khan, *Breast Cancer Res. Treat*. **2008**, *109*, 273–283.

3.11. Selected ^{1}H, ^{13}C NMR copies of synthesized products:

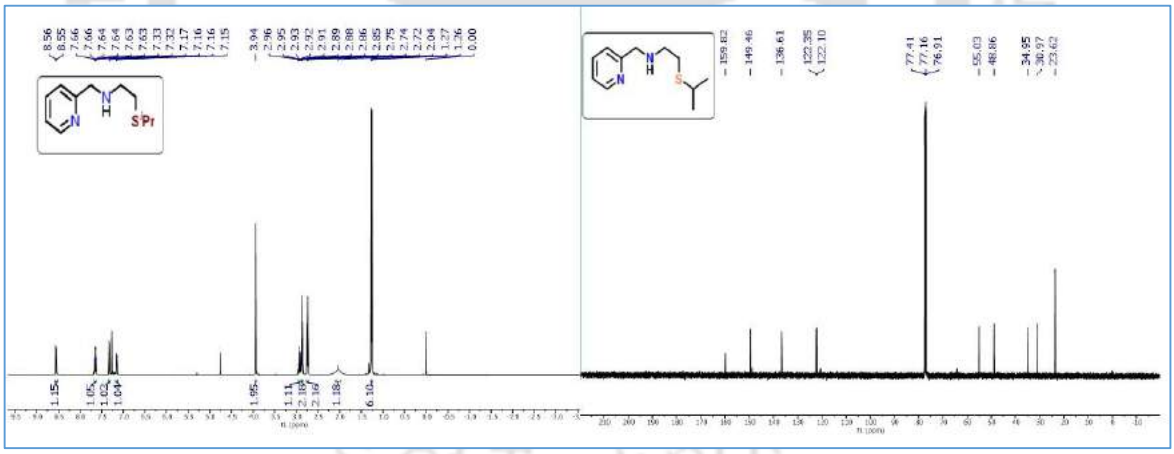


Figure 3.3. ^{1}H NMR (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of 2-(isopropylthio)-N-(pyridin-2-ylmethyl) ethan-1-aminein $CDCl_3$.

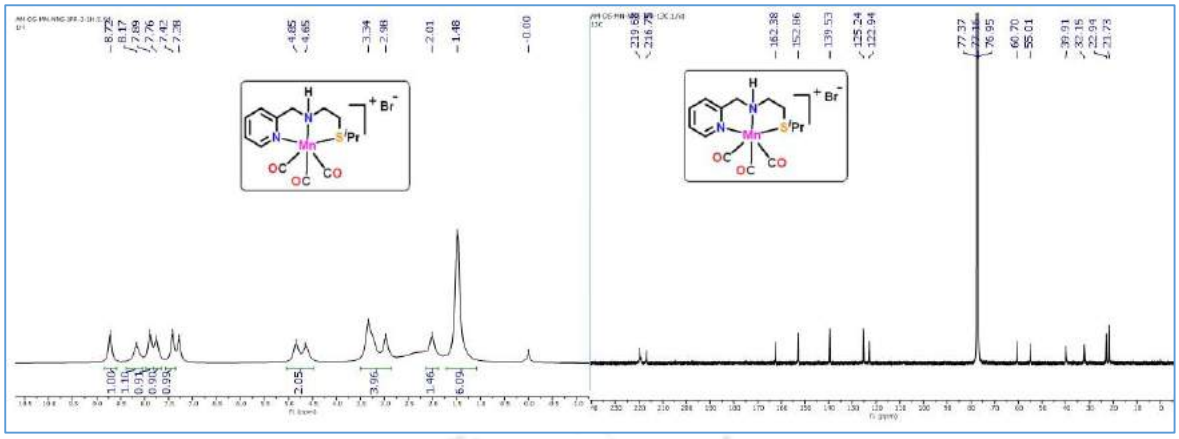
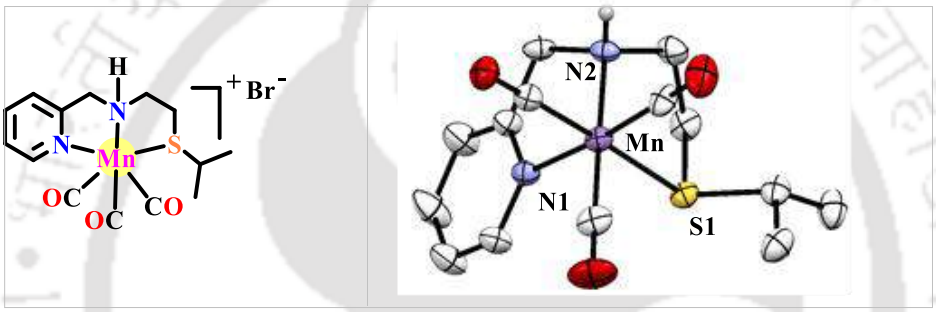


Figure 3.4. ^{1}H (600 MHz) and $^{13}C\{^{1}H\}$ (150 MHz) NMR Spectrum of Mn-20in $CDCl_3$.

Crystal structure of **Mn-20**



Crystal system	triclinic
Space group	'P -1'
Unit cell dimensions	a= 8.5316(7) Å, α=90.472° b= 10.0335(8) Å, β= 100.812° c= 11.3881(8) Å, γ= 96.762°
Volume, V (Å3)	950.42(13)
Z	2
Index ranges	-10 ≤ h ≤ 10, -11 ≤ k ≤ 11, -13 ≤ l ≤ 13
Goodness-of-fit on F2	1.075
Final R indices [I>2sigma(I)]	R1 = 0.0249 (3011), wR2= 0.0661 (3332)
R indices (all data)	R1= 0.0293, WR2=0.0637
Selected bond lengths	Selected bond angles
Bond lengths [Å]	Bond angles [°]
Mn1 N1 2.0592(18)	N1 Mn1 S1 83.77(5)
Mn1 N2 2.0804(18)	N2 Mn1 S1 84.64(6)

Mn1 S1 2.3745(6)	N1 Mn1 N2 80.28(7)
Mn1 C12 1.807(3)	C12 Mn1 S1 96.65(7)
Mn1 C13 1.794(3)	C13 Mn1 S1 90.94(8)
Mn1 C14 1.813(2)	C14 Mn1 S1 175.24(7)

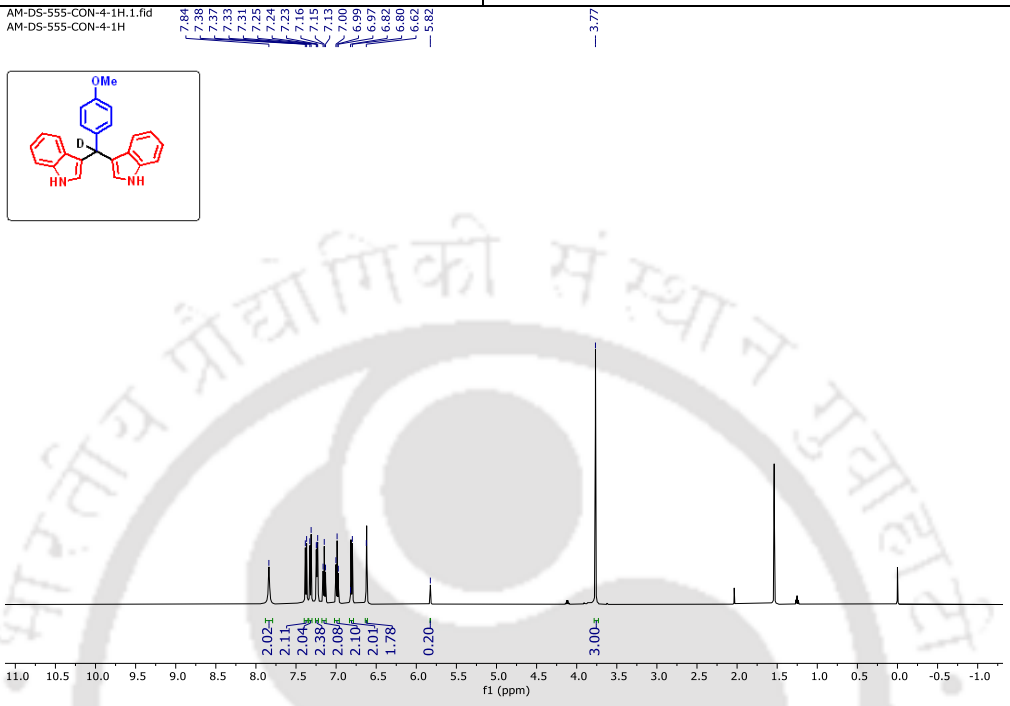


Figure 3.5. ^{1}H NMR Spectrum of (**3.4a-d1**) in $CDCl_3$ (600 MHz).

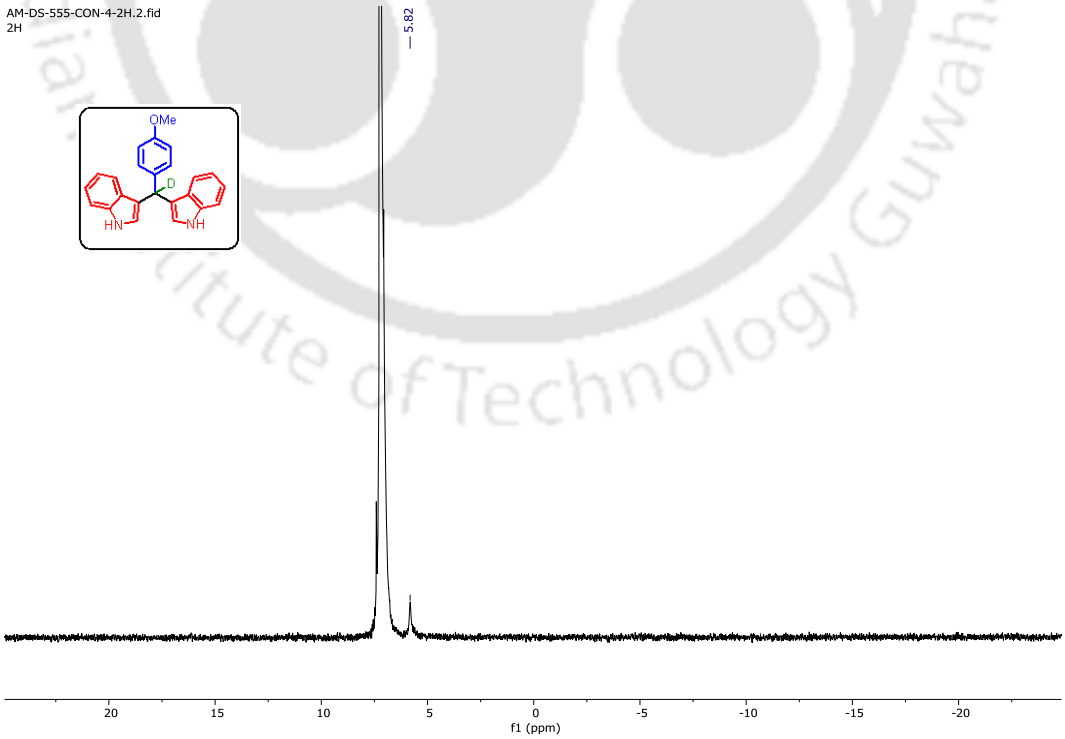


Figure 3.6. ^{2}H NMR Spectrum of (**3.4a-d1**) in $CDCl_3$ (600 MHz).

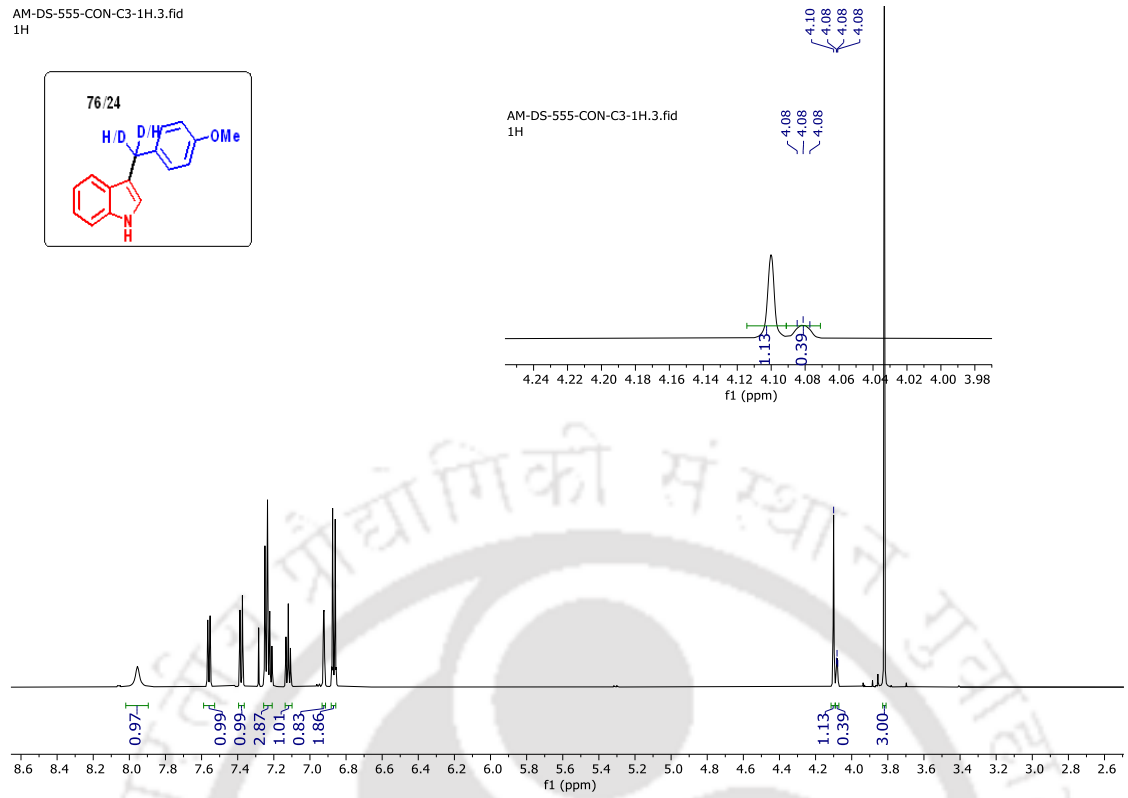


Figure 3.7. ^{2}H NMR Spectrum of (**3.3a-d2**) in $CDCl_3$ (600 MHz).

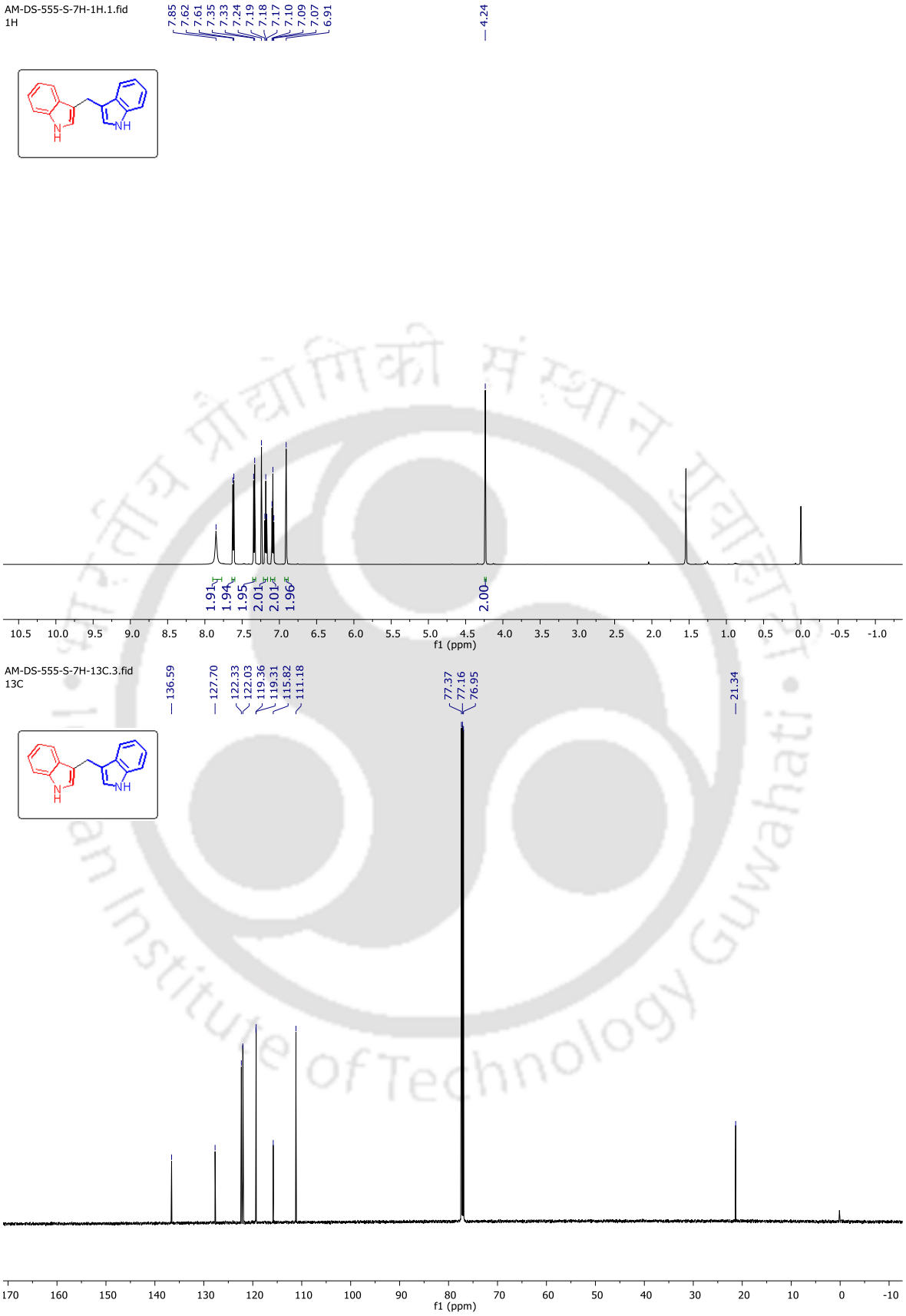


Figure 3.8. ^{1}H (600 MHz) and $^{13}C\{^{1}H\}$ (150 MHz) NMR Spectrum of di(1H-indol-3-yl) methane (**3.3h**) in $CDCl_3$.

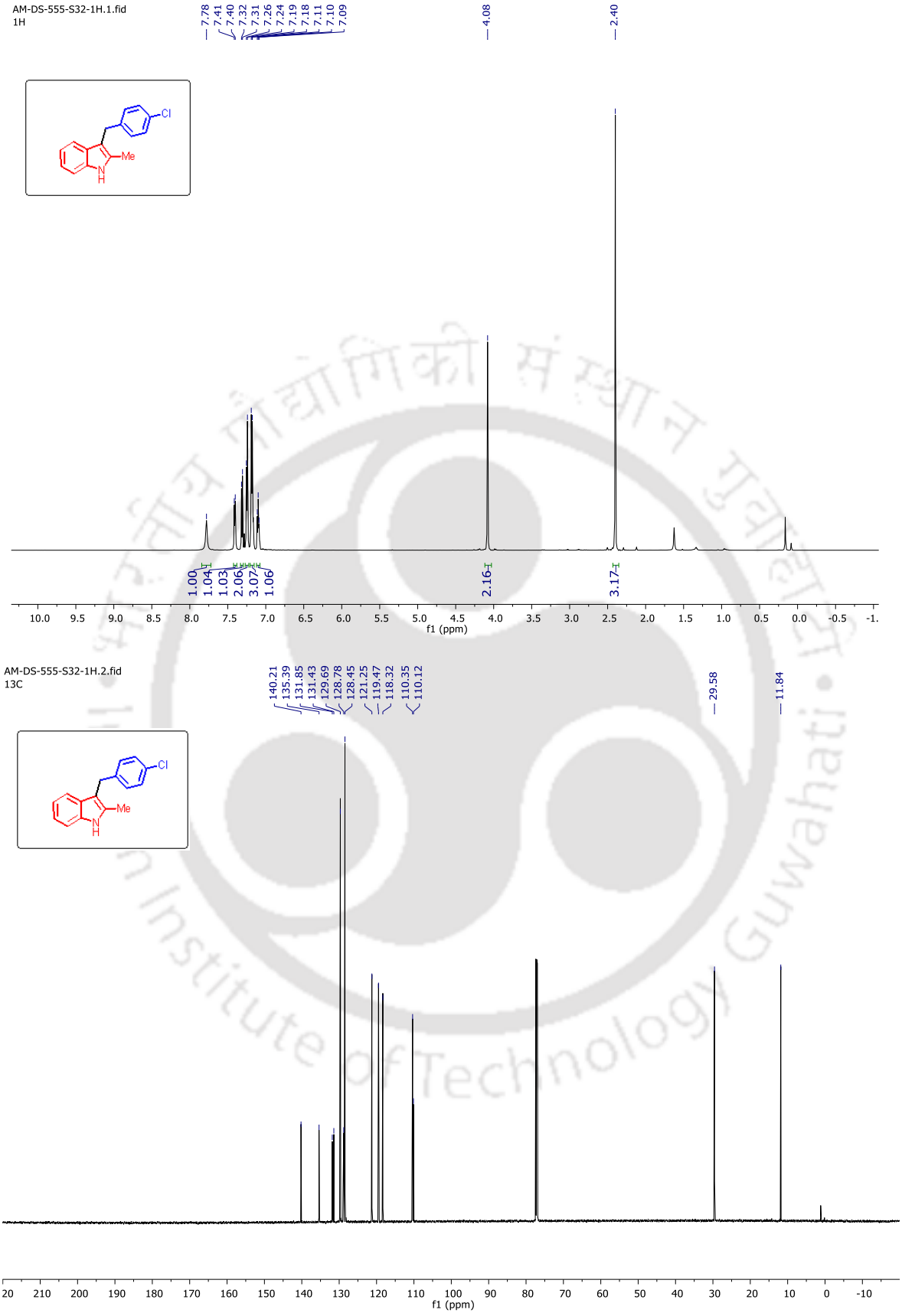


Figure 3.9. ^{1}H (600 MHz) $^{13}C\{^{1}H\}$ (150 MHz) NMR Spectrum of 3-(4-chlorobenzyl)-2-methyl-^{1}H-indole (**3.3n**) in $CDCl_3$.

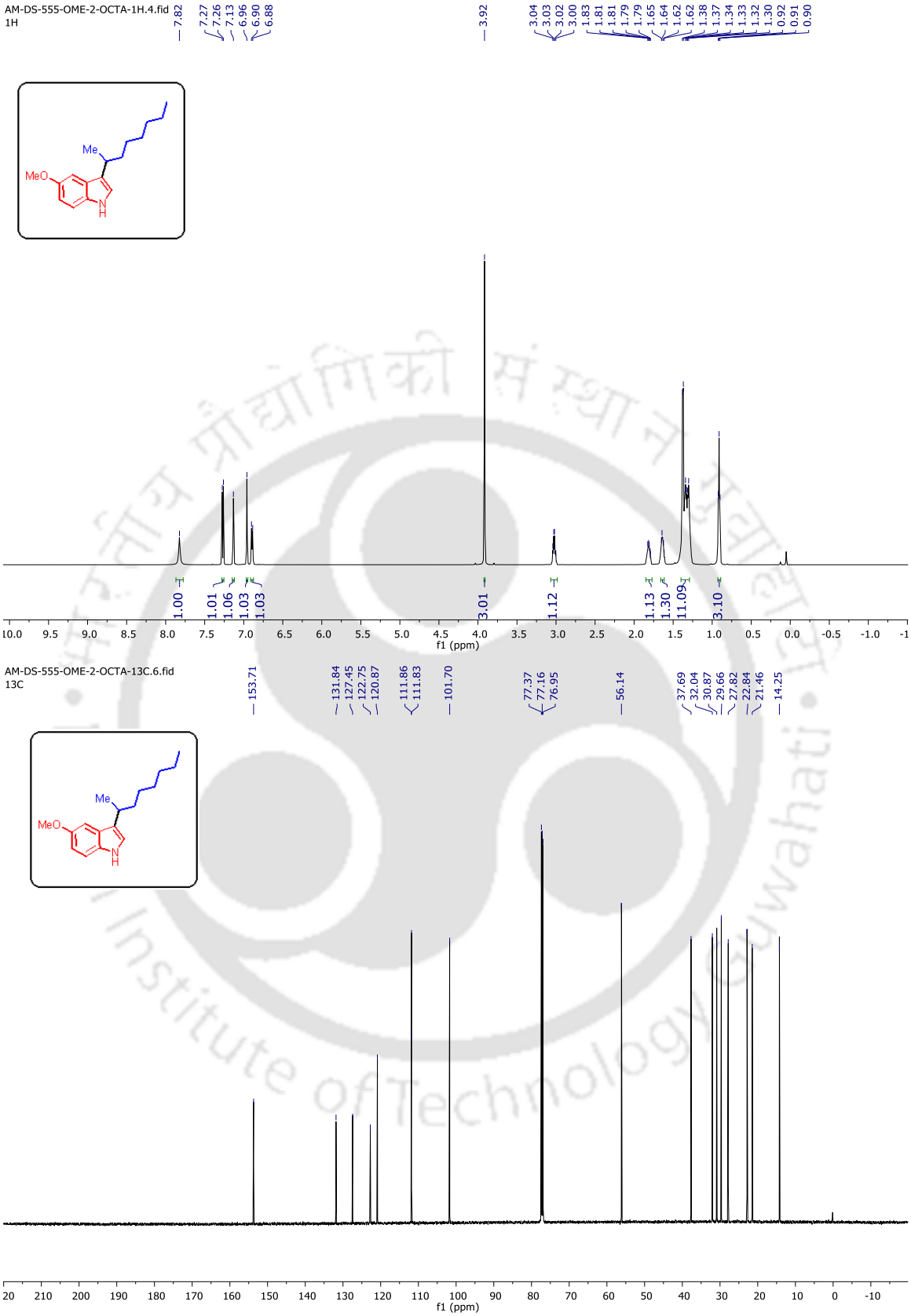


Figure 3.10. ^{1}H (600 MHz) and $^{13}C\{^{1}H\}$ (150 MHz) NMR Spectrum of 5-methoxy-3-(octan-2-yl)-1H-indole (**3.3x**) in $CDCl_3$.

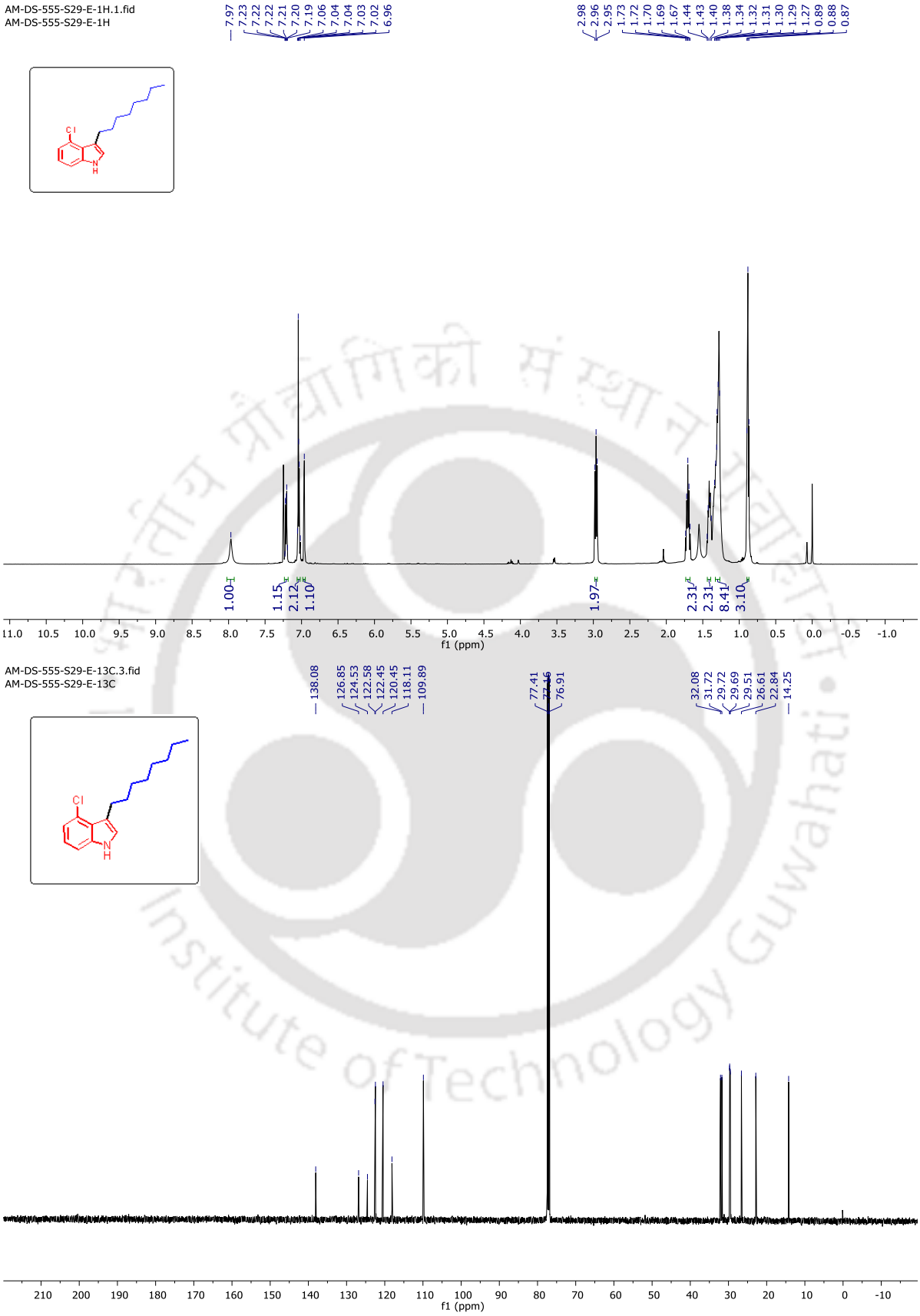


Figure 3.11. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of 4-chloro-3-octyl-1H-indole (**3.3ac**) in $CDCl_3$.

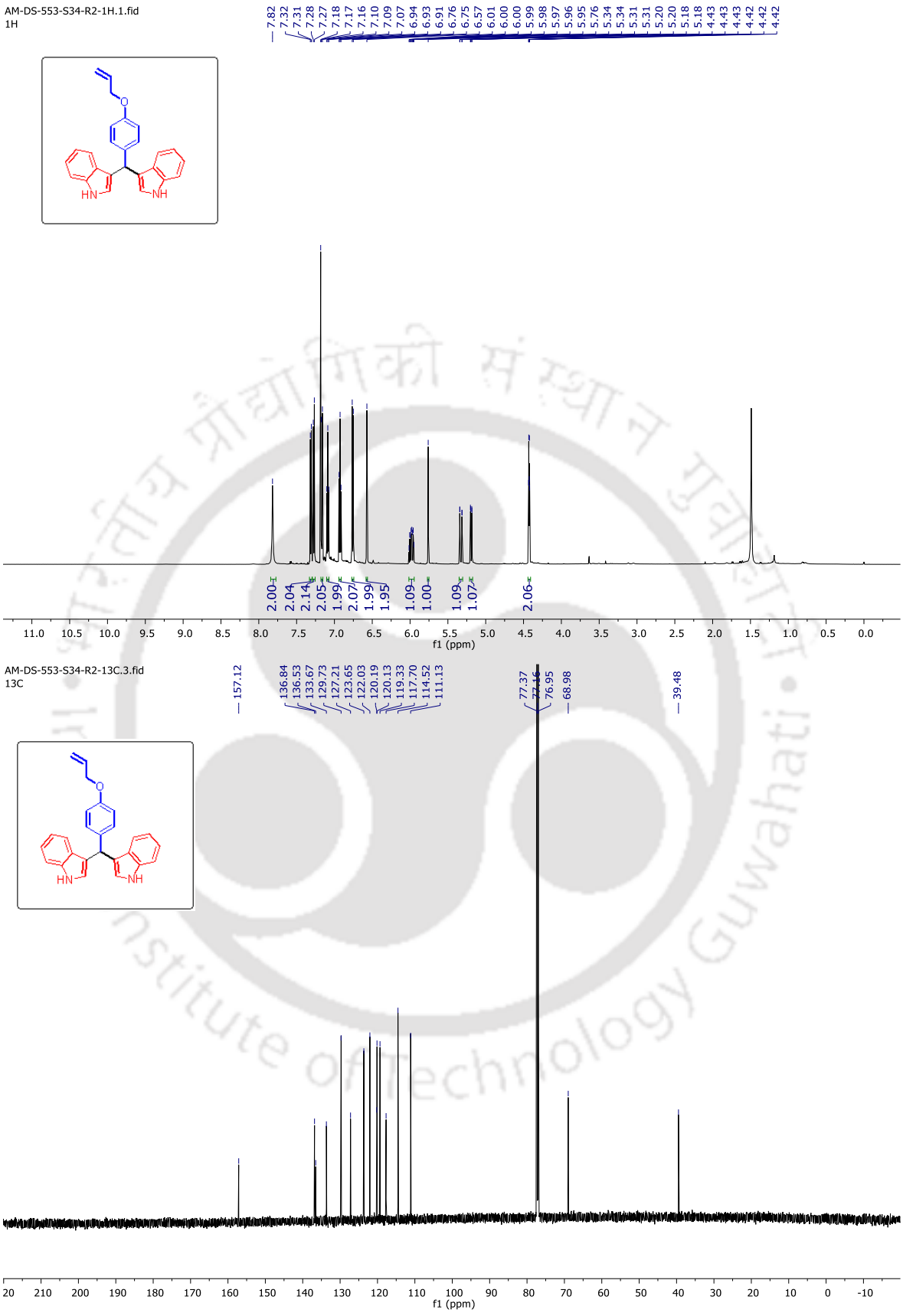


Figure 3.12. ^{1}H (600 MHz) and $^{13}C\{^{1}H\}$ (150 MHz) NMR Spectrum of 3,3'-((4-(allyloxy)phenyl)methylene)bis(1H-indole) (**3.4j**) in $CDCl_3$.

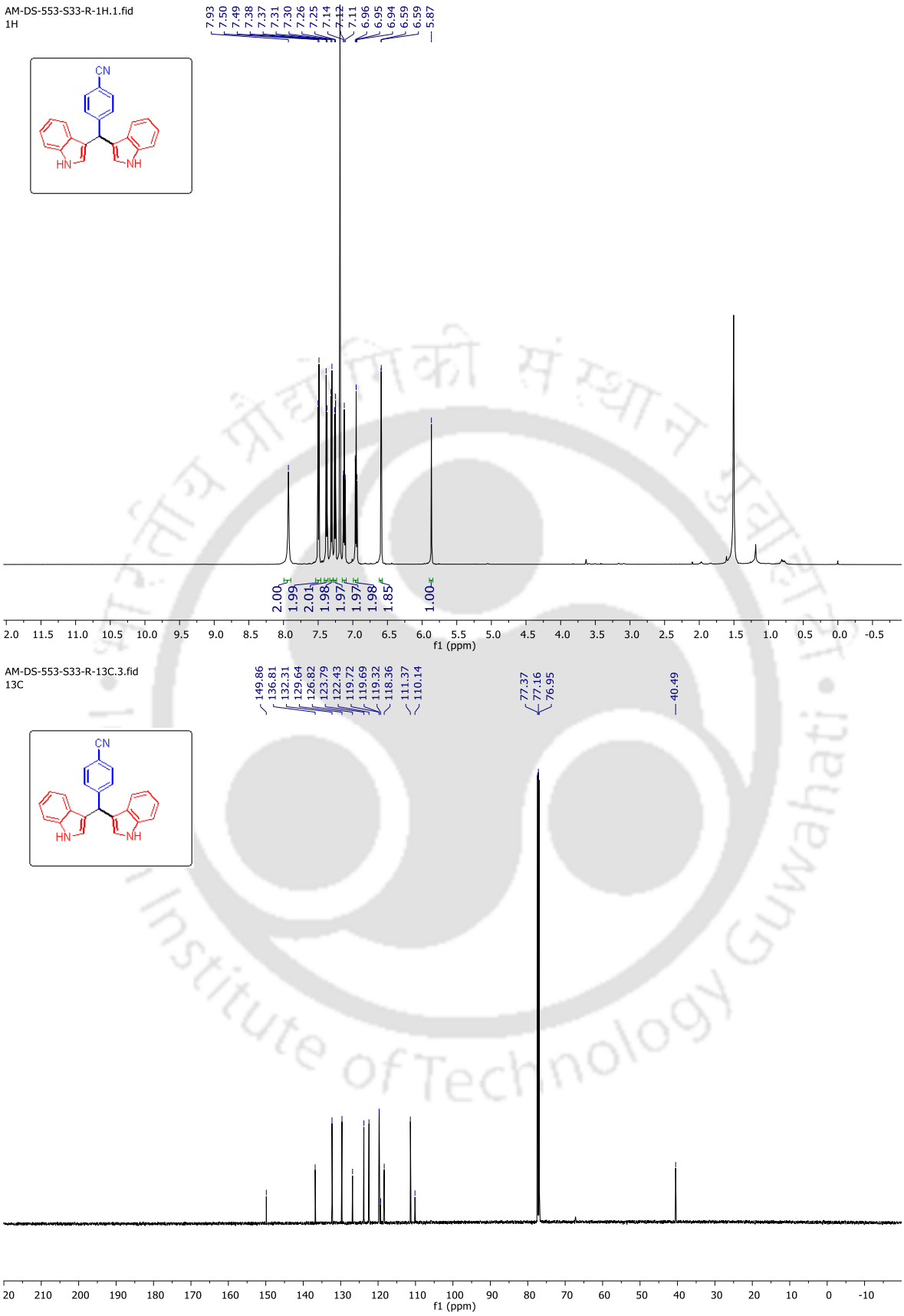


Figure 3.13. ^{1}H (600 MHz) and $^{13}C\{^{1}H\}$ (150 MHz) NMR Spectrum of 4-(di(1H-indol-3-yl)methyl)benzonitrile(**3.4k**) in $CDCl_3$.

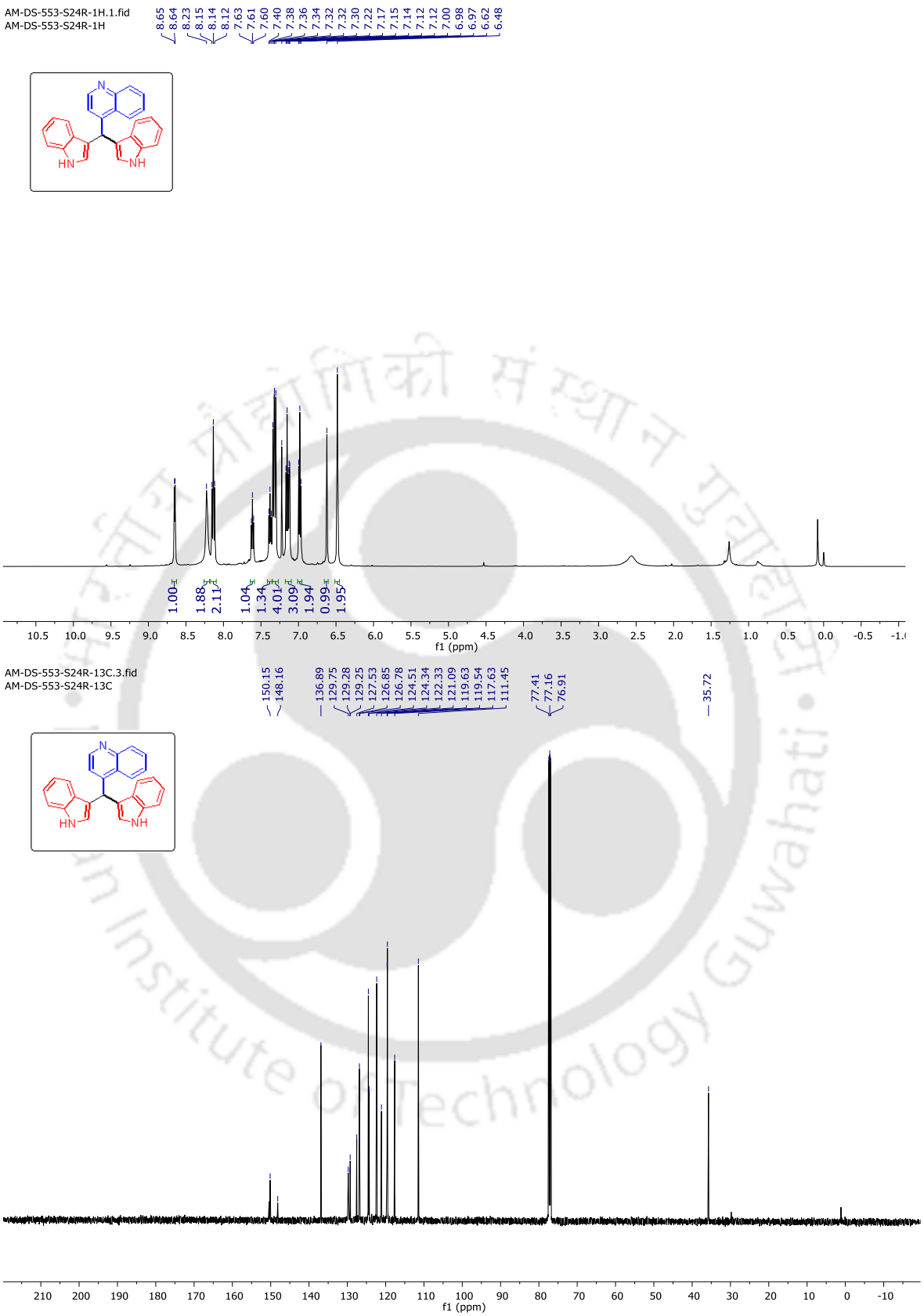


Figure 3.14. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of 4-(di(1H-indol-3-yl)methyl)quinoline(**3.4r**) in $CDCl_3$.

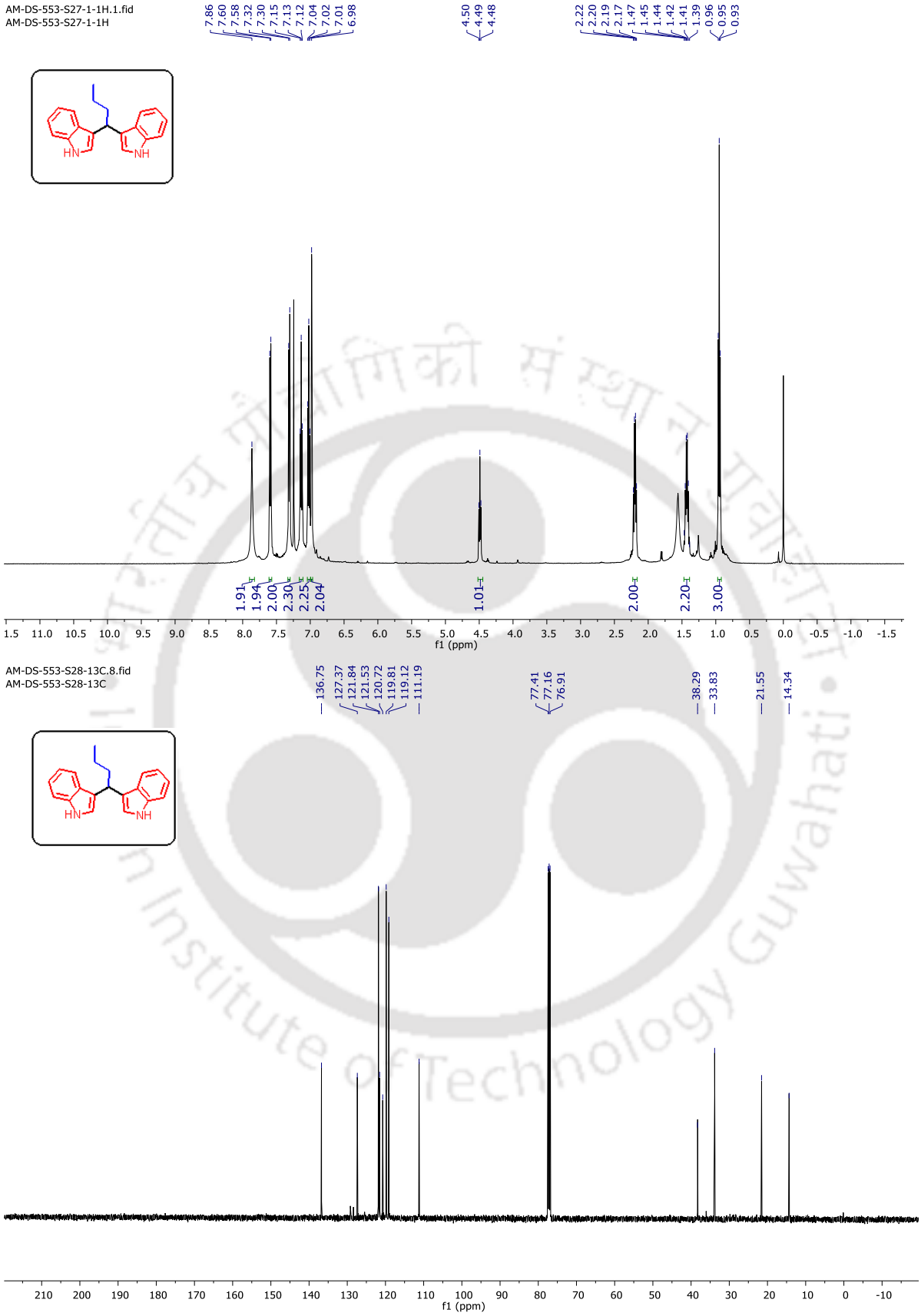


Figure 3.15. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of 3,3'-(butane-1,1-diyl)bis(1H-indole) (**3.4x**) in $CDCl_3$.

CHAPTER 4

Mn(I) Complex Catalysed Multicomponent Approach for Poly-substituted Quinolines synthesis: A Strategic Route to Quinoline based Azafluorenes via Direct C(sp^3)-H Bond Hydroxylation

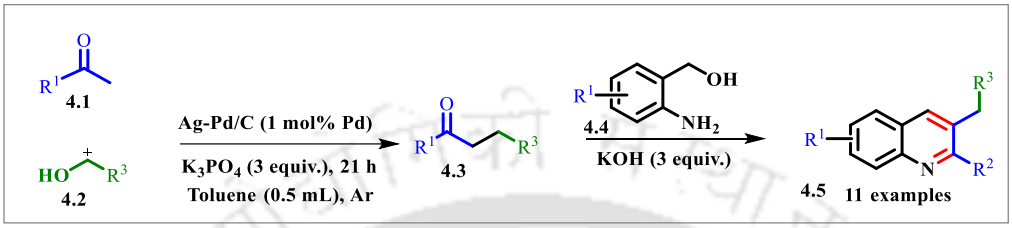
A. Mondal, D. Pal, H.J. Phukan, M. Roy, S. Kumar, S. Purkayastha, A.K. Guha, D. Srimani, *ChemSusChem*, **2024**, e202301138.

4.1. Introduction: The development of new green and sustainable protocols for the synthesis of N-containing heterocycles has captivated much consideration of the agrochemical and pharmaceutical industries because of the significant interaction of these compounds with biological organisms.[1] Particularly, aromatic N-heterocyclic compounds are more important because of their diverse range of usage as drugs,[2a] agrochemicals,[2b] dyes,[2c] vitamins,[2d] and flavours.[2e] As a result, there is a noteworthy demand for new atom-efficient, cost-effective and more sustainable synthetic methods that enable the creation of variously functionalized N-heterocycles.

Quinoline derivatives are important class of *N*-heterocycles that possess myriad of pharmacological[3] and biological properties[4] including alzheimer's disease,[5] antimalarial,[6] neuroprotective,[7] antiparkinson[8] etc. Quinolines can also be used as important organocatalyst,[9] photoelectric materials[10] and dyes.[11] The presence of various substituents on the quinoline moiety has a significant impact on their properties. Therefore, there is a constant need for innovative synthetic methods that enable the creation of highly functionalized quinoline derivatives, ideally in a sustainable and atom-efficient manner. Recently acceptorless dehydrogenation and BH-catalysis evolved as highly atom-efficient and sustainable tools for making various useful compounds utilizing renewable alcohols.[12] Employing these powerful technologies, recently, several catalytic protocols have been discovered to construct the *N*-heterocycles.[13]

In this context, dehydrogenative synthesis of quinolines was also achieved by reacting 2-amino alcohols with secondary alcohols or its corresponding ketones. However, due to a lack of a diverse range of readily available α-branch ketones, most of these protocols are limited to the synthesis of mainly 2-substituted quinolines.[14] Thus, the synthesis of a wide range of 2,3-disubstituted quinolines via dehydrogenative approach would be interesting.[15] This could be achieved by the BH-mediated alkylation of ketone followed by the dehydrogenative annulation with 2-amino alcohols via one-pot multicomponent reactions (MCRs) or by sequential manner. This would be highly advantages because this will minimize the production of wastes by eliminating multiple isolation/purification steps and also give high atom-economy.[16] The main challenges associated in this approach would be the selectivity of the catalyst and fine-tuning the reaction parameters to reach the targeted molecule while avoiding the formation of undesired side products such as chalcone,[17] Guerbet alcohol,[18] self-condensation,[19] and dialkylation[20] products. In this direction pyrimidine and pyrrole are the two heterocycles, which are reported by manganese complexes via dehydrogenative one pot multicomponent strategy.[21]

4.2. Literature reports: In 2013 Ying group[22] reported one pot quinolines synthesis via a two-step tandem reaction catalysed by Ag-Pd alloy nanoparticles supported on carbon. Under an argon atmosphere, 3 equiv. K_3PO_4, AgPd alloy nanoparticles promoted the coupling of a ketone with a primary alcohol via a hydrogen auto-transfer mechanism, then 2-aminobenzyl alcohols and again 3 equiv. KOH was used to produce poly-substituted quinolines in moderate to good yields with only 11 substrates.



Scheme 4.1. One pot Ag-Pd/C catalysed poly-substituted quinoline synthesis.

Thus, the limited substrate scope of this protocol and the use of noble metals leave a scope to develop a first-row transition metal-derived efficient catalyst, which can be applied to a wide range of substrates. Furthermore, this will open up the opportunity to construct a diverse range of quinolines having a C3-methylene group which can be converted to new quinoline-derived azafluorenes via C(sp^3)-H bond hydroxylation and Friedel–Crafts-type annulation.

4.3. Present work: This current approach discloses a one-pot sequential multicomponent strategy for poly-substituted quinolines having C-3 methylene group using newly synthesized Mn(I)-catalyst by minimizing multiple side product formation. The developed protocol is suitable for a wide range of substrates including aliphatic primary and secondary alcohols with good to excellent yields. The newly synthesized 2,3-disubstituted quinoline derivatives are further utilized for medicinally important azafluorenes synthesis via unprecedented C(sp^3)-H hydroxylation and annulation. A series of control experiments, hydride trapping experiments, reaction kinetics, catalytic intermediate and DFT studies were performed to comprehend the detailed reaction route and the catalyst's function in the MCR sequence.

4.4. Result and discussion: To synthesize the poly-substituted quinoline six air stable Mn(I) complexes were prepared and characterized various spectroscopic and spectrometric methods (preparation procedure is mentioned in experimental section).

Figure 4.1. Used catalysts in this chapter for poly-substituted quinoline synthesis.

4.4.1. Reaction optimization: The concept of one-pot sequential multicomponent de(hydrogenative) synthesis of poly-substituted quinolines was exploited by employing above Mn-complexes. To materialize this hypothesis, first the most efficient catalyst has to be selected for the synthesis of *α*-branched ketones and also it must have an excellent ability to dehydrogenate amino alcohols.

Table 4.1. Optimization table of first step of multicomponent reaction:

Initially, reaction optimization was started using 4-methoxy acetophenone (**4.1a**) and benzyl alcohol (**4.2a**) as a model substrate to find out the optimum reaction conditions.

4.1a 4.2a 4.3a 4.3a'

Entry	1a	:	2a	Base (mmol)	Solvent (mL)	Cat. (mol%)	Time (h)	4.3a	4.3a'
1	1		1.1	KOH (0.25)	Toluene	.....	24	Trace	..
2	1		1.1	KOH (0.25)	Toluene	Mn-6(5)	24	95%	...
3	1		1.1	KOH (0.15)	Toluene	Mn-6(5)	24	71%	..
4	1		1.1	KOH (0.25)	Toluene	Mn-6(1)	24	95%	..
5	1		1.1	KOH (0.25)	Toluene	Mn-6(0.5)	24	71%	..
6	1		1.1	KOH (0.25)	Toluene	Mn-6(1)	12	86%	..
7	1		1.1	KOH (0.25)	Toluene	Mn-6(1)	15	95%	..
8	1		1.0	KOH (0.25)	Toluene	Mn-6(1)	15	95%	..
9	1		1.0	NaOH (0.25)	Toluene	Mn-6(1)	24	81%	..
10	1		1.0	KO^{t}Bu (0.25)	Toluene	Mn-6(1)	24	67%	20%
11	1		1.0	Na^{t}Bu (0.25)	Toluene	Mn-6(1)	24	60	22%
12	1		1.0	K_2CO_3 (0.25)	Toluene	Mn-6(1)	24	Trace	..
13	1		1.0	Na_2CO_3 (0.25)	Toluene	Mn-6(1)	24	Trace	..
14	1		1.0	Cs_2CO_3 (0.25)	Toluene	Mn-6(1)	24	Trace	..
15[b]	1		1.0	KOH (0.25)	Toluene	Mn-6(1)	15	67%	..
16	1		1.0	KOH (0.25)	Toluene	Mn-6(1)	15	84%	..
17	1		1.0	KOH (0.25)	Toluene	Mn-20(1)	15	85%	..
18	1		1.0	KOH (0.25)	Toluene	Mn-17(1)	15	81%	..
19	1		1.0	KOH (0.25)	Toluene	Mn-21(1)	15	61%	..
20	1		1.0	KOH (0.25)	Toluene	Mn-23(1)	15	77%	..

[a]**Conditions: 4.1a** (1 mmol), **4.2a** (1.0-1.1 mmol), base (0.15-0.25 mmol), Mn-catalyst (0.5-5.0 mol %) under argon, temperature 130 °C, time: 12-24 h, [b]time 100 °C.

Various reaction parameters like base, temperature, time catalyst loading and ratio of two reactants were screened. When a mixture of 4-methoxy acetophenone (**4.1a**) and benzyl alcohol (**4.2a**) was taken in 1: 1.1 ratio in toluene, in presence of only KOH (25 mol%) and heated at 130 °C for 24 h

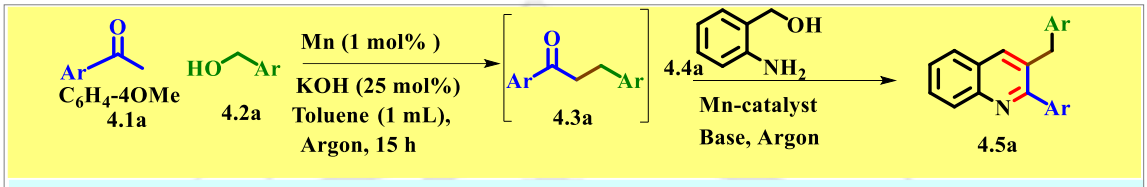
under argon atmosphere, only trace amount of corresponding *α*-alkylated ketone (**4.3a**) was detected (Table **4.1**, entry **1**). But addition of 5 mol% Mn-catalyst under the same reaction conditions surprisingly, 95% of desired product (**4.3a**) was isolated which indicates that the presence of catalyst in this transformation has tremendous role (Table **4.1**, entry **2**). Keeping all the parameters identical only reducing the KOH concentration, the yield was also reduced from 95% to 71% (Table **4.1**, entry **3**). On decreasing the catalyst loading up to 1 mol% yield of the desired product was same but further decreasing to 0.5 mol% the yield was turned down to 71% (Table **4.1**, entry **5**). Interestingly, when reaction time reduced to 12 h, slightly lower amount of *α*-alkylated ketone product (**4.3a**) was obtained but 15 h reaction time delivered 95% *α*-alkylated product (Table **4.1**, entry **6-8**). Then, the influences of different bases in this reaction was checked. Use of NaOH instead of KOH, keeping other parameters constant, lower yield of the desired product (**4.3a**) was isolated (Table **4.1**, entry **9**). The weak bases such as Na_2CO_3, K_2CO_3 and Cs_2CO_3 failed to deliver the α-alkylated ketone product (**4.3a**) but in case of strong bases like KO^{t}Bu and NaO^{t}Bu mixture of α-alkylated product (**4.3a**) and corresponding carbonyl hydrogenated product (**4.3a´**) were observed (Table **4.1**, entry **10-14**). Furthermore, a reduced yield was observed when the reaction temperature was reduced to 100 °C (Table **4.1**, entry **15**). Efficiency of other catalysts were also tested. Results suggest that other catalysts are less effective to deliver the desired product (Table **4.1**, entry **16-20**).

Table 4.2. Optimization of the second addition of consecutive one pot multicomponent poly-substituted quinoline synthesis:

To produce the required poly-substituted quinoline in a single pot with all of the reactants combined, several screenings of the reaction parameters were also examined. However, instead of targeted 2,3-disubstituted quinoline, 2-substituted quinoline was formed in 81% yield (discussed in experimental section **4.16**)

Next, the efforts have been made to furnish 2,3-di-substituted quinoline in sequential addition of the reactants in one-pot. At the outset, when only 2-amino benzyl alcohol (**4.4a**) was added to the previous reaction mixture (after the synthesis *α*-branched ketones) without adding any additives or catalyst, only 12% of the desired product (**4.5a**) was isolated (Table **4.2**, entry **1**). However, slight improvement of yield of the desired product was observed when 2 mol% catalyst (**Mn-22**) was added in the reaction mixture (Table **2**, entry **2**) after 15h and continued for another 24 h. Pleasingly, yield of the desired product was further improved to 70% simply by adding both base (KOH, 1 equiv.) and 2 mol% **Mn-22** catalyst (Table **4.2**, entry **3**). On decreasing the base loading up to 0.6 equiv. showed identical result but further lowering the base showed detrimental effect on the yield of the product (Table **4.2**, entries **5** & **4**). Next, the effect of other bases in this current protocol was tested. Weak bases such as Na_2CO_3, K_2CO_3 and $Cs_2CO_3.H_2O$ were failed to catalyze the reaction whereas ^{t}BuOK and NaOH showed inferior results (Table **4.2**, entries **6-9**). Furthermore, reducing

the reaction temperature, time and catalyst loading have deleterious effect and the yield of the desired product was obtained 32%, 43% and 39% respectively (Table **4.2**, entries **10-12**). Other Mn catalysts (**Mn-6, Mn-17, Mn-20, Mn-21 & Mn-23**) were found to be less efficient under the similar reaction conditions (Table **4.2**, entries **13-17**). Further increase of the amount of amino alcohol (1.3 equiv.) or the catalyst loading (3 mol %), did not improve the product yield appreciably (Table **4.2**, entries **18-19**). When the same tandem transformation is performed in 25 mL round bottom flux instead of 100 mL pressure tube under identical reaction conditions, comparable yield of the desired quinoline was isolated (Table **4.2**, entry **20**).



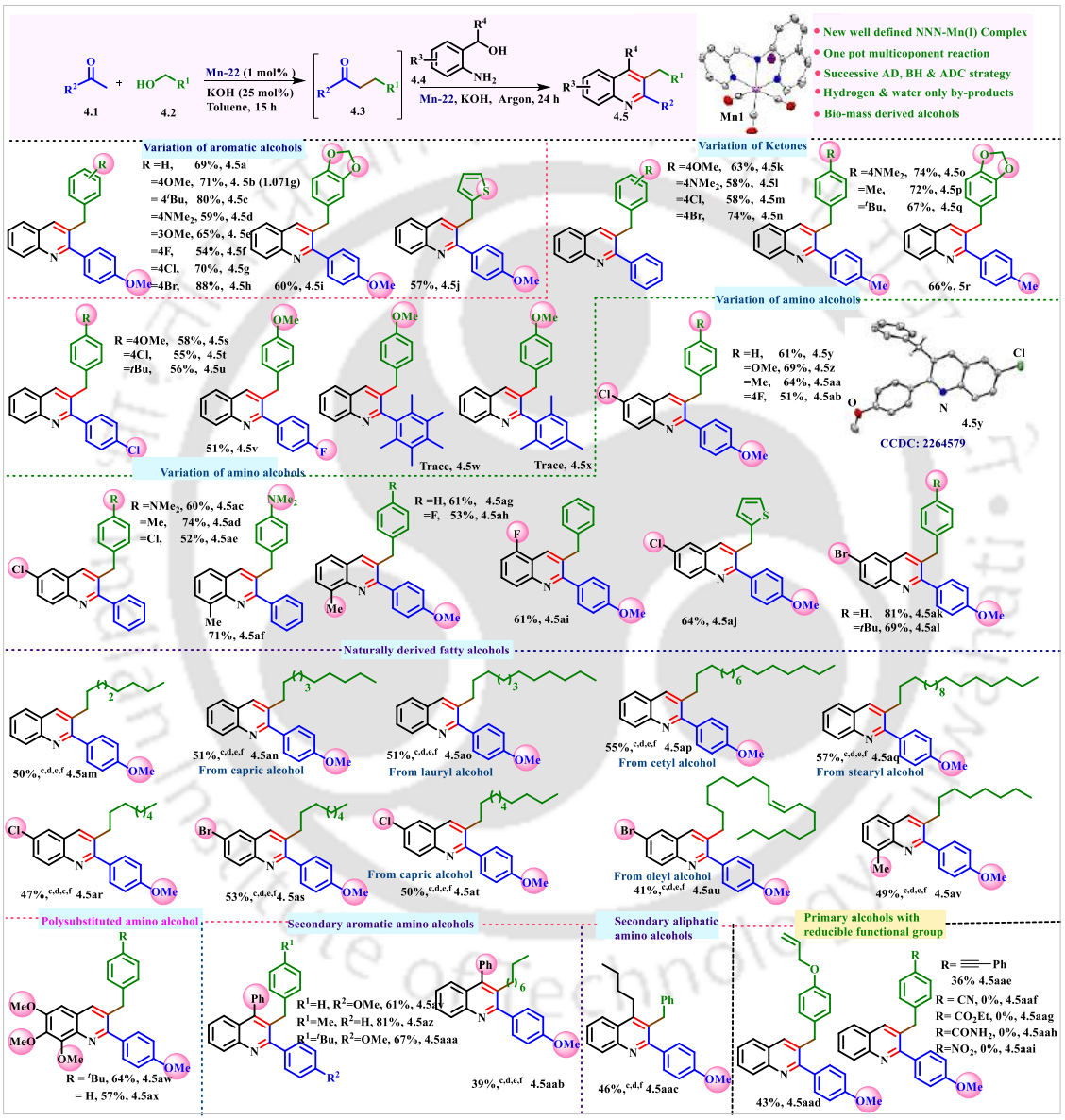
Entry	Catalyst (mol%)	Base (equiv.)	Time (h)	Amino alcohol (equiv.)	% Yield [b] 4.5a
1	.....	.....	24	1.1	12
2	Mn-22(2)	.....	24	1.1	26
3	Mn-22(2)	KOH(1)	24	1.1	70
4	Mn-22(2)	KOH(0.5)	24	1.1	56
5	Mn-22(2)	KOH(0.6)	24	1.1	69
6	Mn-22(2)	K_2CO_3(0.6)	24	1.1	--
7	Mn-22(2)	$Cs_2CO_3.H_2O$(0.6)	24	1.1	--
8	Mn-22(2)	^tBuOK (0.6)	24	1.1	54
9	Mn-22(2)	NaOH(0.6)	24	1.1	37
10[c]	Mn-22(2)	KOH(0.6)	24	1.1	32
11	Mn-22(2)	KOH(0.6)	15	1.1	43
12	Mn-22(2)	KOH(0.6)	24	1.1	39
13	Mn-6(2)	KOH(0.6)	24	1.1	60
14	Mn-20(2)	KOH(0.6)	24	1.1	57
15	Mn-17(2)	KOH(0.6)	24	1.1	56
16	Mn-21(2)	KOH(0.6)	24	1.1	41
17	Mn-23(2)	KOH(0.6)	24	1.1	55
18	Mn-22(3)	KOH(0.6)	24	1.1	68
19	Mn-22(2)	KOH(0.6)	24	1.3	69
20[d]	Mn-22(2)	KOH(0.6)	24	1.1	68

[a]**Conditions**: **4.1a** (1 mmol), **4.2a** (1 mmol), **4.4a** (1.1-1.3 mmol), Base (0.5-1.0 mmol), **Mn-22** (1-3 mol %), Under argon, [c]Temperature 100 °C, [d]Reaction is carried out in two neck round bottom flux, all reactions were carried in 100 mL seal tube.

4.5. Substrate paradigm: After achieving the optimized reaction conditions, the scope and limitations of this tandem one-pot sequential multicomponent synthetic method for the synthesis of highly substituted quinolines was investigated. At first, various *p*-substituted electronically rich and neutral benzyl alcohols were tested with 4-methoxy acetophenone (**4.1a**) and 2-amino benzyl alcohol (**4.4a**). Delightfully, in all cases good to excellent yields of the desired 2,3-disubstituted

quinolines were isolated (Table **4.3**, **4.5a-4.5d**, 59-80%). Aromatic primary alcohol containing electron-donating substituent at *m*-position also yielded good results as well (Table **4.3**, **4.5e**). Halo substituted aromatic primary alcohols were also subjected to the standard reaction conditions. Notably, on decreasing the electronegativity of the halo substituents, yields of the desired quinoline derivatives were increased up to 88% without any signs of dehalogenation (Table **4.3**, **4.5f-4.5h**).

Table 4.3. Well defined NNN Mn(I) complex catalysed synthesis of highly substituted quinolines.[a,b]



[a]**Reaction conditions: Step I: 4.1**(1 mmol), **4.2** (1 mmol), KOH (25 mol%), **Mn-22**(1 mol%), toluene (2 mL), Temperature 130 °C, 15 h, [b]Isolated yields, [c]Aliphatic alcohols: 1.5-2 equiv., [d]Base:1 equiv., [e]Time: 36 h, [f]**Mn-22**(5 mol%) & 140 °C oil bath temperature; **Step II: 4.4** (1.1 mmol), **Mn-22** (2 mol%), KOH (0.6 mmol), 24 h, all reaction is carried out in 100 mL seal tube.

Under the established conditions, heteroaromatic alcohols were also found to be suitable coupling partners for this transformation (Table **4.3**, **4.5i** & **4.5j**). Next, different aromatic ketones were introduced with aromatic primary alcohol and 2-amino benzyl alcohol to bring out a wide variety of 2,3-disubstituted quinolines in good to excellent yield (Table 2, **4.5k**–**4.5v**, 51-74%). However, highly substituted ketone derivatives failed to give desired quinolines even after longer reaction time while corresponding α-branched ketone isolated in 64% & 79% yields (Table 2, **4.5w** & **4.5x**). This underpins that the highly substituted aromatic ring at the *β*-position of ketones hinders the dehydrogenative annulation step. The scope of differently substituted 2-amino benzyl alcohols was examined to synthesize poly-substituted quinolines. Initially, 2-amino-5-chloro benzyl alcohol was reacted with a range of 4-substituted aromatic alcohols to furnish poly substituted quinoline products in good to excellent yields (Table **4.3**, **4.5y**-**4.5ab**). One representative single crystal structure analysis of **4.5y** was performed to understand the special arrangement of different groups. Afterwards, various amino alcohol derivatives such as 2-amino-3-methyl benzyl alcohol, 6-fluoro, 5-bromo-2-amino benzyl alcohol were responded with a range of different primary alcohols and aromatic ketones to deliver functionally diverse quinolines in good to excellent yields (Table **4.3**, **4.5af-4.5al**). Next, challenging aliphatic alcohols were introduced to produce long chain substituted functionalized quinoline motifs, which are tricky to synthesize by conventional techniques and are, therefore, unexplored in the literature. **Mn-22** catalyst successfully activates aliphatic alcohols under slightly modified reaction conditions and furnishes moderate yields of the long chain containing poly-substituted quinolines (Table **4.3**, **4.5am-4.5av**). Notably, various naturally derived fatty alcohols like capric, lauryl, cetyl, and stearyl alcohols reacted well to form the desired heterocycles in moderate yields (50-57%) (Table **4.3**, **4.5an-4.5aq & 4.5at-4.5av**). Naturally occurring unsaturated oleyl alcohol chemo selectively furnished 2,3-disubstituted quinoline under borrowing hydrogen conditions (Table **4.3**, **5au**). Highly electron rich 3,4,5-trimethoxy amino alcohol also responded well, providing 61-64% yields of the desired penta-substituted quinolines (Table **4.3**, **4.5aw** & **4.5ax**). With the help of established streamlined reaction conditions, a number of 2,3,4-trisubstituted quinolines were produced in good to excellent yields (Table **4.3**, **4.5ay-4.5aac**). Next, primary alcohols containing reducible functional groups were introduced under standard catalytic protocol. Gratifyingly, alcohols contain terminal alkene and internal alkyne are chemo selectively delivered desired quinolines in moderate yields but functional group like nitro, nitrile, ester and amide are failed to produce corresponding targeted products (Table **4.3**, **4.5aad-4.5aai**).

4.6. Mechanistic investigation: After successful application of bench stable NNN-Mn(I) manganese complex in multicomponent quinoline synthesis, next, to study the reaction mechanism and reactivity pattern several control, kinetics and DFT calculation were performed. Under the identical reaction conditions, corresponding dehydrogenated products (aldehydes) of 4-methoxy benzyl alcohol and 2-amino benzyl alcohol were detected (Figure **4.2A & B**, **4.6** & **4.7**). Next, separately four reactions were conducted to identify the possible reaction intermediates. At first, reaction of amino alcohol with α-branch ketone under standard reaction conditions afforded 83% yield of the desired product, however the intermediate chalcone and guerbet type of intermediate (**4.8**) gave trace amount of the desired quinoline (**4.5a**). Amino aldehyde and intermediate (**4.7**) under standard reaction conditions delivered 77% of the **4.5a**. These results reveals that α-branch ketone is the reactive intermediate for the

formation of complex quinoline derivatives (Figure**, 4.2C**). During the catalysis, evolved hydrogen (H_2) gas was confirmed by gas chromatography analysis (Figure **4.2D**). Involvement of single electron in the catalytic cycle is nullified by performing the radical trapping experiment (Figure **4.2E**). Addition of excess amount of mercury (Hg 2 equiv.) in the standard catalytic system did not effect on the product yield which approved the homogeneous nature of catalytic cycle (Figure **4.2F**). The gradual decrement of the desired α-branched ketone product yields was observed in presence of trityl cation and complete quenching of the product was observed in presence of 20 mol% (with respect to catalyst) trityl cation. This result indicates the involvement of Mn-H species [27] in the catalytic cycle to hydrogenate the intermediate chalcone (Figure **4.2G**). Comparative reactivity if aliphatic and electron rich amino alcohol were tested (Figure **4.2H** & **I**).

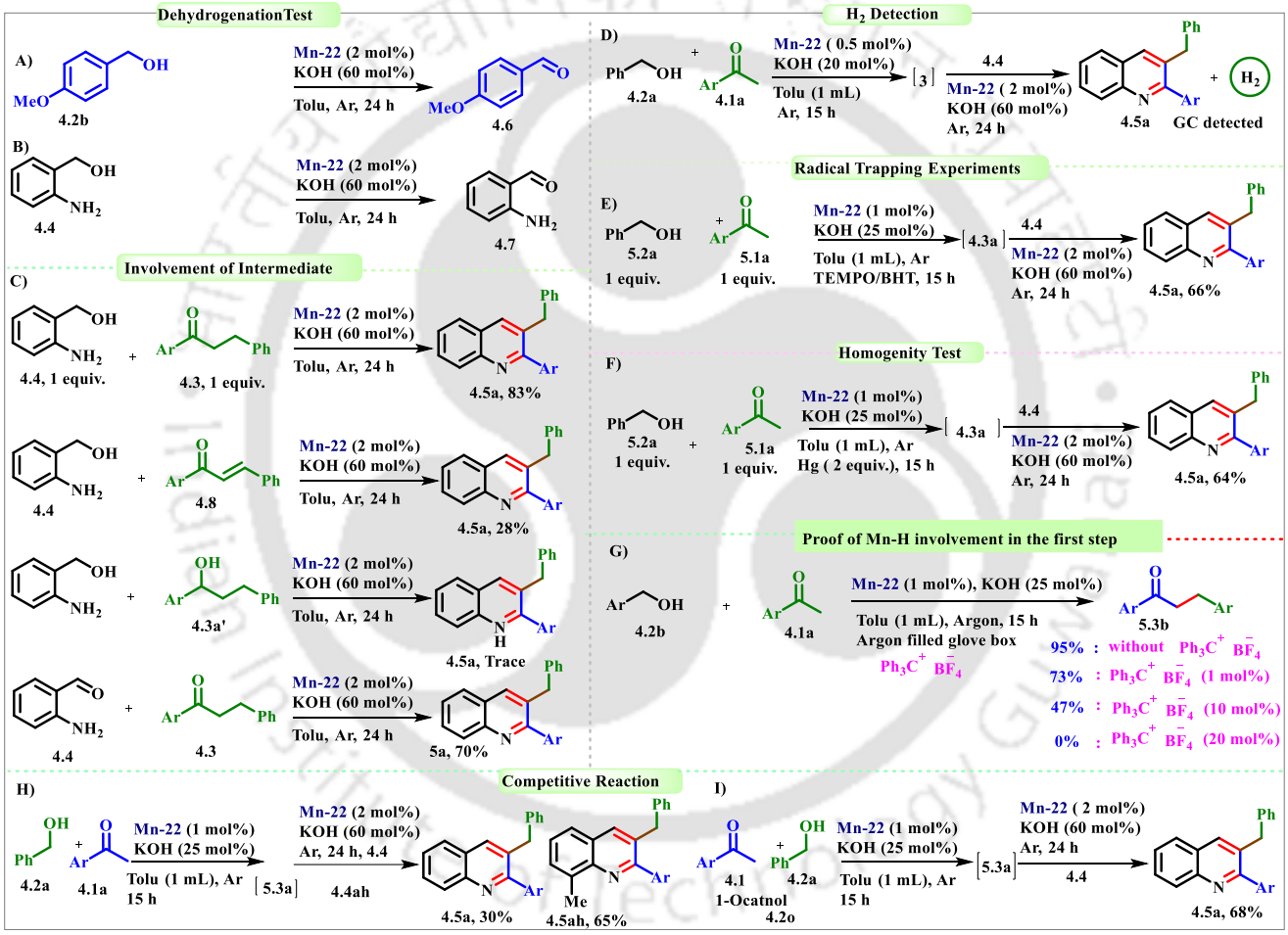


Figure 4.2. Control and competitive experiments.

4.7. Kinetic experiments: To understand the reactivity pattern of this multicomponent reaction the kinetic profile for both the step were examined separately. Kinetic monitoring of the reaction between 4-methoxy acetophenone and benzyl alcohol revealed that the concentration of the formed aldehyde/the chalcone (**4.6**/**4.8**) is low throughout the reaction. This indicates that the alcohol dehydrogenation step is relatively slower than the base catalysed

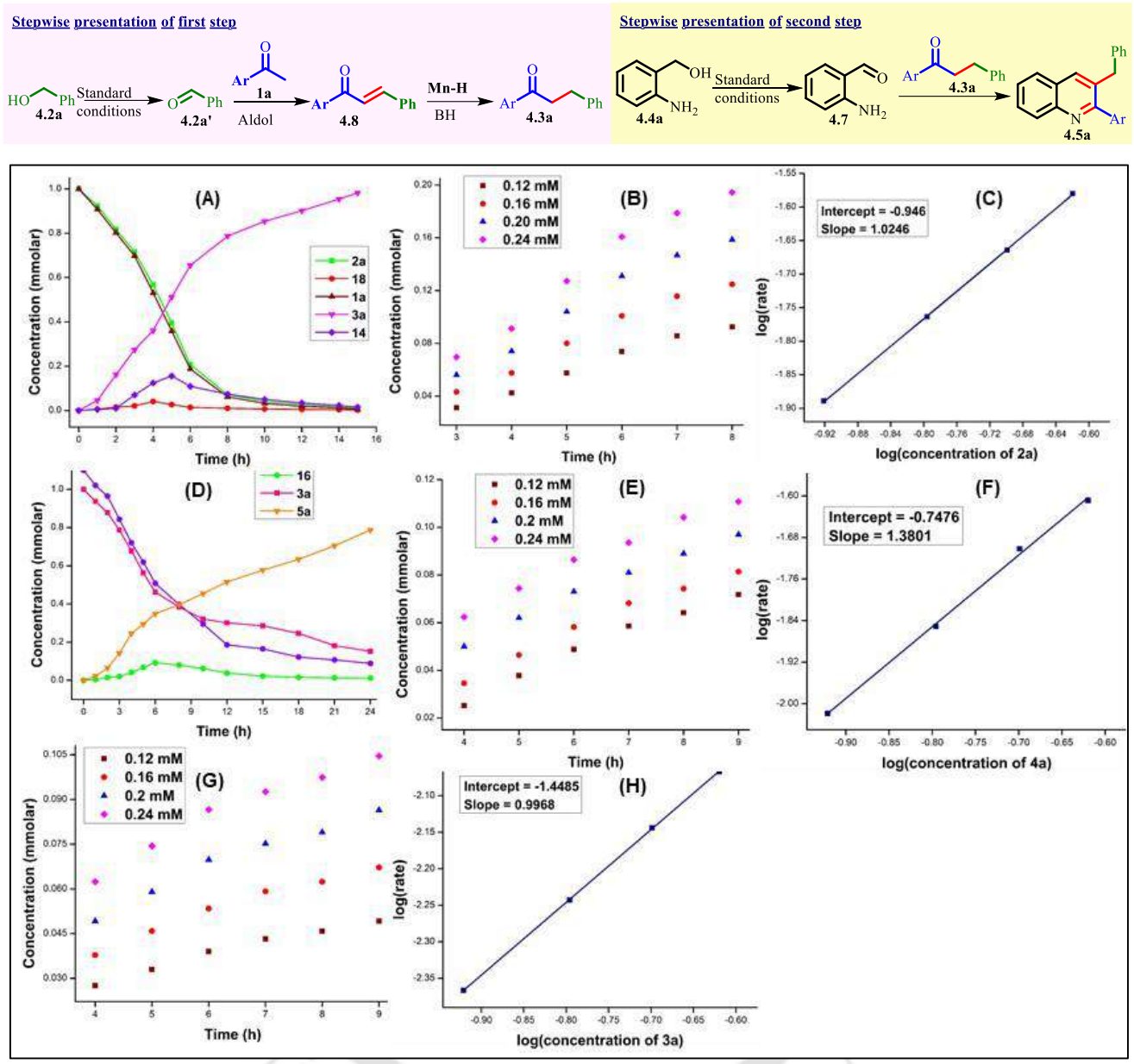


Figure 4.3. (A) Kinetic profile of first step for Mn-catalysed MCR protocol. Graph of (B) concentration of **4.3a** vs time with various concentrations of **4.2a.** (C) log (rate) vs log (conc. of **4.2a**). (D) Full reaction kinetics of second step for Mn-catalysed quinoline synthesis. (E) Concentration of 5a vs time with various concentrations of 2-aminobenzyl alcohol **4.4a.** (F) log (rate) vs log (conc. of **4.4a**). (G) Concentration of 5a vs time with various concentrations of the α-branched ketone **4.3a**. (H) log (rate) vs log (conc. **4.3a**).

aldol condensation and transfer hydrogenation of chaclone. The reaction kinetic of the second step (i.e. dehydrogenative annulation of α-branch ketone **4.3a** and 2-aminobenzyl alcohol) also underpins the dehydrogenation of 2-aminobenzyl alcohol is the slowest step. Furthermore, the effect of alcohol concentration in the first step to synthesize α-branch ketone was also determined using initial rate method. The product formation was increased with increasing the initial concentration of the alcohol that actually implies that the reaction is first order with respect to alcohol (Figure **4.3D**). Moreover, to understand the role of both 2-aminobenzyl alcohol (**4.4**)

and intermediate α-branch ketone (**4.3a**) in the second step the rate order was disclosed using an initial rate technique.

4.8. Elucidation of amido complex formation: Next, the formation of reactive catalytic intermediate on treatment of base was studied to shed light on the catalytic insight. The amino functionality in the ligand scaffold of metal complexes is very susceptible to undergoing a deprotonation reaction in the presence of a base and creating an amido-metal complex, which is involved in the alcohol activation process via MLC-bifunctional mechanism.[23] Indeed, when KO^{t}Bu was added to THF solution of **Mn-22** precatalyst immediate colour change from yellow to deep purple to red was observed. This basic solution was refluxed at 90 °C and IR spectra was recorded, spectra suggested a mixture of tri, di carbonyl and base coordinated dicarbonyl amido complexes[24] were formed. (Figure 4.4) Notably, base coordinated manganese complex (**Mn-22d**) was decomposed with time because of it's light sensitivity and tricarbonyl amido complex (**Mn-22a**) exit in equilibrium with neutral precatalyst in presence of polar protic medium.

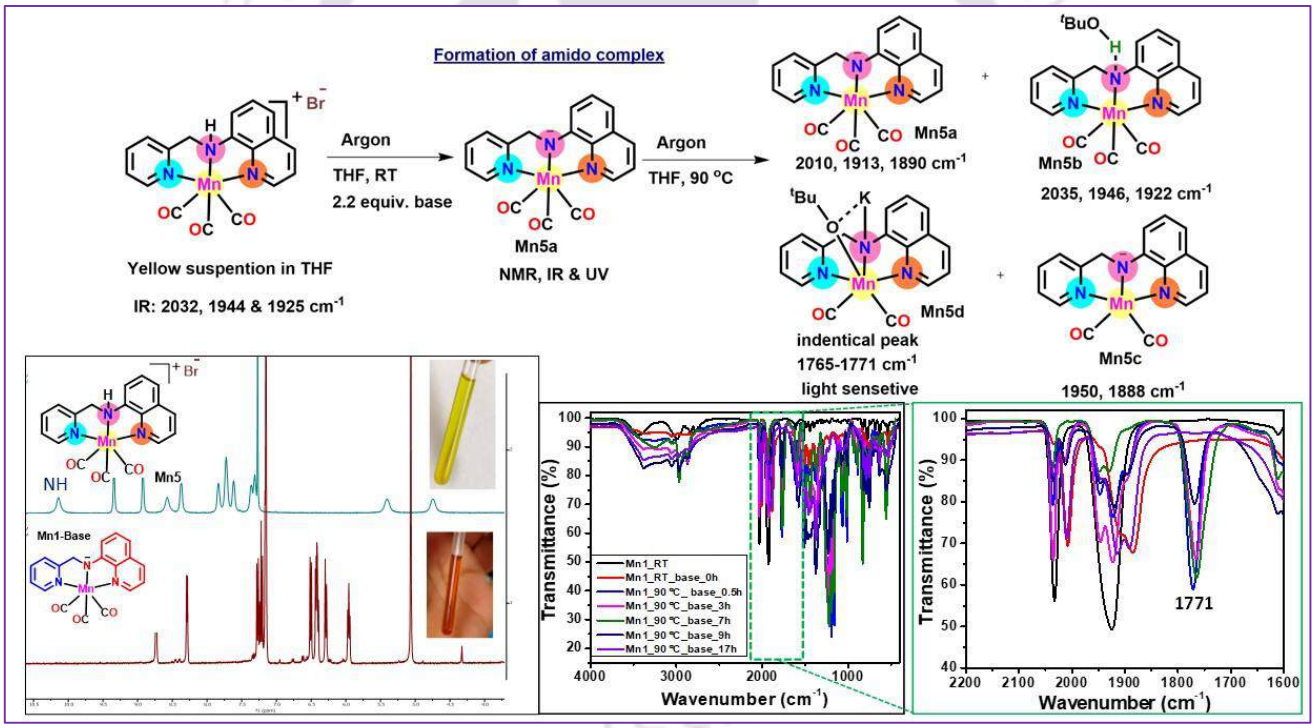


Figure 4.4. Elucidation of **Mn-22** intermediates.

4.9. Proposed catalytic cycle: To gain further understanding of the reaction pathway, density functional theory (DFT) studies were executed for manganese catalysed sequential multicomponent reaction at M062X/def2-TZVP level in solvent phase (toluene) using polarizable continuum model (PCM).[25] The catalytic cycle is prevailed from DFT. The overall tandem protocol was described in four steps-(I) dehydrogenation of alcohol and the formation of Mn-hydride complex, (II) Transfer hydrogenation of in situ formed chalcone by Mn-hydride species, (III) further dehydrogention of 2-amino benzyl alcohol and generation of Mn-H species and (IV) liberation of dihydrogen and regeneration of active amido complex to run the next catalytic cycle. Initially, hexa coordinate tricarbonyl cationic

bromide complex (**Mn-22**) formed pentacoordinated active amido complex (I) on treatment of base under heating condition via N-H deprotonation and subsequent decarbonylation of trans-carbonyl ligand to the anionic nitrogen. Experimentally the mixture of amido complex formation on the treatment of KO^{t}Bu in THF at 90 °C was observed (Figure **4.4**). The amido complex was formed hydrogen bonding adduct (II) with benzyl alcohol (**4.2a**) which stabilized by 4.2 kcal/mol. Next, the cleavage of O-H bond and hydride transfer to the metal center from α-methylene group of alcohol via transition state TS (II-III) forms the manganese hydride complex III with the liberation of benzaldehyde. This step involves an activation barrier of 17 kcal/mol. Notably, the free-energy barrier for dehydrogenation of benzyl alcohol with **Mn-22** complex is slightly lower than previously developed NNSEt Mn(I) complex (**Mn-17**).[27b] Next, the formed Mn-H species participate in the hydrogenation of in situ produced chalcone (**4.8**) through outer sphere bifunctional mechanism to form α-branched ketone. Noticeably, **Mn-22** catalytic system requires 24 kcal/mol for this step which is similar to the PNP based Mn(I) catalytic system (26.6 & 22.8 kcal/mol).[26] Next, the formed *α*-alkylated ketone (**4.3a)** undergoes dehydrogenative annulation with 2-amino benzyldehyde (**4.4a**), which is formed in the second catalytic cycle to form the desired product. Thus, in the second catalytic cycle, dehydrogenation of amino alcohol was also calculated which follows a similar mechanistic path but travels 9.5 kcal/mol higher energy barrier than benzyl alcohol dehydrogenation to deliver amino aldehyde and metal hydride complex **III**. To regenerate active amido complex **I** to run the next catalytic cycle, the two possible pathways were investigated-(a) amino alcohol assisted H-H bond formation and (b) water assisted H-H bond formation. In amino alcohol assisted pathway the manganese-coordinated η^2-H_2 complex **VI** was formed via **TSb III-VI**. The enthalpy of activation is 19.3 Kcal/mole. During the condensation process, H_2O is liberated in the medium. Thus the possibility of a water-assisted pathway is also calculated. Theoretical calculation data suggested that H_2 liberation via water coordinated transition state (**TSa III-VI**) required lower Gibbs free energy (11.9 kcal/mol) than alcohol coordinated transition state (19.3 kcal/mol) which indicates water assisted[27a-d] pathway is the most favourable route to get active amido complex **I** with the liberation of hydrogen gas. Accounting for all the above controlled experiments, DFT study[31b] and literature reports[27] a plausible reaction pathway has been depicted for the current sequential multicomponent reaction in Figure **4.5**. Initially, under the standard reaction conditions, precatalyst **Mn-22** leads to the formation of active amido complex I. This catalytically active Mn amido complex I dehydrogenates alcohol to its corresponding carbonyl compound in situ via hydride transfer to Mn(I) center through an agostic type of interaction **II** and generates Mn-H complex **III**. A chalcone intermediate **4.8** was produced by the base-mediated aldol condensation reaction of the in situ generated carbonyl compound with the ketone. Then Mn-H species **III** hydrogenates *α, β* unsaturated carbonyl compound (chalcone) to mono alkylated ketone (**4.3a**) with the revival of active amido complex **II**. Next, in the second step amino alcohol dehydrogenation also follows similar pathways to generate amino aldehyde with the generation of metal hydride species **III**. Then, under the standard reaction conditions in situ formed amino aldehyde reacted with mono alkylated ketone to form an intermediate (**4.5a´**). This intermediate (**4.5a´**) subsequently undergoes a condensation reaction between keto and amino group in the same intermediate, furnishing desired quinoline (**4.5a**) with the liberation of water molecule

(H_2O). Active amido complex was regenerated to continue the next catalytic cycle with hydrogen liberation via the most favourable water-assisted transition state (**Tsa III-VI**) from metal hydride complex (**III**).

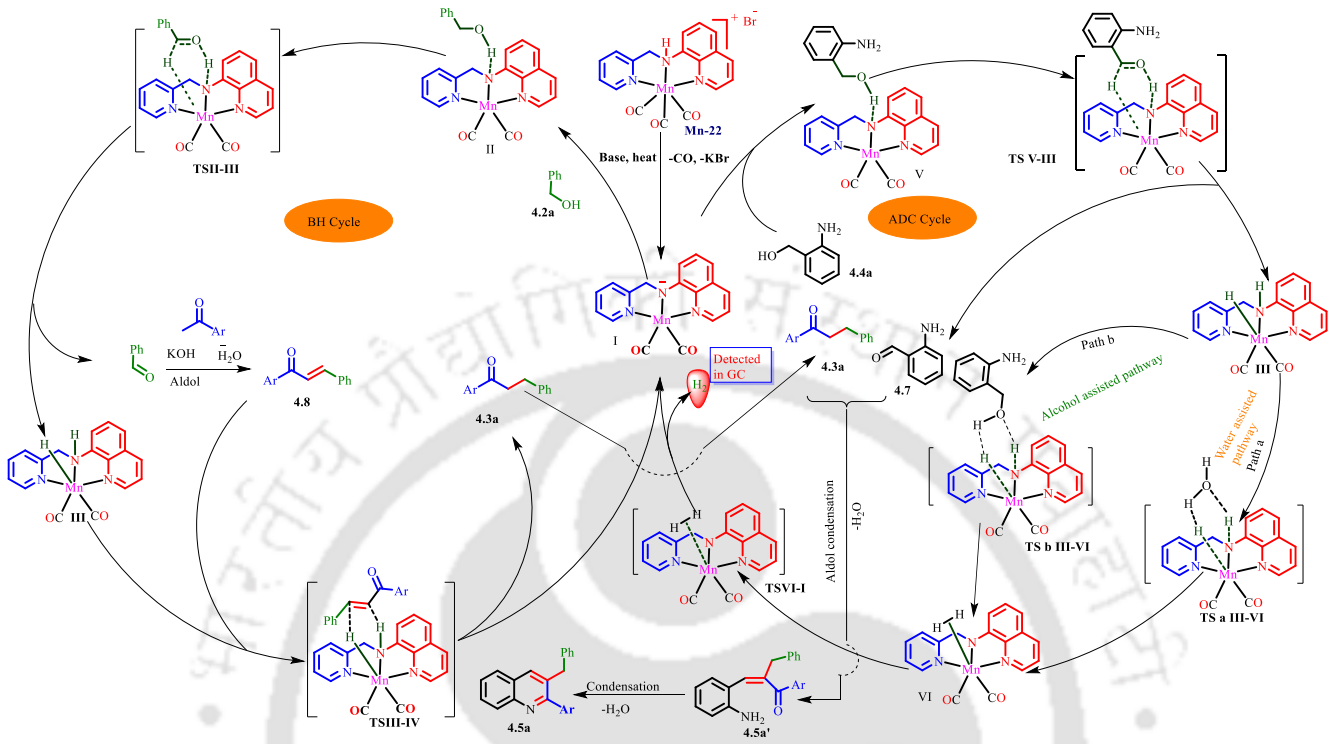


Figure 4.5. Proposed catalytic cycle of one pot MCR strategy.

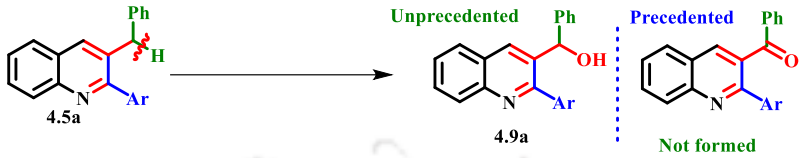
4.10. Construction of novel molecular scaffolds azafluorene via unprecedented direct C(sp^3)-H hydroxylation of C-3 benzylic methylene of poly-substituted quinoline and annulation:

4.10.1. Direct C(sp^3)-H hydroxylation: Next, the newly synthesized 2-aryl 3-benzylic methylene group substituted quinoline derivative could provide a new synthetic route to new class of azafluorene via benzylic C-H hydroxylation and annulation.

4.10.2. Optimization for C-H hydroxylation: To pursue this objective, several traditional oxidation methods were tried (summarized in scheme **4.2**.) to synthesize 3-acyl quinoline moiety. Unfortunately, most of the reported methods for benzylic oxidation failed to deliver 3-acylquinoline. After a series of reaction optimizations, when quinoline moiety **4.5a** was treated with 18-crown-6 (1.6 equiv.) and KO^{t}Bu (1.6 equiv.) under O_2-atmosphere at 0 °C to room temperature for 12 h, 92% direct benzylic 3-hydroxylated quinoline product **4.9a** (Scheme **4.2**) was isolated instead 3-acylquinolines. This unprecedented and challenging C(sp^3)-H bond activation[28] prompted us to explore generality of this new C(sp^3)-H hydroxylation strategy as this product can be directly applied for the synthesis of targeted azafluorenes. Delightfully, both aryl as well as alkyl C(sp^3)-H are smoothly hydroxylated to furnish the corresponding products **4.9** in excellent yields (Scheme **4.2**, **4.9a**-**4.9j**). To clarify the molecular

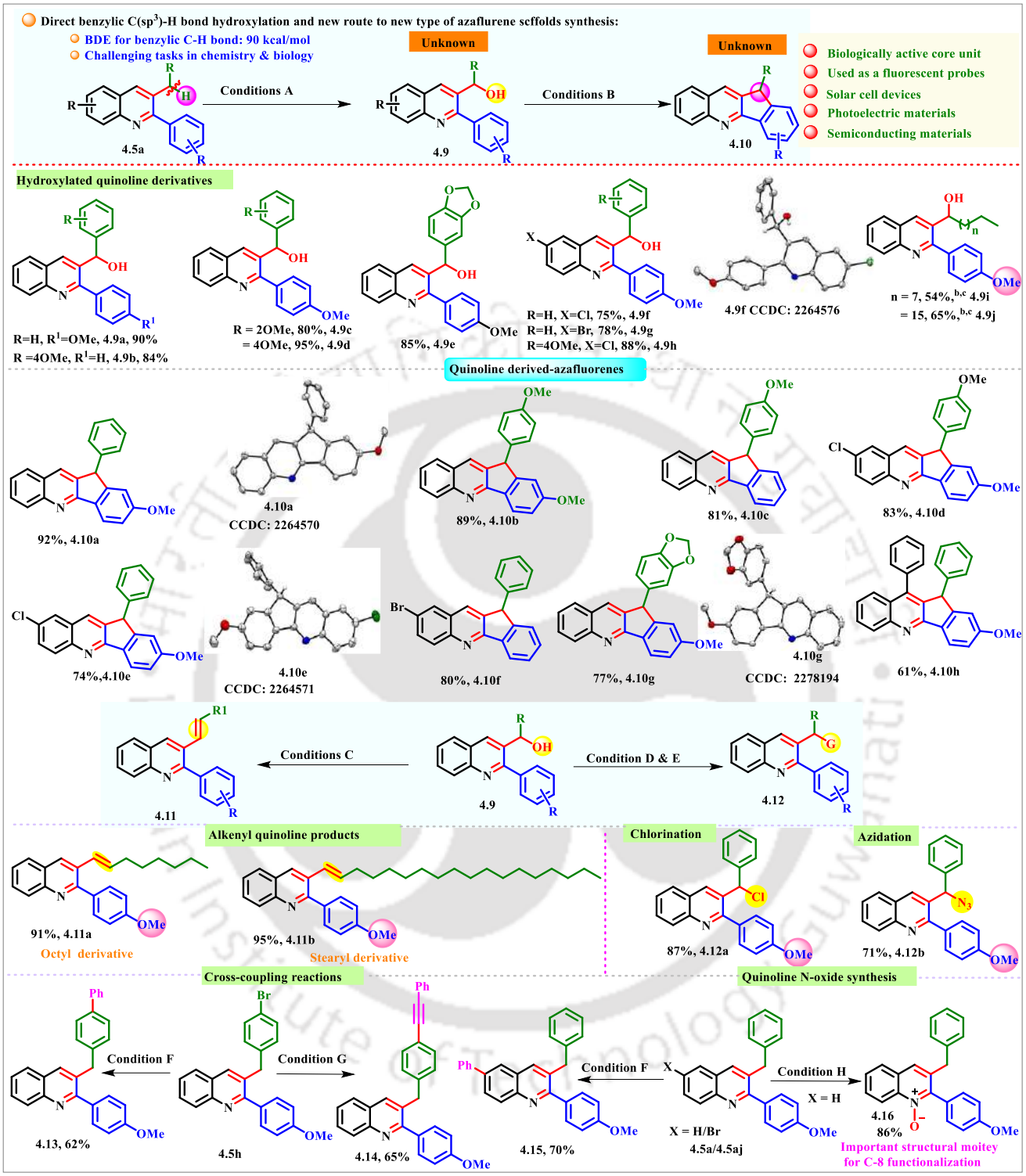
structure of C-H hydroxylated products, single crystal of **4.9f** have been grown as one of the representative molecule

Scheme 4.2. Optimization for C-H functionalization of C(sp^3)-H of poly-substituted quinoline.



Entry	Reaction conditions	References	Result (Isolated yields)	Entry	Reaction conditions	References	Result (Isolated yields)
1	SeO_2 (1.3 equiv.) Dioxane, Argon 80 °C, 4 h, 10 mL Rb	ACS Catal. 2023, 13, 6509–6517	No Reaction(NR)	6	$AcONH_4$ (1 equiv.), O_2 100 °C, I_2 (10 mol%), 24 h 30 mL seal tube	Org. Lett. 2015, 17, 2078-2081	NR
2	SeO_2 (2 equiv.) Dioxane, Argon 100 °C, 5 h, 10 mL Rb	Modified	NR	7	TBHP (12 equiv.), Air 130 °C, 10 h, 30 mL seal tube	RSC Adv., 2017, 7, 15176-15180	Multiple sopts
3	SeO_2 (5 equiv.) Dioxane, Argon 100 °C, 5 h, 10 mL Rb	Modified	NR	8	TBHP (12 equiv.), light 12 h, 30 mL seal tube	Modified	Multiple sopts
4	AcOH (1 equiv.), O_2, 24 h DMSO, CuI (10 mol%) 30 mL seal tube	Angew. Chem. Int. Ed. 2012, 51, 2745 –2748	NR	9	18-Crown-6 (1 equiv.) KO^{t}Bu (1 equiv.), O_2 10 mL Rb	Org. Lett. 2016, 18, 5680-5683	47%
5	$AcONH_4$ (1 equiv.), O_2 100 °C, I_2 (10 mol%), 24 h 30 mL seal tube	Org. Lett. 2015, 17, 2078-2081	NR	10	18-Crown-6 (1.6 equiv.) KO^{t}Bu (1.6 equiv.), O_2 10 mL Rb	Modified	90%

and X-ray crystallographic structure confirms the formation of hydroxylated product (Scheme **4.2**, **4.9f**). In presence of TfOH, the C-H hydroxlated products (**4.9**) undergoes a Friedel-Crafts cyclization, yielding medicinally and synthetically important new azafluorens derivatives[29] with good to excellent yields (Scheme 4.**2, 4.10a-4.10e**). Notably, azafluorenes containing halo substituent derivatives (Scheme **4.2**, **4.10d-4.10f**) are useful materials for further cross coupling reactions, which could be used as fluorescent probes.[30] When the C-H hydroxylated products (**4.9i** & **4.9j**) of 3-alkyl quinolines were treated with TfOH; 3-alkenylated quinolines were obtained via dehydration instead of cyclization to azafluorene. Moreover, these new 2-arylated, 3-alkenylated and 3-hydroxylated quinoline scaffolds could also be used to incorporate new functionalities for further diversification.[31] Incorporation of chloride and azide functionality at benzylic position of **4.9a** also demonstrated (Scheme **4.2**, **4.12a** & **4.12b**), which can be easily used for other synthetic transformations. Synthesized 2,3-disubstituted quinoline **4.5a** was further transformed into *N*-oxide **4.16** which could be used for C-8 functionalization.[32] Morever, to showcase the synthetic utility further, **4.5j** was subjected to Suzuki and Sonogashira cross coupling reactions to construct diversified quinoline scaffolds (Scheme **4.2**, **10-12**).

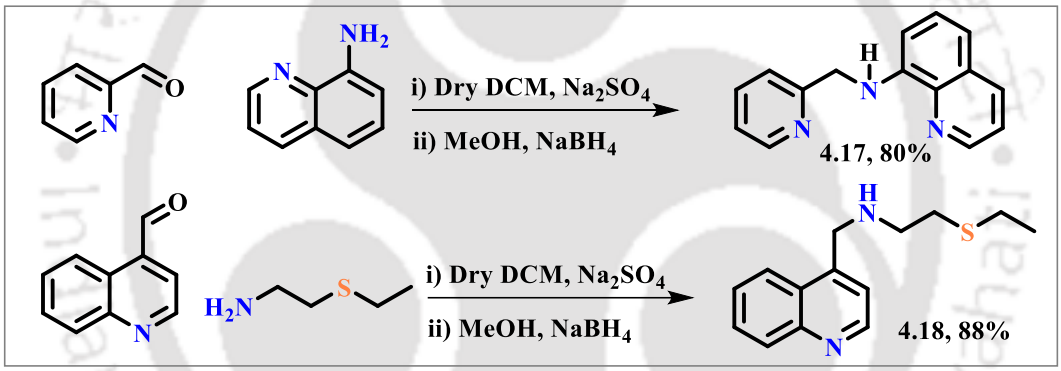


[a]Reaction conditions: [A]: 18-Crown-6 (1.6 equiv.), KO^{t}Bu (1.6 equiv.), O_2, DMF, 0 ^{o}C-RT, 12 h, [b]18-Crown-6 (2 equiv.), [c]KO^{t}Bu (2 equiv.); **[B]:** TfOH (2 equiv.), RT, 6 h; **[C]:** TfOH (3 equiv.), RT, 4 h; **[D]:** $SOCl_2$, $CHCl_3$, 100 °C, 6 h; **[E]:** $TMSN_3$ (4 equiv.), TFA (4 equiv.), DCM, RT, 6 h; **[F]:** $Pd(OAc)_2$ (25 mol%), Phenylboronic acid (1.3 equiv.), $(iPr)_2NH$ (2 equiv.), distilled H_2O, 100 °C; **[G]:** $PdCl_2(PPh_3)_2$ (3 mol%), CuI (2 mol%), 2-ethanolamine (2 equiv.), and dry THF; **[H]:** *m*CPBA (2.2 equiv.), DCM, RT, 12 h, [b]All isolated yields.

4.11. Conclusion: In conclusion, the rational design of dehydrogenative MCR approach permits the synthesis of new classes of poly-substituted quinolines, which can be further converted into novel azafluorenes scaffold via an unprecedented C(sp^3)-H bond hydroxylation and Friedel−Crafts-type cyclization. This current protocol covers a broad range of substrate scope, including various challenging primary and secondary alcohols, providing genres of C-3 functionalized poly substituted quinolines. Synthesized quinolines with aryl moiety at C-3-methylene group were successfully converted to the corresponding azafluorenes whereas alkyl group at the same position delivered dehydrated products. Nevertheless, this would be an interesting approach to install alkene functionality at the C-3 position of quinolines. Both experimental and computational studies were executed to probe the plausible mechanism of the MCR process. This current study unveils some fundamental aspects of dehydrogenative MCR approach, which could be useful in spurring the development of novel classes of heterocycles in a sustainable manner.

4.12. Experimental section:

4.12.1. Synthesis of Ligands:

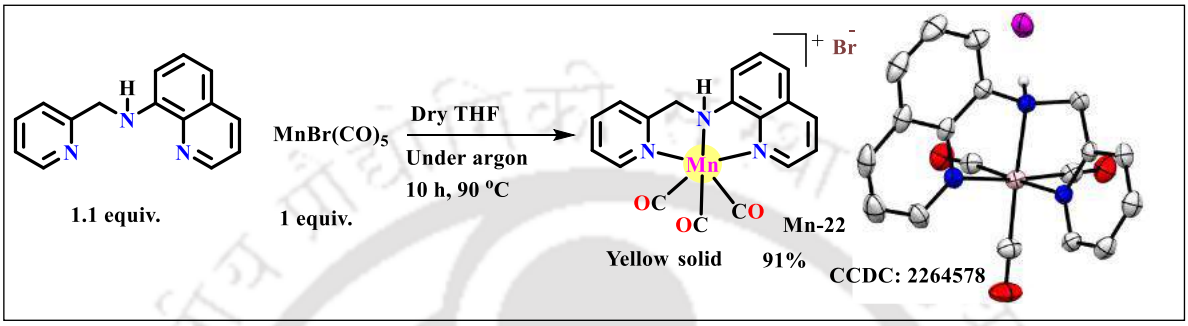


Aldehyde (2 mmol) and amine compound (2 mmol,) were dissolved in dry CH_2Cl_2 (3 mL) and then Na_2SO_4 (5 mmol) was added to it. The resulting suspension was stirred for 20 h at room temperature. Then, it was filtered and the filter residue was washed thoroughly with CH_2Cl_2 and the combined solvent was removed under reduced pressure. The residue obtained was directly used for the next step without further purification. The residue was dissolved in methanol (30 ml) and $NaBH_4$ (4 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 15 mL of water was added. After that, it was extracted by CH_2Cl_2 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 (100-200 mess) column chromatography using 20-40 % ethyl acetate in hexane.

N-(pyridin-2-ylmethyl) quinolin-8-amine (4.17): (Yellow liquid, 191 mg): ^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.77 – 8.76 (m, 1H), 8.64 – 8.62 (m, 1H), 8.08 (dd, *J* = 8.3, 1.6 Hz, 1H), 7.62 (td, *J* = 7.7, 1.7 Hz, 1H), 7.42 – 7.38 (m, 2H), 7.32 (t, *J* = 7.9 Hz, 1H), 7.20 – 7.16 (m, 1H), 7.07 (d, *J* = 8.1 Hz, 1H), 7.00 (t, *J* = 5.7 Hz, 1H), 6.61 (d, *J* = 7.6 Hz, 1H), 4.72 (d, *J* = 5.7 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 159.0, 149.3, 147.1, 144.4, 138.4, 136.9, 136.1, 128.7, 127.8, 122.1, 121.5, 121.3, 114.5, 105.4, 49.2.

2-(ethylthio)-N-(quinolin-4-ylmethyl) ethan-1-amine (4.18): (Yellow liquid, 218 mg): ^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.79 (d, *J* = 4.3 Hz, 1H), 8.05 (d, *J* = 8.4 Hz, 1H), 8.01 (d, *J* = 8.5 Hz, 1H), 7.64 (t, *J* = 7.6 Hz, 1H), 7.50 (t, *J* = 7.6 Hz, 1H), 7.40 (d, *J* = 4.3 Hz, 1H), 4.22 (s, 2H), 2.87 (t, *J* = 6.3 Hz, 2H), 2.69 (t, *J* = 6.3 Hz, 2H), 2.46 (q, *J* = 7.4 Hz, 2H), 1.18 (t, *J* = 7.4 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 150.4, 148.4, 145.7, 130.3, 129.3, 127.1, 126.7, 123.3, 119.9, 49.8, 48.4, 32.1, 26.0, 15.0.

4.12.2. Preparation of Mn-22:



Ligand (517 mg, 2.2 mmol) was taken in 10 mL dry THF and was added dropwise to the orange-yellow suspension of [$MnBr(CO)_5$] (548 mg, 2.0 mmol) in 5 mL degassed dry THF. Afterwards, the suspension was refluxed for 10 h under an argon atmosphere. After the completion of the reaction, the reaction mixture was cooled down to room temperature, then the solvent was evaporated to obtain the residue, which was further washed with diethyl ether and hexane, and dried under vacuum to get a yellow solid of Mn-complex. Then 30 mg of **Mn-22** was dissolved in chloroform-d and another 30 mg was dissolved in MeOH. Chloroform solution is kept at RT in NMR tube and MeOH solution kept is in a refrigerator at -10 °C. After few a day's yellow orange crystals were formed in both the system and the crystals are suitable for SC-XRD analysis.

4.12.3. NNN-Manganese (I) complex (Mn-22): Purification by washing using diethyl ether (10×4 mL) and hexane (10×2 mL afforded the title complex in 91% yield (823 mg, 1.82 mmol) as yellow crystalline solid.**^{1}H NMR (600 MHz, Chloroform-*d*)** δ 10.09 (s, 1H), 9.34 (s, 1H), 8.92 (s, 1H), 8.59 (s, 1H), 8.37 (d, *J* = 6.8 Hz, 1H), 7.83 – 7.73 (m, 4H), 7.37 – 7.30 (m, 2H), 5.37 – 4.76 (m, 2H).**^{13}C NMR (150 MHz, $CDCl_3$)** δ 220.2, 218.2, 217.9, 159.9, 153.8, 152.3, 146.2, 144.9, 139.1, 138.8, 129.5, 128.9, 127.8, 125.2, 123.4, 123.1, 65.6. **IR (ATIR in cm^{-1}): γ_{CO} 2032, 1944 & 1925. HRMS: (ESI):** Calc'd for. **$C_{18}H_{13}MnN_3O_3$ [M-Br]$^{+}$: 374.0337**; found = **374.0351; Crystallization:** Saturated solution of $CDCl_3$ at room temperature in NMR tube and saturated solution of MeOH in glass vial at -10 °C.

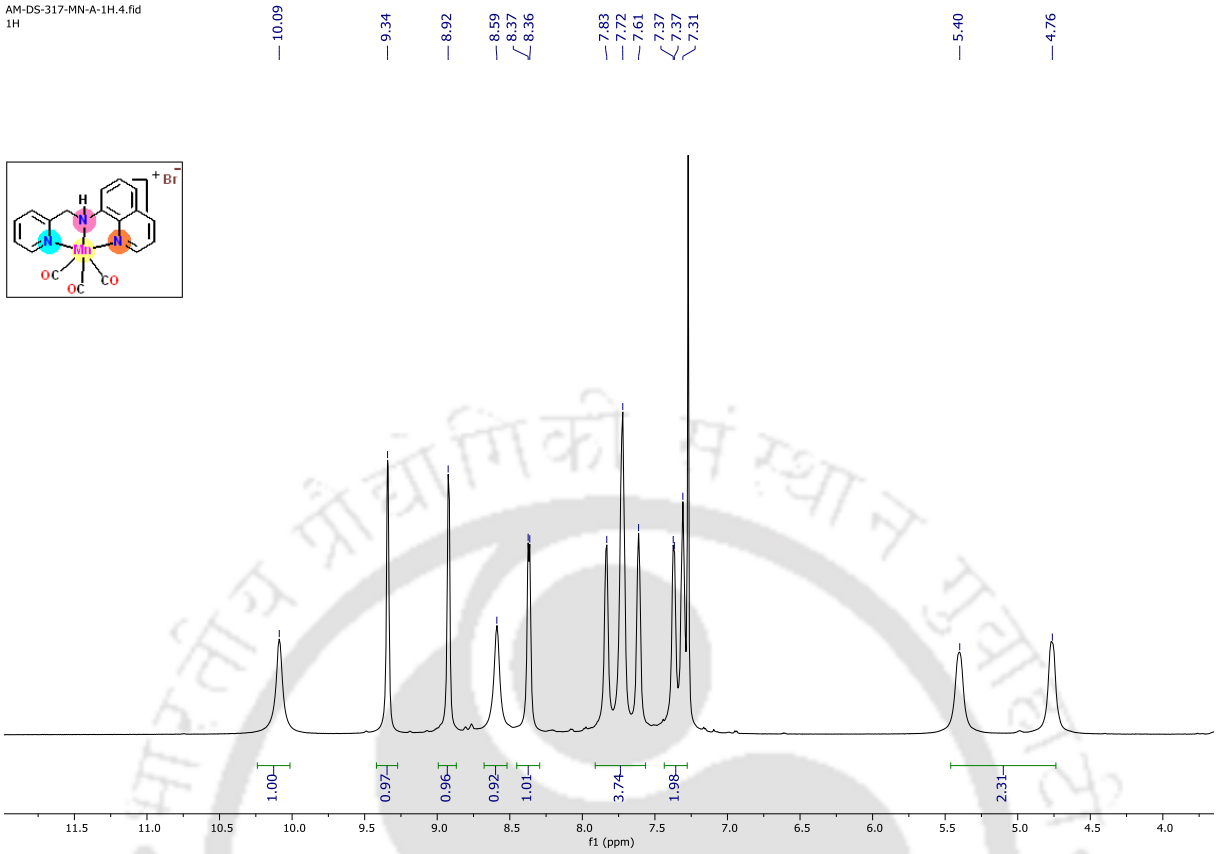


Figure 4.6. ^{1}H (600 MHz) NMR Spectrum of **Mn-22** in $CDCl_3$.

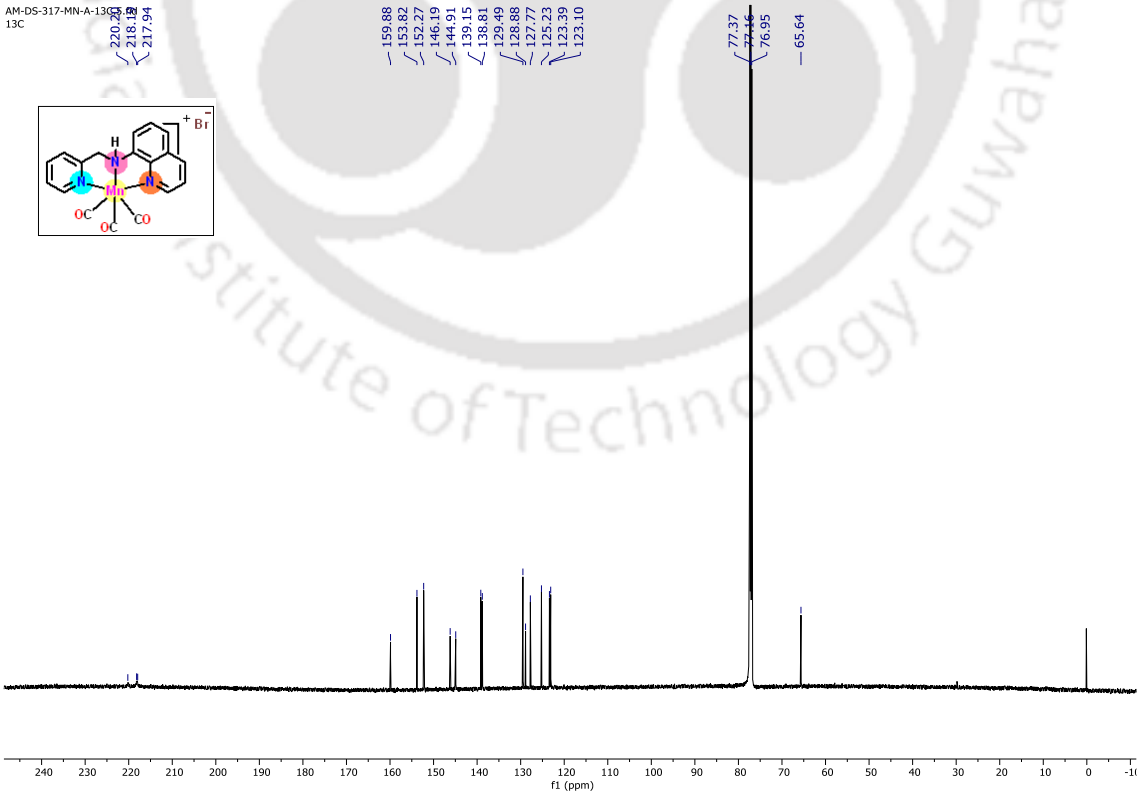


Figure 4.7. ^{13}C (150 MHz) NMR Spectrum of **Mn-22** in $CDCl_3$.

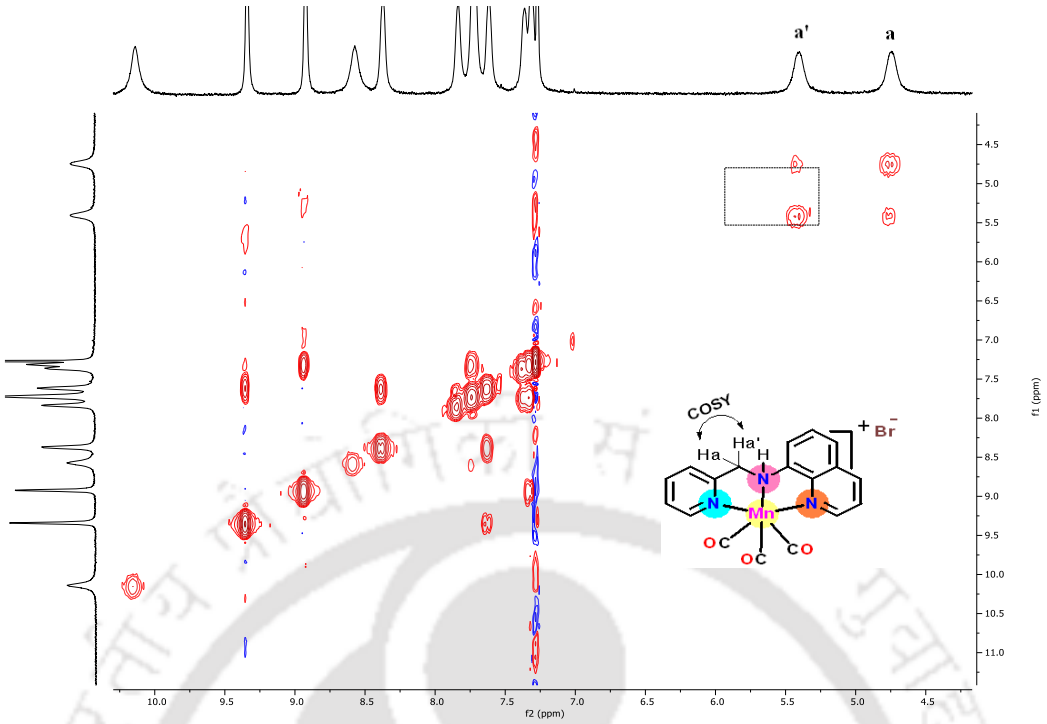
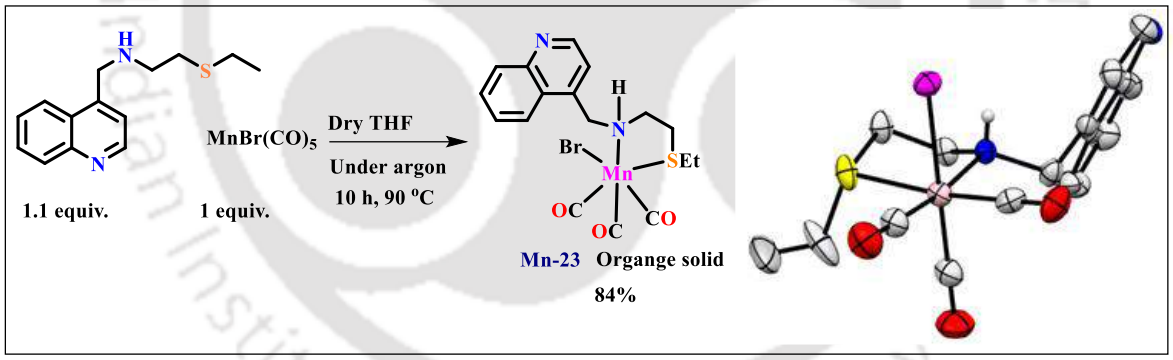


Figure 4.8. ^{1}H COSY (500 MHz) NMR Spectrum of **Mn-22** in $CDCl_3$.

4.12.4. Preparation of Mn-23:



Ligand **4.18** (148 mg, 0.6 mmol) was taken in 3 mL dry THF and was added drop wise to the orange-yellow suspension of [$MnBr(CO)_5$] (137 mg, 0.5 mmol) in 3 mL degassed dry THF. Afterward, the suspension was refluxed for 10 h under argon atmosphere. After the completion of the reaction, the reaction mixture was cooled down to the room temperature, then the solvent was evaporated to obtain the residue, which was further washed with diethyl ether and hexane, and dried under vacuum to get the orange solid of Mn-complex. Then 30 mg of **Mn-23** was dissolved in chloroform-d kept in NMR tube at room temperature. After few days' yellow orange crystals were formed which are suitable for single crystal analysis.

4.12.5. Bidentate manganese (I) complex (Mn-23): Purification by washing using diethyl ether (10×2 mL) and hexane (10×2 mL afforded the title complex in 84% yield (195 mg, 0.42 mmol) as orange crystalline solid.**^{1}H NMR (400 MHz, Chloroform-*d*)** δ 8.94 (s, 1H), 8.21 – 8.12 (m, 2H), 7.82 – 7.59 (m, 2H), 7.39 (s, 1H), 5.34 (brs,

1H), 4.22 – 3.67 (m, 2H), 3.07 – 2.87 (m, 3H), 2.70 – 2.28 (m, 3H), 1.50 – 1.37 (m, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 222.4, 220.8, 219.0, 150.0, 149.0, 140.5, 131.0, 130.3, 128.5, 125.9, 122.2, 122.0, 57.5, 50.0, 32.8, 32.1, 13.1. **IR (ATIR in cm^{-1}): γ_{CO} 2020, 1932 & 1905. HRMS: (ESI): Calc'd for $C_{17}H_{18}MnN_2O_3S$ [M + H]$^+$: 464.9680**; found = **464.9679**. **Crystalization:** Saturated solution of $CDCl_3$ at room temperature in NMR tube.

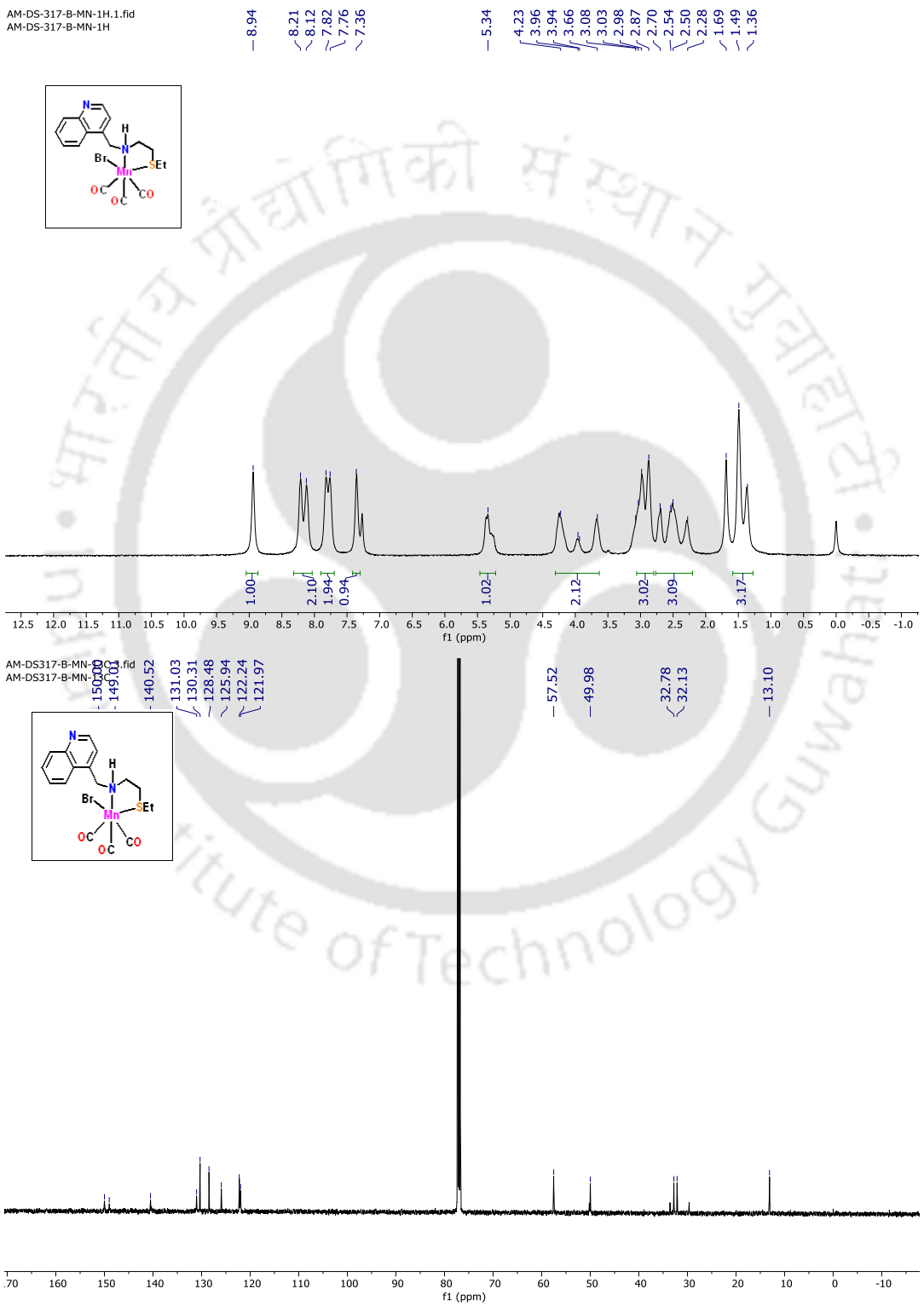


Figure 4.9. ^{1}H (400 MHz) & ^{13}C (125 MHz) NMR Spectrum of **Mn-23** in $CDCl_3$.

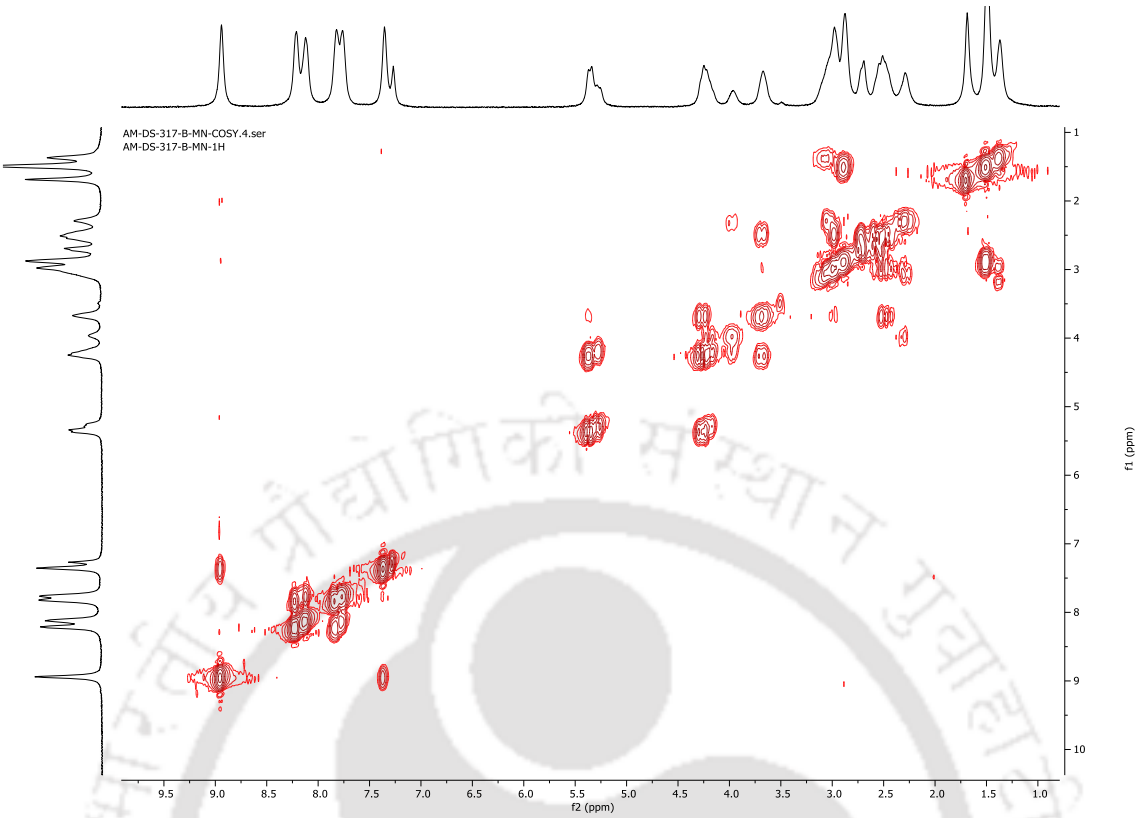
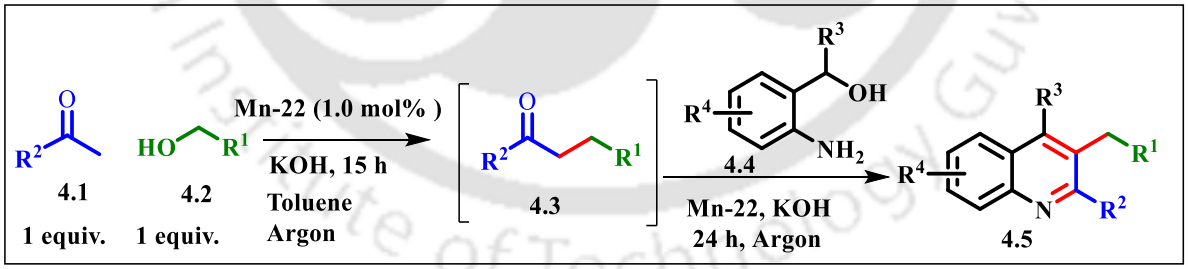


Figure 4.10. ^{1}H COSY (500 MHz) NMR Spectrum of **Mn-23** in $CDCl_3$.

4.12.6. Preparation of Mn-6, Mn-17, Mn-20 and Mn-21: Preparation procedure of these four complexes were discussed in chapter II, section 2.4.1.

4.13. General experimental procedure for multicomponents quinolines synthesis:



Primary alcohol, **4.2** (1.0 mmol), aryl ketone, **4.1** (1.0 mmol), **Mn-22** (1.0 mol%), KOH (0.25 mmol) and 2 mL toluene were taken in a 100 mL seal tube. The tube was sealed under argon atmosphere and refluxed at 130 °C in preheated oil bath for 15 h. After that, the tube was cooled to room temperature. Next, another portion of **Mn-22** (2 mol %), KOH (0.6 mmol) and 2-amino aryl alcohol, **4.4** (1.1 mmol) were added under argon flow. Then the tube was sealed under argon atmosphere and heated at 130 °C for next 24 h. The reaction mixture was cooled and 3 mL water was added. The organic part was extracted with ethyl acetate (3 x 8 mL). The combined organic part was dried over anhydrous Na_2SO_4 and the solvent was evaporated under reduced pressure. Poly-substituted quinolines (**4.5**) were purified through silica gel column chromatography using ethyl acetate/hexane as eluent. The final products were authenticated by NMR.

4.14. Mechanistic investigation:

4.14.1. Treatment of base with Mn-22 catalyst: Inside the glovebox, 20 mg of **Mn-22** (0.1 mmol) was taken in 5 mL glass vial, then benzene-d_6 (0.5 mL) was added to it. Then, ^{t}BuOK (11.2 mg, 0.1 mmol) was added to the solution slowly. The very light-yellow solution converted into red. After stirring for 30 min in argon atmosphere at room temperature. The resulting solution was filtered through celite pad inside the glove box, after removing the salt red colour filtrate was submitted for ^{1}H NMR analysis. Clean ^{1}H-NMR spectra suggested the formation of amido complex. **^{1}H NMR (400 MHz, Benzene-d_6)** δ 9.18 – 9.16 (m, 1H), 8.73 (d, *J* = 5.4 Hz, 1H), 7.26 – 7.20 (m, 1H), 7.66 (t, *J* = 7.8 Hz, 1H), 7.61 – 7.59 (m, 1H), 6.95 (d, *J* = 7.7 Hz, 1H), 6.81 – 6.83 (m, 2H), 6.73 (d, *J* = 7.7 Hz, 1H), 6.40 (t, *J* = 6.3 Hz, 1H), 5.51 (s, 2H).

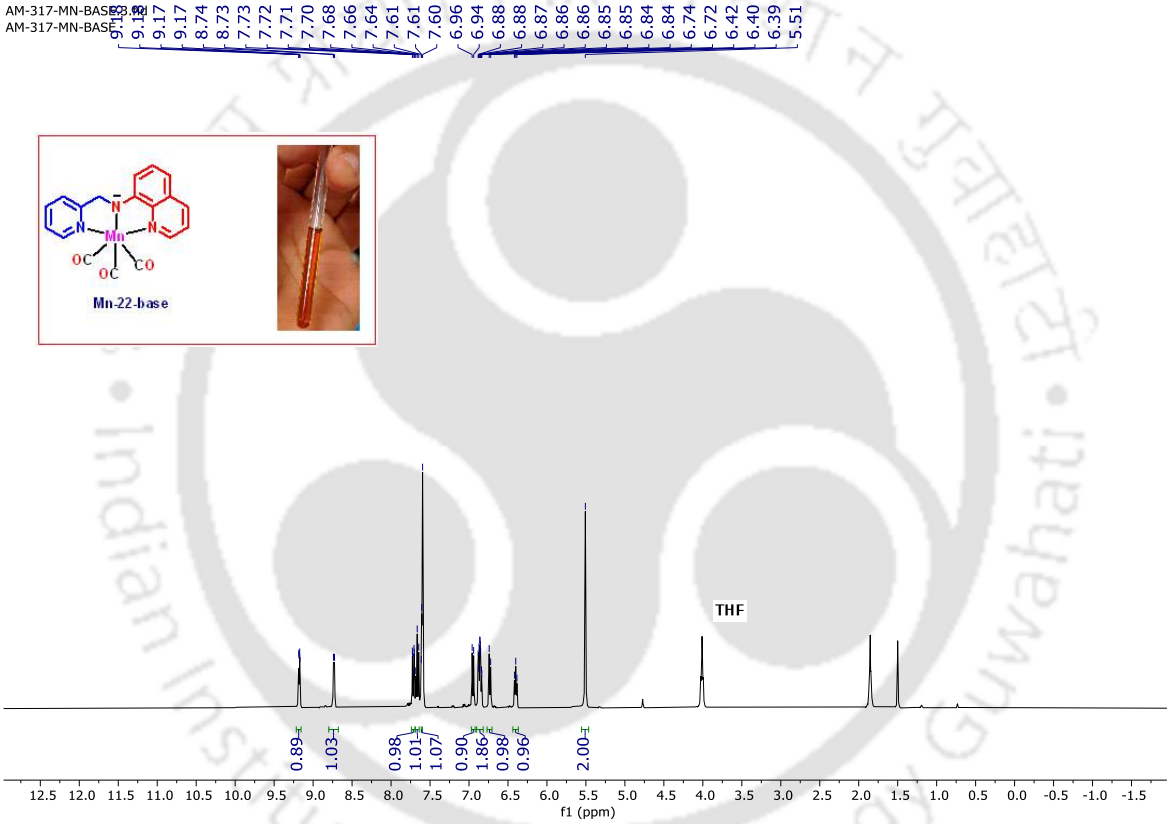


Figure 4.11. ^{1}H NMR (500 MHz) spectrum of **Mn-22**-base in C_6D_6.

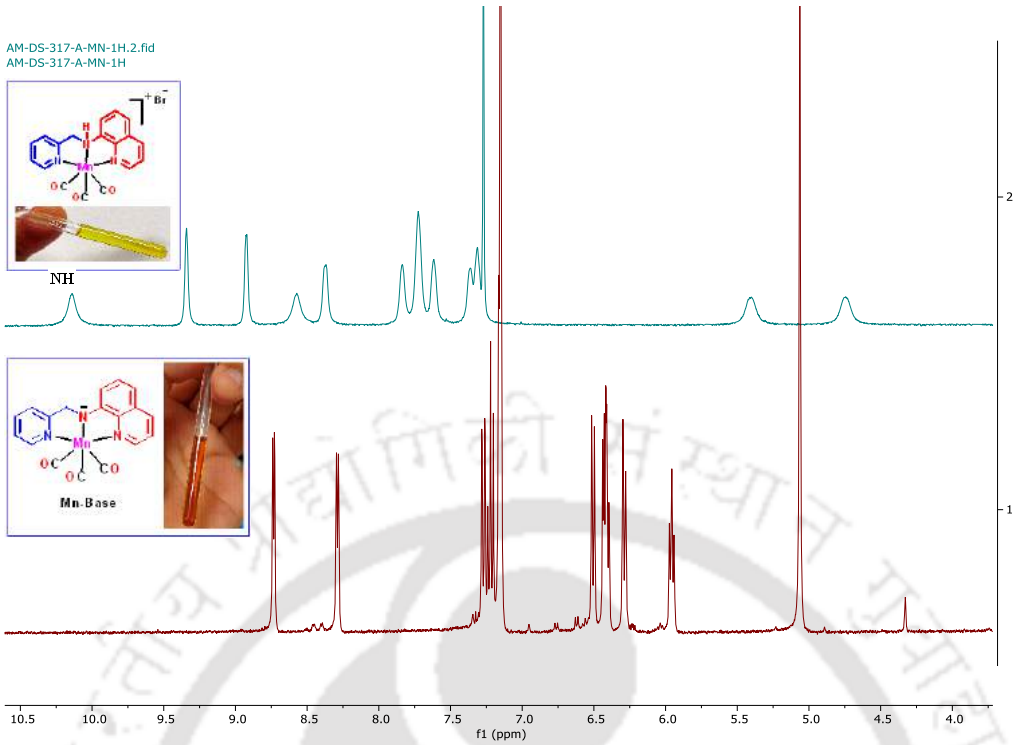


Figure 4.12. Merge ^{1}H NMR (500 MHz) spectrum of **Mn-22** & **Mn-22**-base.

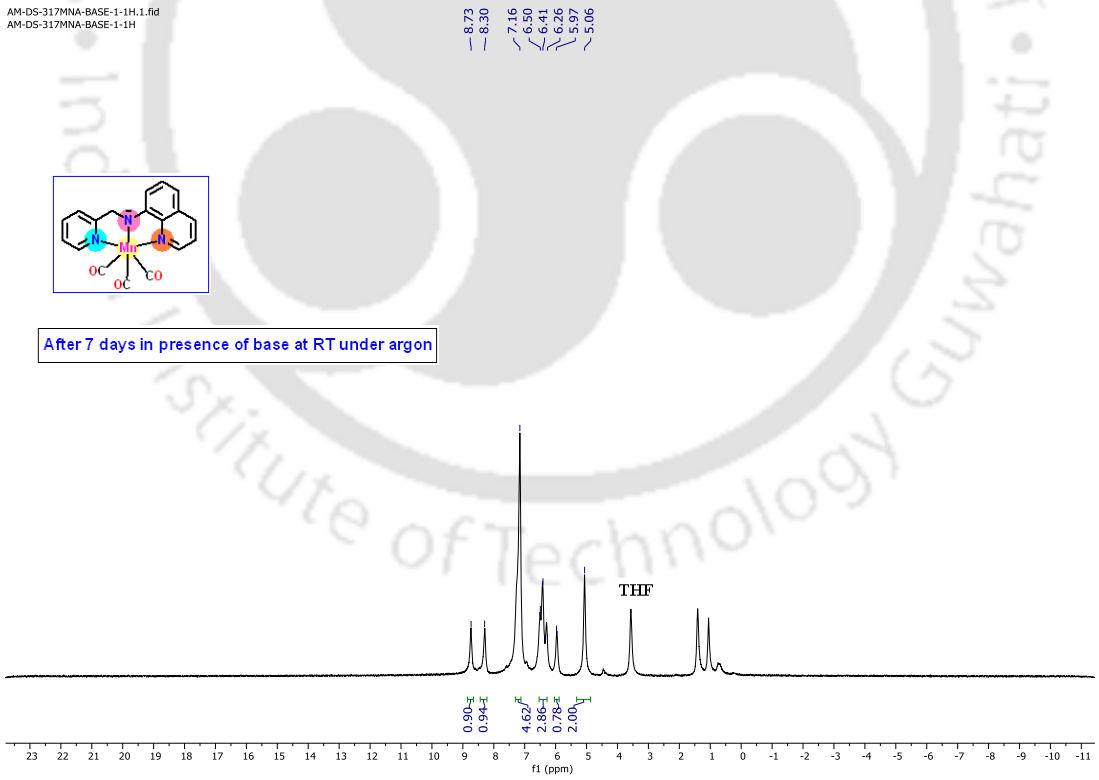
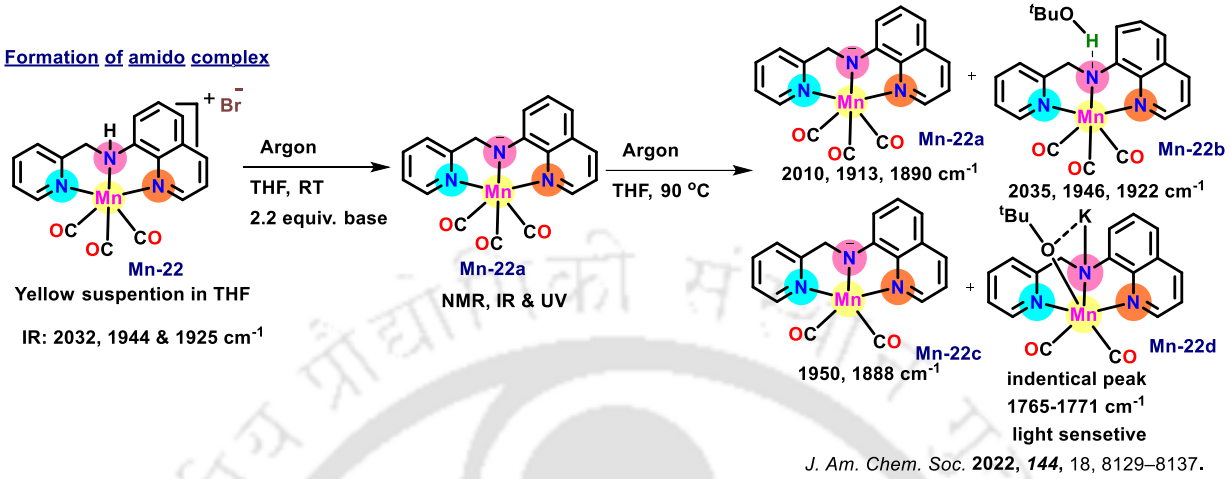


Figure 4.14. ^{1}H NMR (500 MHz) spectrum of **Mn-22-base** in C_6D_6 after 7 days.

4.14.2. IR Study: Treatment of base on **Mn-22** complex was studied to understand the nature amido complex formation during the catalysis. In 25 mL schlenk tube **Mn-22** (20 mg, 0.1 mmol) was taken inside the glove box and then dry THF (5 mL) was added, a yellow suspension solution was formed. In this yellow suspension THF

solution of **Mn-22**, ^{t}BuOK (11.2 mg, 0.1 mmol) was added slowly. Then infrared spectra were recorded after different time interval at room temperature and 90 °C. IR studied reveal that the mixture of different amido complexes[2] were formed and all the recorded spectra was shown in Figure **4.15**.



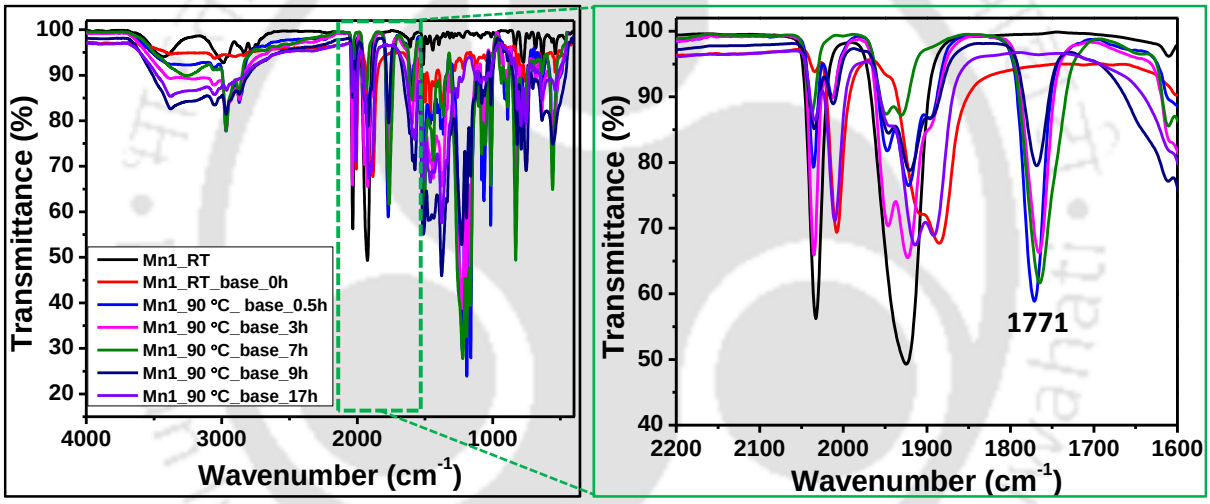
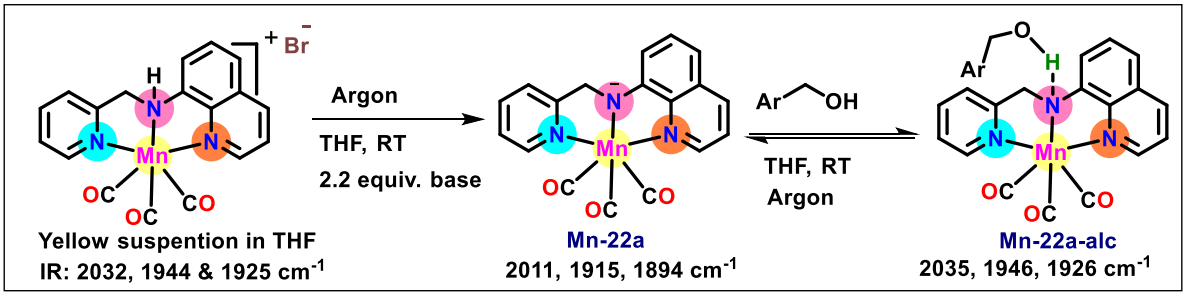


Figure 4.14. IR spectrum of **Mn-22** in presence base in different time interval in dry THF.

4.14.3. Effect of alcohol addition in basic solution of Mn-22: Inside the glovebox, 22 mg (0.1 mmol) of **Mn-22** was taken in 25 mL schlenk tube and dry THF (5 mL) was added to it. Then, 11.2 mg ^{t}BuOK (0.1 mmol) was added slowly to this yellow suspension solution. The very light-yellow solvent converted into purple. After stirring for 5 min in argon atmosphere at room temperature and IR spectra was recorded. Then 5 equiv. of 4-methoxy benzyl alcohol was added to the basic THF solution of **Mn-22** and again IR spectra was recorded.



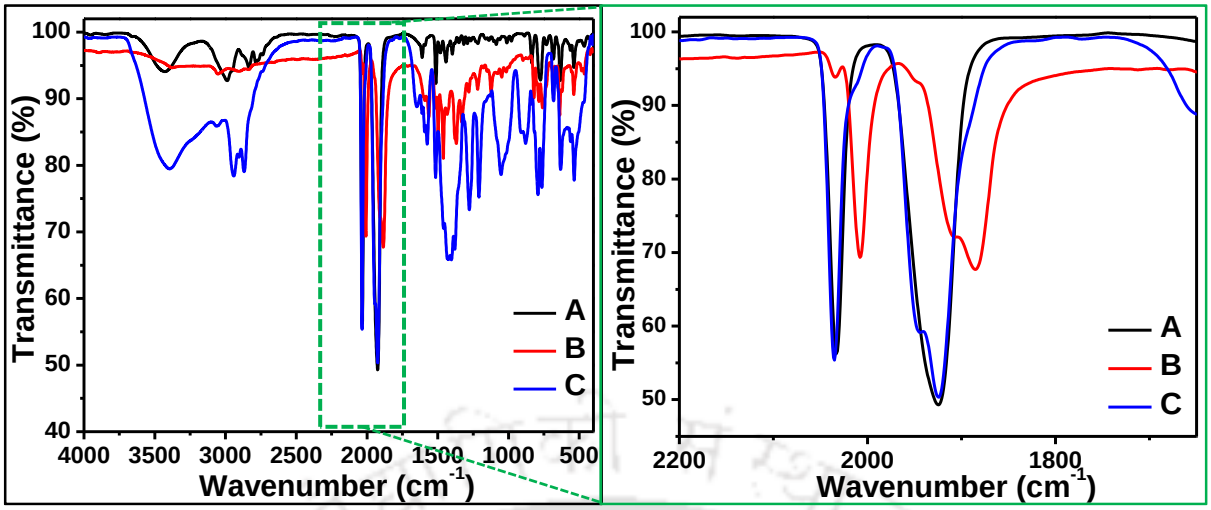


Figure 4.15. IRspectrum of **[A]: Mn-22**, **[B]:** after of addition base & **[C]:** after addition of alcohol.

4.14.4. UV-study:

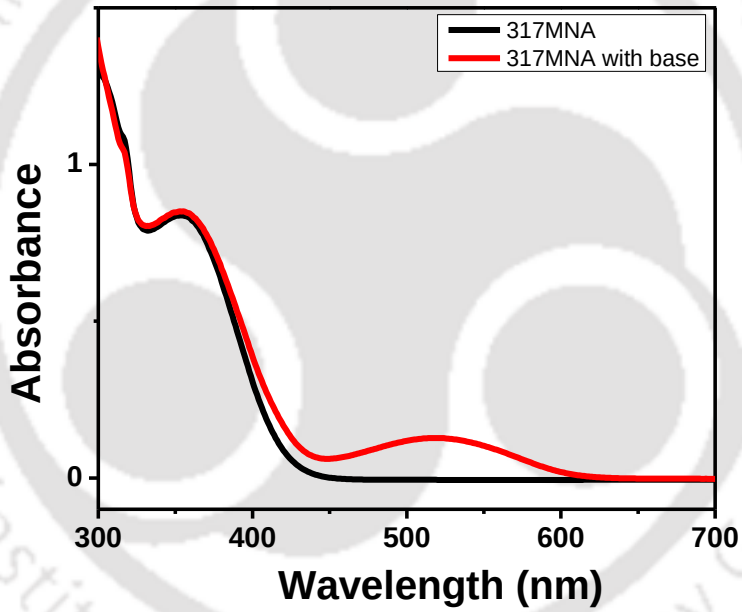


Figure 4.16. UV-spectrum of **Mn-22** (black line) & **Mn-22** in presence of base (red line).

4.14.5. Manganese catalysed dehydrogenation of alcohol: To an oven-dried 100 mL seal tube, **Mn-22** (5 mol%), 4-methoxy benzyl alcohol (1.0 mmol), toluene (2 mL) were added under argon. The reaction mixture was kept for heating at 130 °C for 10 h. Then, the reaction mixture was submitted for crude NMR analysis. Similar experiment was also conducted for 2-amino benzyl alcohol. Aldehydes of corresponding alcohols were also detected in GC during the catalysis.

4.14.6. Detection of evolved hydrogen gas: A mixture of α-branch ketone, **4.3a** (2 mmol, 480 mg), 2-amino benzyl alcohol, **4.4a** (2.2 mmol, 273 mg) and KOH (1.2 mmol, 81 mg) were taken in 100 mL seal tube and connected with high vacuum for 10 mins, then 4 mL toluene and **Mn-22** (2 mol%) was added under argon atmosphere. Then the reaction mixture was kept for stirring into preheated oil bath at 130 °C for next 24 h. After

completion of the reaction, seal tube was cooled at 0 °C. Then the evolved gas was syringe out and detected from PerkinElmer clarus-590 GC instrument using Elite Plot-Q column (30 m length x 530 µm x 20 µm ID) employing the following method:

TCD starting temperature: 40 °C

Oven temperature: 60 °C

Time at starting temperature: 0 min

Hold time: 5 min

Ramp: 28 °C/ min up to 200 °C

Flow rate: 5 ml/ min (N_2)

Split ration: 20

Inlet temperature: 40 °C

Detector temperature TCD: 200 °C

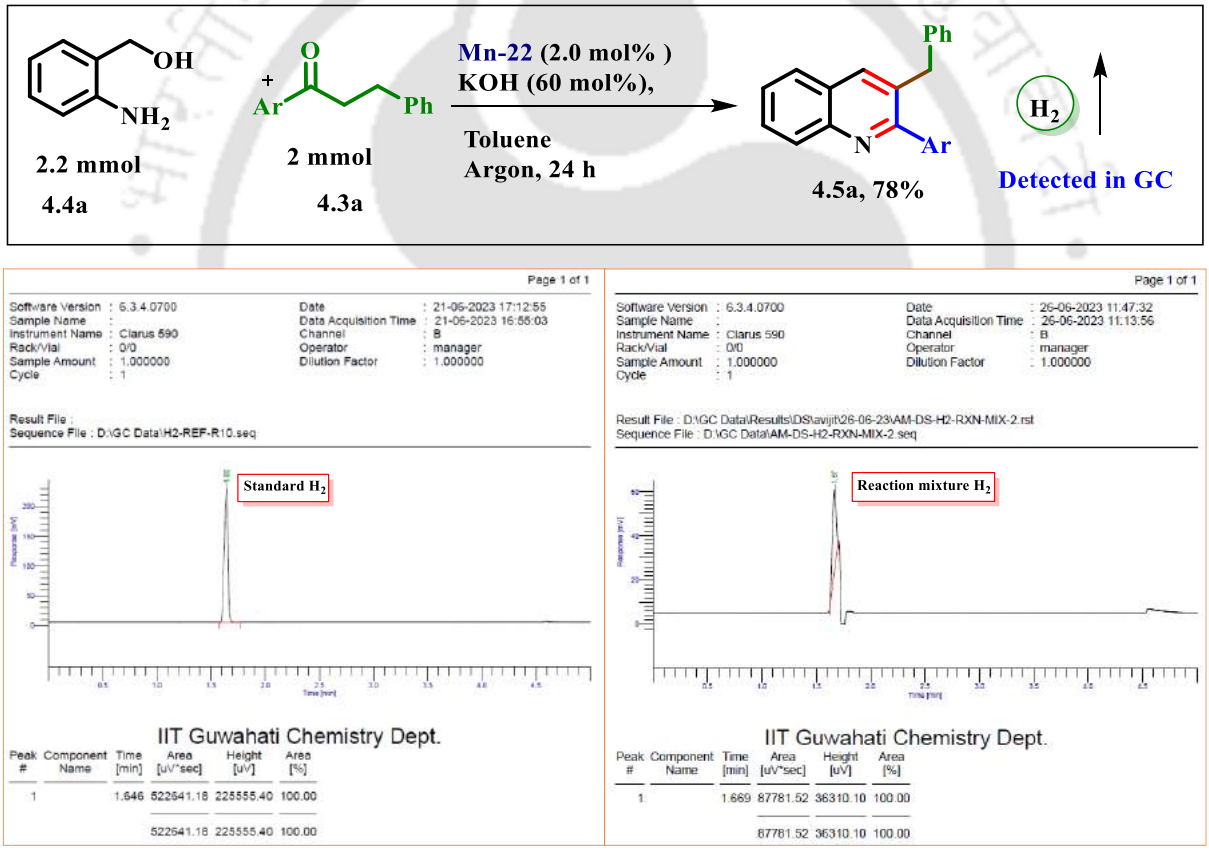


Figure 4.17. Chromatogram of standard hydrogen gas (left) and evolved hydrogen gas during catalysis (right).

4.14.7. Identification of possible intermediates: These controlled experiments were performed to find out the possible intermediates which are involved in this multicomponent reaction (The reaction schemes are shown in **Figure 4.2. C)**.

a) A mixture of α-branch ketone, **4.3a** (0.5 mmol, 87 mg), 2-amino benzyl alcohol, **4.4a** (0.5 mmol, 62 mg) and KOH (0.3 mmol, 18 mg) were taken in 100 mL seal tube and connected with high vacuum for 10 mins, then 1 mL toluene and **Mn-22** (2 mol%) was added under argon atmosphere. Then reaction mixture was stirred for 24 h under

argon atmosphere at 130 °C temperature. After completion of the reaction, ethyl acetate was added and filtered through celite. Solvent was evaporated in reduced pressure and purified by column chromatography using hexane/ethyl acetate as eluent to afford the corresponding pure product (**4.5a**) with 83% isolated yields.

b) To an oven dried seal tube chalcone, **4.8** (0.5 mmol, 85 mg), 2-amino benzyl alcohol, **4.4a** (0.55 mmol, 65 mg), KOH (0.3 mmol, 18 mg) were taken and connected with high vacuum for 10 mins, then 1 mL toluene and **Mn-22** (2 mol%) was added under argon atmosphere. The resulting mixture was then placed into the preheated oil bath at 130 °C for 24 h. After completion the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100-200 mesh) with hexane/ethyl acetate mixture (2-5%) as eluent, and 28% of **4.5a** was obtained.

c) To an oven dried seal tube gurbet alcohol, **4.3a´** (0.5 mmol, 88 mg), 2-amino benzyl alcohol, **4.4a** (0.55 mmol, 62 mg), KOH (0.3 mmol, 18 mg) were taken and connected with high vacuum for 10 mins, then 1 mL toluene and **Mn-22** (2 mol%, 5 mg) was added under argon atmosphere. The resulting mixture was then placed into the preheated oil bath at 130 °C for 24 h. After completion the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite pad. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100-200 mesh) with petroleum ether/ethyl acetate mixture (2-5%) as eluent, and 15% of **4.5a** was obtained.

d) To an oven dried 100 mL seal tube *α*-alkylated ketone, **4.3a** (0.5 mmol, 87 mg), 2-amino benzaldehyde, **4.7** (0.55 mmol, 61 mg), KOH (0.3 mmol, 18 mg) were taken and connected with high vacuum for 10 mins, then 1 mL toluene and **Mn-22** (2 mol%, 9 mg) was added under argon atmosphere. The resulting mixture was then placed into the preheated oil bath at 130 °C for 24 h. After completion the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100-200 mesh) with hexane/ethyl acetate mixture 5-20%) as eluent, and 70% of **4.5a** was obtained.

4.14.8. Radical involvement test in the catalysis: An oven dried 100 mL sealed tube was taken and charged with 4-methoxy acetophenone, **4.1a** (150 mg, 1 mmol), benzyl alcohol, **4.2a** (108 mg, 1 mmol), **Mn-22**(1 mol%, 5 mg,), (KOH, 25 mol%), 14 mg, and TEMPO or BHT (1.2 mmol, 187 mg or 264 mg), and 2 mL toluene was added inside an argon-filled glove box and sealed prior to bring out from the glovebox. The resulting reaction mixture was allowed to stir at 130 °C for 15 h in an oil bath. The reaction was cooled down to room temperature and 2-amino benzyl alcohol, **4.4a** (1.1 mmol, 136 mg), KOH (0.6 mmol, 34 mg), and **Mn-22** (2 mol%, 10 mg) were added under argon. The final reaction mixture was heated again at 130 °C for 24 h. After completion of reaction, passed through celite pad using 20 mL ethyl acetate (EtOAc). Next, the solvent was evaporated under reduced

pressure and purified the reaction mixture using 10-20% ethyl acetate and hexane as an eluent (Reaction scheme is mentioned in **Figure 4.2. E**).

4.14.9. Homogeneity test: In an oven dried 100 mL seal tube 4-methoxy acetophenone, **4.1a** (1 mmol, 150 mg), benzyl alcohol, **4.2a** (1 mmol, 108 mg), KOH (0.25 mmol, 14 mg, 25 mol %), and 2.2 equiv. metallic Hg were taken together and connected with high vacuum for 10 minutes. Then 2 mL dry toluene and **Mn-22** (1 mol%, 5 mg) are added to the mixture tube under argon. The reaction mixture is heated at 130 °C. After stirring for 15 h, the mixture is cooled down to room temperature. Next, 2-amino benzyl alcohol (1.1 mmol, 136 mg), KOH (0.6 mmol, 34 mg) and precatalyst **Mn-22** (2 mol%, 10 mg) again added to the previous reaction mixture. Then the reaction mixture was stirred at 130 °C on a preheated oil bath for another 24 h. Then, reaction tube was taken out from hot oil bath and cooled to room temperature. Then purified the crude reaction mixture using 10-20% petroleum ether and ethyl acetate as an eluent (Reaction scheme is mentioned in **Figure 4.2. F**).

4.14.10. Metal hydride trapping experiment: In an oven dried 100 mL seal tube 4-methoxy acetophenone, **4.1a** (1 mmol, 150 mg), 4-methoxy benzyl alcohol, **4.2b** (1 mmol, 138 mg), KOH (0.25 mmol, 14 mg, 25 mol %) 2 mL dry toluene and **Mn-22** (1 mol%, 5 mg) are added sequentially inside the argon filled glove box. Then reaction mixture is stirred at room temperature. After stirring for 0.5 h, tritylium tetrafluoroborate is added to the previous reaction mixture. Then, the tube was sealed and placed in a preheated oil bath at 130 °C (oil bath temperature) for 15 h. This experiment was carried out three time separately in different mol% (1 mol%, 10 mol% & 20 mol%) of tritylium cation (Reaction scheme is mentioned in **Figure 4.2. G**).

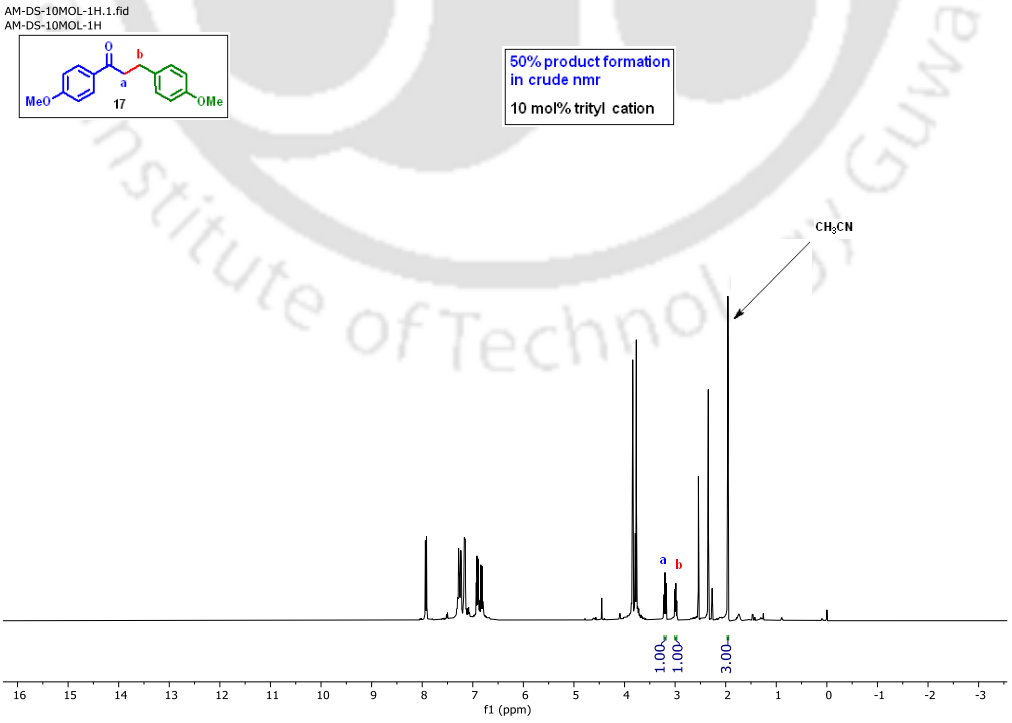


Figure 4.18. ^{1}H-NMR of crude reaction mixture in presence of 10 mol% trityl cation (500 MHz) $CDCl_3$.

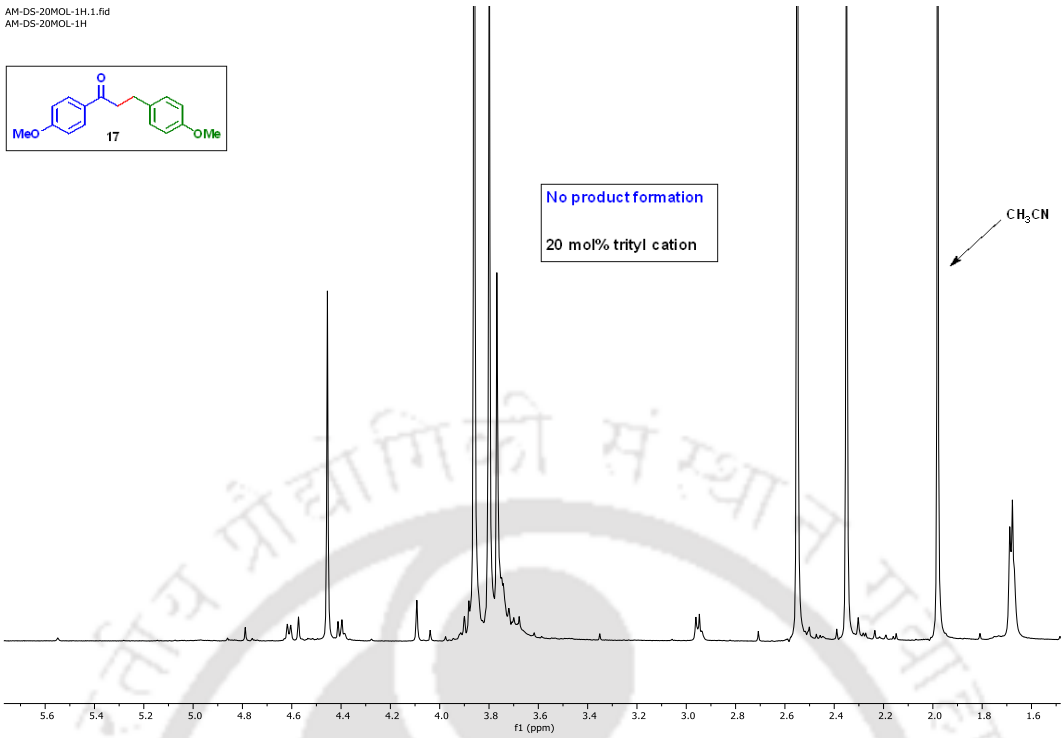


Figure 4.20. ^{1}H-NMR of crude reaction mixture in presence of 20 mol% trityl cation (500 MHz) $CDCl_3$.

After completion of the reaction, the tube was allowed to cool at room temperature. Then, the solvent was evaporated and the crude residue was purified by silica gel column chromatography using petroleum ether-ethyl acetate as eluent which afforded 73%, 47% & 0% isolated yields respectively of the desired product. Result indicates that when 20 mol% trityl cation was used complete quenching of the desired α-alkylated ketone was observed. In parentheses crude yields of the α-alkyalted product was highlighted. This result indicates the insitu formation of Mn-H which hydrogenate the chalcone intermediates to corresponding α-branch ketone.[3]

4.14.11. Competitive study between neutral and electron donating armomatic 2-amino alcohol: In an oven dried 100 mL seal tube 4-methoxy acetophenone, **4.1a** (1 mmol, 150 mg), benzyl alcohol, **4.2a** (1 mmol, 108 mg), KOH (0.25 mmol, 14 mg, 25 mol %) were taken sequentially and connected with high vacuum for 10 minutes. Then 2 mL dry toluene and **Mn-22** (1 mol%, 5 mg) are added to the mixture tube under argon. The reaction mixture is heated at 130 °C. After stirring for 15 h, the mixture is cooled down to room temperature. Next, 2-amino benzyl alcohol, **4.4a** (1.1 mmol, 136 mg), 3-methyl-2-amino benzyl alcohol, **4.4ag** (1.1 mmol, 137 mg), KOH (0.6 mmol, 34 mg) and precatalyst **Mn-22** (2 mol%, 10 mg) again added to the previous reaction mixture. Then the reaction mixture was stirred at 130 °C on a preheated oil bath for another 24 h. Then, reaction mixture was take out from the reaction mixture and cooled to room temperature. Then purified the crude reaction mixture using 10-20% petroleum ether and ethyl acetate as an eluent (Reaction scheme is mentioned in **Figure 4.2. H**).

4.14.12. Competitive study between aromatic and aliphatic primary alcohols: In an oven dried 100 mL seal tube 4-methoxy acetophenone, **4.1a** (1 mmol, 150 mg), benzyl alcohol, **4.2a** (1 mmol, 108 mg), 1-octanol,

4.2am (1 mmol, 130 mg), KOH (0.25 mmol, 14 mg) were taken sequentially and connected with high vacuum for 10 mins. Then 2 mL dry toluene and **Mn-22** (1 mol%, 10 mg) are added to the mixture under argon. The reaction mixture is heated at 130 °C. After stirring for 15 h, the mixture is cooled down to room temperature. Next, 2-amino benzyl alcohol, **4.4a** (1.1 mmol, 136 mg), KOH (0.6 mmol, 34 mg) and precatalyst **Mn-22** (2 mol%, 10 mg) again added to the previous reaction mixture. Then the reaction mixture was stirred at 130 °C on a preheated oil bath for another 24 h. Then, reaction mixture was take out from the reaction mixture and cooled to room temperature. Then purified the crude reaction mixture using 10-20% petroleum ether and ethyl acetate as an eluent (Reaction scheme is mentioned in **Figure 4.2. I**).

4.14.13. Gram scale synthesis: To an oven dried 100 mL seal tube 4-methoxy acetophenone, **4.1a** (6.0 mmol, 900 mg), 4-methoxy benzyl alcohol, **4.2b** (**6** mmol, 830 mg), KOH (1.5 mmol, 85 mg) were taken sequentionally and connected with high vacuum for 10 minutes. Then 10 mL dry toluene and **Mn-22** (1 mol%, 23 mg) are added to the mixture under argon. The resulting mixture was then placed into the preheated oil bath at 130 °C for 15 h. Then the reaction mixture was cooled to room temperature and then under gentle argon flow 2-amino benzyl alcohol, **4.4a** (6 mmol, 812 mg), KOH (3.6 mmol, 202 mg) and **Mn-22** (2 mol%, 60 mg) were added to the reaction. Then again placed into preheated oil bath. After 24 h the reaction mixture was cooled to room temperature and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100-200 mesh) with petroleum ether/ethyl acetate mixture (5%-20%) as eluent, and 62% of **4.5b** was obtained. Yield 62% (1.071 g).

4.15. Kinetic experiments:

4.15.1. Monitoring the kinetics of the first step reaction

4.15.1.1. Experimental procedure: To an oven dried 10 mL 2-neck round bottomed flask, 4-methoxy acetophenone, **4.1a** (1.0 mmol, 1 equiv.), benzyl alcohol **4.2a** (1.0 mmol, 1 equiv.), KOH (0.25 mmol, 25 mol%) and **Mn-22** (0.01 mmol, 1 mol%), mesitylene (1.0 mmol, 1 equiv.) as an internal standard and toluene as a solvent were added under argon to make up the total volume of the reaction mixture 2 mL. Afterwards, the reaction mixture was kept in a preheated oil bath for stirring at 130 °C. At regular intervals (1 h, 2 h, 3 h, 4 h, 5 h, 6 h, 8 h, 12 h, 14 h, 15 h) the reaction mixture was cooled to ambient temperature and an aliquot of mixture was taken in a GC vial. The GC sample was diluted with ethyl acetate and subjected to gas chromatographic analysis. The concentration of the product was determined with respect to mesitylene internal standard. The data was accomplished to draw the concentration of the product (mmolar) *vs* time (h) plot (Kinetic are profile is drawn in **Figure 4.3**. **A**).

4.15.2. Monitoring the kinetics of the second step reaction

4.15.2.1. Experimental procedure: To an oven dried 10 mL 2-neck round bottomed flask, α-branch ketone **4.3a** (1.0 mmol, 1equiv.), 2-aminobenzyl alcohol **4.4a** (1.1 mmol, 1.1 equiv.), KOH (0.60 mmol, 60 mol%) and **Mn-22** (0.02 mmol, 2 mol%), mesitylene (1.0 mmol, 1 equiv.) as an internal standard and toluene as a solvent were added under argon to make up the total volume of the reaction mixture 2 mL. Afterwards, the reaction mixture was

kept in a preheated oil bath for stirring at 130 °C. At regular intervals (1 h, 2 h, 3 h, 4 h, 5 h, 6 h, 8 h, 10 h, 12 h, 15 h, 18 h, 21 h, 24 h) the reaction mixture was cooled to ambient temperature and an aliquot of mixture was taken in a GC vial. The GC sample was diluted with ethyl acetate and subjected to gas chromatographic analysis. The concentration of the product was determined with respect to mesitylene internal standard. The data was accomplished to draw the concentration of the product (mmolar) *vs* time (h) plot **(**Kinetic are profile is drawn in **Figure 4.3**. **D**.).

4.15.3. Rate order determination: The initial rate method was used to determine the rate order of the α-branch ketone **4.3a** and 3-benzyl-2-(4-methoxyphenyl) quinoline **4.5a** synthesis reaction with respect to various components of the reaction. The data of the concentration (mM) *vs* time (h) plot was fitted to linear using origin pro 9. The slope of the linear fitted curve represents the initial rate of the reaction. The order of the reaction was determined by plotting log(rate) *vs* log(concentration) of that particular component.

4.15.4. Rate order determination for the synthesis of *α*-branch ketone 3a with respect to benzyl alcohol (4.2a): To determine the order of the *α*-branch ketone **4.3a** synthesis reaction, initial rates at different initial concentration of benzyl alcohol **4.2a** were recorded.

4.15.4.1. Experimental procedure: To an oven dried 10 mL 2-neck round bottomed flask, 4-Methoxyacetophenone**4.1a** (0.5 mmol, 1equiv.), KOH (0.25 mmol, 25 mol%) and **Mn-22** (0.01 mmol, 1 mol%), mesitylene (1.0 mmol, 1 equiv.) as an internal standard, specific amount of benzyl alcohol **4.2a** and toluene as a solvent were added under argon to make up the total volume of the reaction mixture 2 mL. Afterwards, the reaction mixture was kept in an oil bath of 130 °C for stirring. At regular intervals (3 h, 4 h, 5 h, 6 h, 7 h, 8 h) the reaction mixture was cooled to ambient temperature and an aliquot of mixture was taken in a GC vial. The GC sample was diluted with ethyl acetate and subjected to gas chromatographic analysis. The concentration of the product was determined with respect to mesitylene internal standard. The data was accomplished to draw the concentration of the product (mM) *vs* time (h) plot **(Figure 4.3.)**. The rate of the reaction at different initial concentration of benzyl alcohol **4.2a** was given below and used to plot the log(rate) *vs* log(concentration of benzyl alcohol **4.2a)** to determine the order of the reaction with respect to benzyl alcohol **4.2a** (Kinetic are profile is drawn in **Figure 4.3**. **B & C**.).

4.15.5. Rate order determination for the synthesis of 3-benzyl-2-(4-methoxyphenyl)quinoline 4.5a with respect to 2-aminobenzyl alcohol (4.4) and *α*-branch ketone (4.3a)

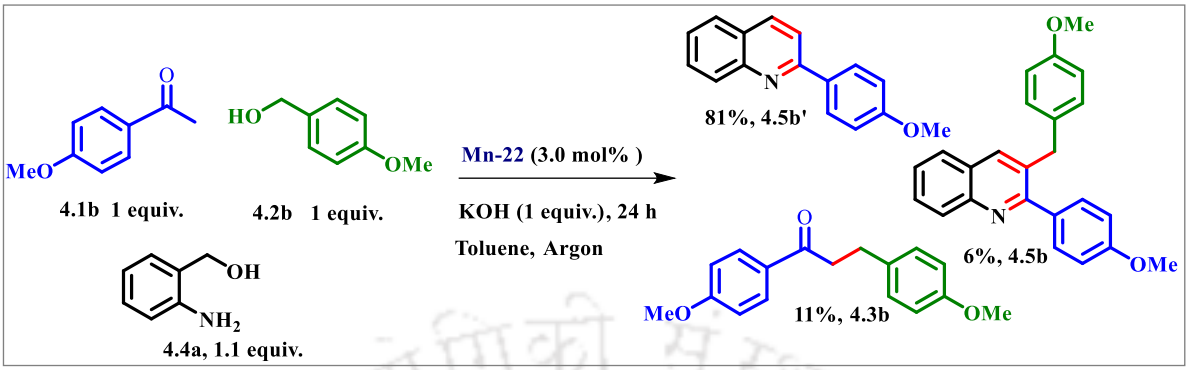
4.15.5.1. Rate order determinationwith respect to 2-aminobenzyl alcohol (4a): To determine the order of the 3-benzyl-2-(4-methoxyphenyl)quinoline **4.5a** synthesis reaction, initial rates at different initial concentration of 2-aminobenzyl alcohol **4.4a** were recorded.

4.15.5.1.1. Experimental procedure: To an oven dried 10 mL 2-neck round bottomed flask, *α*-branch ketone **4.3a** (1.0 mmol, 1equiv.), KOH (0.60 mmol, 60 mol%) and **Mn-22** (0.02 mmol, 2 mol%), mesitylene (1.0 mmol, 1 equiv.) as an internal standard, specific amount of 2-aminobenzyl alcohol **4.4a** and toluene as a solvent were added under argon to make up the total volume of the reaction mixture 2 mL. Afterwards, the reaction mixture was kept in an oil bath of 130 °C for stirring. At regular intervals (4 h, 5 h, 6 h, 7 h, 8 h, 9 h) the reaction mixture was cooled to ambient temperature and an aliquot of mixture was taken in a GC vial. The GC sample was diluted with ethyl acetate and subjected to gas chromatographic analysis. The concentration of the product was determined with respect to mesitylene internal standard. The data was accomplished to draw the concentration of the product (mM) *vs* time (h) plot **(Figure 4.3.)**. The rate of the reaction at different initial concentration of 2-aminobenzyl alcohol **4.4a** was given below and used to plot the log(rate) *vs* log(concentration of 2-aminobenzyl alcohol **4.4a**) to determine the order of the reaction with respect to 2-aminobenzyl alcohol **4.4a** (Kinetic are profile is drawn in **Figure 4.3**. **E & F**.).

4.15.5.2. Rate order determinationwith respect to α-branch ketone (4.3a): To determine the order of the 3-benzyl-2-(4-methoxyphenyl) quinoline **4.5a** synthesis reaction, initial rates at different initial concentration of *α*-branch ketone **4.3a** were recorded.

4.15.5.2.1. Experimental procedure: To an oven dried 10 mL 2-neck round bottomed flask, 2-aminobenzyl alcohol **4.4a** (1.1 mmol, 1.1 equiv.), KOH (0.60 mmol, 60 mol%) and **Mn-22** (0.02 mmol, 2 mol%), mesitylene (1.0 mmol, 1 equiv.) as an internal standard, specific amount of α-branch ketone **4.3a** and toluene as a solvent were added under argon to make up the total volume of the reaction mixture 2 mL. Afterwards, the reaction mixture was kept in an oil bath of 130 °C for stirring. At regular intervals (4 h, 5 h, 6 h, 7 h, 8 h, 9 h) the reaction mixture was cooled to ambient temperature and an aliquot of mixture was taken in a GC vial. The GC sample was diluted with ethyl acetate and subjected to gas chromatographic analysis. The concentration of the product was determined with respect to mesitylene internal standard. The data was accomplished to draw the concentration of the product (mM) *vs* time (h) plot **(Figure 4.3)**. The rate of the reaction at different initial concentration of α-branch ketone **4.3a** was given below and used to plot the log(rate) *vs* log(concentration of α-branch ketone **4.3a**) to determine the order of the reaction with respect to α-branch ketone **4.3a** (Kinetic are profile is drawn in **Figure 4.3**. **G & H**.).

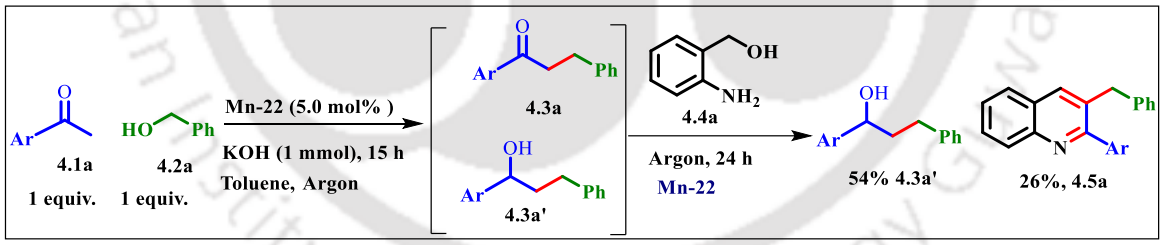
4.16. Possible products formation in addition of all reactants altogether in a one pot:



4-methoxy benzyl alcohol, **4.2b** (1.0 mmol), 4-methoxy acetophenone, **4.1b** (1.0 mmol), 2-amino benzyl alcohol (**4.4a**, 1.1 mmol), **Mn-22** (3.0 mol%), KOH (1 mmol) and 2 mL toluene were taken in a 100 mL seal tube. The tube was sealed under argon atmosphere and refluxed at 130 °C in preheated oil bath for 24 h. After that, the tube was cooled to room temperature. Then the reaction mixture was cooled and 3 mL ethyl acetate was added. Then, the reaction mixture was filtered through celite pad and the solvent was evaporated under reduced pressure. After the purification of all the three spots through silica gel column chromatography using ethyl acetate/hexane as eluent. The NMR analysis of three indicated the formation of **4.5b´**, **4.3b** and trace amount of **4.5b**.

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.21 – 8.10 (m, 4H), 7.83 (d, *J* = 8.7 Hz, 1H), 7.80 (d, *J* = 8.1 Hz, 1H), 7.75 – 7.66 (m, 1H), 7.49 (t, *J* = 7.5 Hz, 1H), 7.05 (d, *J* = 8.9 Hz, 2H), 3.89 (s, 3H).

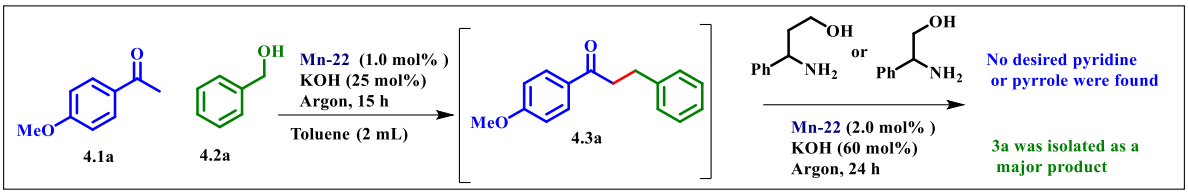
4.17. Possible products formation in addition of base, catalyst at a time in the first step:



Benzyl alcohol, **4.2a** (1.0 mmol), 4-methoxy acetophenone, **4.1a** (1.0 mmol), **Mn-22** (5.0 mol%), KOH (1 mmol) and 2 mL toluene were taken in a 100 mL seal tube. The tube was sealed under argon atmosphere and refluxed at 130 °C in preheated oil bath for 15 h. After that, the tube was cooled to room temperature. Next, only 2-amino benzyl alcohol, **4.4a** (1.1 mmol) were added under argon flow. Then the tube was sealed under argon atmosphere and heated at 130 °C for next 24 h. The reaction mixture was cooled and 3 mL ethyl acetate was added and filtered through celite pad. Carbonyl hydrogenated product of α-branched ketone (guerbet, **4.3a´** and corresponding poly-substituted quinolines (**4.5a**) were purified through silica gel column chromatography using ethyl acetate/hexane as eluent. The final products were authenticated by NMR.

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.28 – 7.19 (m, 4H), 7.18 – 7.12 (m, 3H), 6.85 (d, *J* = 8.7 Hz, 2H), 4.72 – 4.37 (m, 1H), 3.87 (s, 3H), 2.79 – 2.47 (m, 2H), 2.22 – 1.85 (m, 3H).

4.18. Poly substituted pyridine and pyrrole synthesis:



Benzyl alcohol (**4.2a**, 1.0 mmol), 4-methoxy acetophenone (**4.1a**, 1.0 mmol), **Mn-22** (1.0 mol%), KOH (0.25 mmol) and 2 mL toluene were taken in a 100 mL seal tube. The tube was sealed under argon atmosphere and refluxed at 130 °C in preheated oil bath for 15 h. After that, the tube was cooled to room temperature. Next, another portion of **Mn-22** (2 mol %), KOH (0.6 mmol) and 2-phenyl glycinol (1.1 mmol) or 3-amino-3-phenylpropan-1-ol (1.1 mmol) were added under argon flow. Then the tube was sealed under argon atmosphere and heated at 130 °C for next 24 h. Then, ethyl acetate was added and the reaction mixture was filtered through celite pad and then solvent was evaporated under reduced pressure. After purification of the reaction mixture only **4.3a** was isolated as major product.

4.19. Construction of novel molecular scaffolds azafluorene and post modifications:

4.19.1. General procedure for direct C-H hydroxylation: Poly-substituted quinoline (**4.5**, 0.2 mmol,) was added slowly to a mixture of ^{t}BuOK (36 mg, 0.3 mmol), 18-Crown-6 (84 mg, 0.3 mmol) and dry DMF (1 mL) at 0 °C under argon. Then, the argon gas in the reaction mixture was removed under vacuum and the reaction vessel was refilled with O_2. This procedure was repeated for three to four times. The reaction mixture was then stirred under an O_2 balloon at room temperature for 12 h. After the reaction was completed, DMF was removed under vacuum. Then the resulting residue was purified by flash chromatography over silica gel (petroleum ether/EtOAc) to give **4.9**.

4.19.2. General procedure for azafluorenes synthesis: To a flask containing 3-hydroxylated quinoline (**4.9**, 0.1 mmol) in CH_2Cl_2 (2 mL) was added TfOH (0.2 mmol, 30 mg). Then, the mixture was stirred at room temperature for 6 h. Upon completion, the reaction was quenched with aqueous $NaHCO_3$ (5 mL) and the mixture was extracted with ethyl acetate (3 × 6 mL). The combined organic layers were washed with water and brine and then dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum, and the crude product was purified by column chromatography on silica gel with a petroleum ether/ethyl acetate as an eluent to afford **4.10**.

4.19.3. Synthesis of alkenyl quinoline: To a round bottom flask containing **4.9i** or **4.9j** (0.1 mmol) in CH_2Cl_2 (2 mL) was added TfOH (0.3 mmol, 46 mg). Then, the mixture was stirred at room temperature for 4 h. Upon completion, the reaction was quenched with aqueous $NaHCO_3$ (2 mL) and the mixture was extracted with ethyl acetate (3 × 6 mL). The combined organic layers were washed with water and brine and then dried over anhydrous

Na_2SO_4. The solvent was evaporated under vacuum, and the crude product was purified by flash column chromatography on silica gel with a petroleum ether/ethyl acetate as an eluent to afford **4.12a** & **4.12b**.

4.19.4. Chlorination of 3-hydroxylated quinoline (4.9a): To a solution of **4.9a** (0.15 mmol, 51 mg) in $CHCl_3$ (1 mL), $SOCl_2$ (0.3 mmol, 36 mg) was added drop wise at 0 °C. The resulting mixture was allowed to warm to room temperature and then refluxed at 100 °C for 6 h. After that the mixture was cooled down to room temperature and basified with saturated sodium bicarbonate solution. The organic part was extracted with DCM (3×3 mL), dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude mixture was purified by silica gel column chromatography using a mixture of EtOAc/petroleum ether as an eluent.

4.19.5. Azidation of 3-hydroxylated quinoline (4.9a): To a mixture of **4.9a** (0.2 mmol, 68 mg) and $TMSN_3$ (0.8 mmol, 92 mg) in CH_2Cl_2 (3 mL) was added trifluoro acetic acid (0.8 mmol, 92 mg) drop wise. The mixture was stirred at room temperature for 6 h. The reaction was quenched with a saturated Na_2CO_3 solution (5 mL), and the mixture was extracted with EtOAc (3 × 5 mL). The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel with petroleum ether/ethyl acetate to give 9-azido-9-(4-methoxybenzyl)-9H-fluorene (71%) as a white solid.

4.19.6. Synthesis of 3-([1, 1'-biphenyl]-4-ylmethyl)-2-(4-methoxyphenyl)quinoline: A mixture of 3-(4-bromobenzyl)-2-(4-methoxyphenyl) quinoline, **4.5h** (0.25 mmol, 100 mg), phenylboronic acid (0.375 mmol, 45 mg), $(^{i}Pr)_2NH$ (0.5 mmol, 30 mg), H_2O (2 mL) was added to a 10 mL round bottom flask**.** The reaction was stirred at 100 °C under air for 5 minutes. Then the mixture was added to brine (100 mL) and extracted with ethyl acetate. The solvent was concentrated under vacuum and isolated by short chromatography on a silica gel column afford the product as a yellow solid (62 mg, yield: 62%).

4.19.7. Synthesis of 2-(4-methoxyphenyl)-3-(4-(phenylethynyl)benzyl)quinoline: A mixture of $PdCl_2(PPh_3)_2$ (105 mg, 3 mmol%), CuI (19 mg, 2 mmol%) and **4.5n** (0.25 mmol, 100 mg) were taken to a 60 mL seal tube sealing under N_2. 2-ethanolamine (1 mmol, 61 mg), ethynylbenzene (0.3 mmol, 31 mg) and dry THF (3 mL) were added to the mixture. The reaction was stirred at 60 °C for 12 h. The mixture was extracted with ethyl acetate. The solvent was concentrated under vacuum and isolated by chromatography on a silica gel column afforded (69 mg, 65% yield) of the product as a yellow solid.

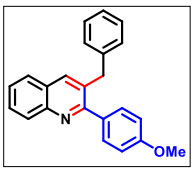
4.19.8. Synthesis of 3-benzyl-2-(4-methoxyphenyl)-6-phenylquinoline: A mixture of 3-benzyl-6-bromo-2-(4-methoxyphenyl) quinoline, **4.5aj** (0.25 mmol, 100 mg), phenylboronic acid (0.375 mmol, 45 mg), $(^{i}Pr)_2NH$ (0.5 mmol, 30 mg), $Pd(OAc)_2$ (25 mol%) and H_2O (2 mL) were taken to a 25 mL round bottom flask**.** The reaction was stirred at 100 °C under air for 5 minutes. Then the mixture was added to brine (100 mL) and extracted with ethyl acetate. The solvent was concentrated under vacuum and isolated by short chromatography on a silica gel column afford the product as a yellow solid (70 mg, yield: 70%).

4.19.9. Synthesis of poly-substituted quinoline *N*-oxide: To a stirred solution of poly-substituted quinoline, **4.5a** (98 mg, 0.3 mmol) in CH_2Cl_2 (2 mL) at 0 °C, a solution of 77% *m*CPBA (113 mg, 0.66 mmol) in CH_2Cl_2 was

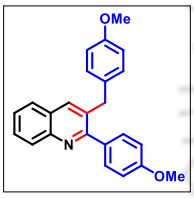
added slowly. The resulting mixture was allowed to warm to room temperature and stirred overnight. The crude product was washed with saturated aqueous $NaHCO_3$ (2 mL), and extracted with CH_2Cl_2 (3x5 mL). The organic phase was dried over anhydrous Na_2SO_4 and the solvent removed under vacuum. The resulting crude N-oxide was purified by flash chromatography on silica gel.

4.20. NMR data:

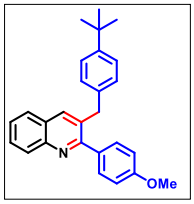
3-benzyl-2-(4-methoxyphenyl) quinoline (4.5a): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 69% yield (226 mg, 0.69mmol) as white solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.06 (d, *J* = 8.4 Hz, 1H), 7.82 (s, 1H), 7.65 (d, *J* = 8.1 Hz, 1H), 7.60 – 7.57 (m, 1H), 7.43 – 7.39 (m, 1H), 7.38 (d, *J* = 8.6 Hz, 2H), 7.18 – 7.15 (m, 2H), 7.13 – 7.09 (m, 1H), 6.95 (d, *J* = 7.3 Hz, 2H), 6.89 (d, *J* = 8.7 Hz, 2H), 4.08 (s, 2H), 3.78 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.5, 159.8, 146.7, 140.2, 137.3, 133.2, 132.7, 130.4, 129.3, 129.2, 129.1, 128.6, 127.5, 127.2, 126.5, 126.4, 113.9, 55.5, 39.3. **HRMS** (H+, m/z) for $C_{23}H_{19}NO$: calcd. = 326.1545; found = 326.1537. **IR (ATIR, DCM, cm^{-1}):** 3059, 3026, 2932, 2885, 1607, 1577, 1557, 1514, 1487, 1453, 1420, 1334, 1174, 1130, 1035, 1019, 841, 755, 736, 696, 616, 517.



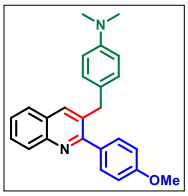
3-(4-methoxybenzyl)-2-(4-methoxyphenyl) quinoline (4.5b): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 20%) afforded the title compound in 71% yield (249 mg, 0.70 mmol) as Yellowish solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.05 (d, *J* = 8.4 Hz, 1H), 7.80 (s, 1H), 7.65 (d, *J* = 8.1 Hz, 1H), 7.60 – 7.56 (m, 1H), 7.42 – 7.36 (m, 3H), 6.90 (d, *J* = 8.7 Hz, 2H), 6.86 (d, *J* = 8.6 Hz, 2H), 6.71 (d, *J* = 8.6 Hz, 2H), 4.01 (s, 2H), 3.78 (s, 3H), 3.70 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.4, 159.8, 158.2, 146.7, 137.1, 133.2, 133.1, 132.2, 130.4, 130.1, 129.2, 129.2, 127.5, 127.2, 126.4, 114.0, 113.8, 55.5, 55.4, 38.4. **HRMS (ESI):** Calc'd for **$C_{24}H_{21}NO_2$[M+H]$^+$:** 356.1651, found: 356.1656. **IR (ATIR, DCM, cm^{-1}):** 3000, 2933, 2906, 1668, 1607, 1582, 1509, 1487, 1440, 1418, 1300, 1242, 1174, 1108, 1033, 954, 835, 789, 757, 629, 616, 566, 528.



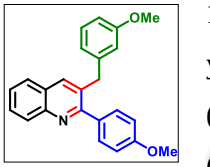
3-(4-(tert-butyl)benzyl)-2-(4-methoxyphenyl)quinoline (4.5C): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 20%) afforded the title compound in 80% yield (305 mg, 0.80 mmol) as brown solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.06 (d, *J* = 8.5 Hz, 1H), 7.84 (s, 1H), 7.65 (d, *J* = 8.1 Hz, 1H), 7.57 (t, *J* = 8.2 Hz, 1H), 7.41 – 7.37 (m, 3H), 7.21 – 7.13 (t, *J* = 8.2, 2H), 6.89 – 6.86 (m, 4H), 4.04 (s, 2H), 3.77 (s, 3H), 1.21 (s, 9H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.4, 159.8, 149.2, 146.6, 137.3, 137.2, 133.2, 132.9, 130.5, 129.2, 128.7, 127.5, 127.2, 126.4, 125.5, 113.7, 55.5, 38.6, 34.5, 31.5. **HRMS (ESI):** Calc'd for **$C_{27}H_{27}NO$ [M+H]$^+$: 382.2171, Found: 382.2169. IR (ATIR, DCM, cm^{-1}):** 2959, 2904, 2836, 1606, 1512, 1486, 1461, 1416, 1290, 1245, 1174, 1108, 1035, 1019, 836, 736, 704, 632, 616, 570, 538, 480.



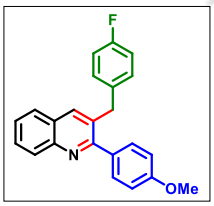
4-((2-(4-methoxyphenyl) quinolin-3-yl)methyl)-N,N-dimethylaniline (4.5d): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 59% yield (217 mg, 0.59 mmol) as brown solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.05 (d, *J* = 8.4 Hz, 1H), 7.81 (s, 1H), 7.64 (d, *J* = 8.1 Hz, 1H), 7.59 – 7.49 (m, 1H), 7.42 – 7.38 (m, 3H), 6.91 – 6.88 (m, 2H), 6.84 – 6.82 (m, 2H), 6.59 – 6.57 (m, 2H), 3.97 (s, 2H), 3.78 (s, 3H), 2.83 (s, 6H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.5, 159.8, 149.3, 146.6, 137.1, 133.6, 133.3, 130.5, 129.8, 129.2, 129.0, 128.2, 127.6, 127.2, 126.3, 113.8, 113.08, 55.5, 40.9, 38.2. **HRMS (ESI):** Calc'd for **$C_{25}H_{24}N_2O$ [M+H]$^+$:369.1967, Found: 369.1968. IR (ATIR, DCM, cm^{-1}):** 2897, 2835, 2799, 1607, 1515, 1485, 1443, 1416, 1339, 1243, 1173, 1129, 1035, 1019, 889, 838, 805, 791, 754, 734, 698, 631, 617, 569, 529, 481.



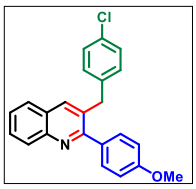
3-(3-methoxybenzyl)-2-(4-methoxyphenyl) quinoline(4.5e): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 65% yield (331 mg, 0.65 mmol) as yellow sticky solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.05 (d, *J* = 8.5 Hz, 1H), 7.82 (s, 1H), 7.64 (d, *J* = 8.1 Hz, 1H), 7.57 (t, *J* = 7.6 Hz, 1H), 7.41 – 7.36 (m, 3H), 7.08 (t, *J* = 7.9 Hz, 1H), 6.89 (d, *J* = 8.6 Hz, 2H), 6.65 (dd, *J* = 8.2, 2.2 Hz, 1H), 6.54 (d, *J* = 7.5 Hz, 1H), 6.47 (s, 1H), 4.04 (s, 2H), 3.76 (s, 3H), 3.63 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.4, 159.9, 159.9, 146.8, 141.8, 137.2, 133.2, 132.5, 130.4, 129.6, 129.3, 129.2, 127.5, 127.2, 126.4, 121.5, 114.9, 113.9, 111.76, 55.5, 55.2, 39.3. **HRMS (ESI):** Calc'd for $C_{24}H_{21}NO_2$ [M+H]$^+$: 356.1651, Found: 356.1652. **IR (ATIR, DCM, cm^{-1}):** 2947, 2835, 1601, 1512, 1457, 1455, 1420, 1246, 1171, 1109, 1000, 839, 785, 732, 695, 635, 616, 535, 480.



3-(4-fluorobenzyl)-2-(4-methoxyphenyl) quinoline(4.5f): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 54% yield (185 mg, 0.54 mmol) as brown solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.06 (d, *J* = 8.5 Hz, 1H), 7.79 (s, 1H), 7.65 (d, *J* = 8.1 Hz, 1H), 7.58 (t, *J* = 7.5 Hz, 1H), 7.41 (t, *J* = 7.5 Hz, 1H), 7.33 (d, *J* = 8.5 Hz, 2H), 6.95 – 6.67 (m, 6H), 4.03 (s, 2H), 3.76 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 161.8 (d, *J* = 243.3 Hz), 160.6, 160.2, 147.0, 137.4, 136.0 (d, *J* = 3.3 Hz), 133.3, 132.8, 130.7 (d, *J* = 7.8 Hz), 130.6, 129.6, 129.5, 127.7, 127.4, 126.8, 115.7 (d, *J* = 21.3 Hz), 114.2, 55.7, 38.8. **HRMS (ESI):** Calc'd for $C_{23}H_{18}FNO$ [M +K]$^+$: 382.1009, Found: 382.1010. **IR (ATIR, DCM, cm^{-1}):** 3040, 2935, 2836, 1607, 1508, 1488, 1455, 1441, 1417, 1244, 1219, 1174, 1157, 1108, 1093, 1034, 1018, 1001, 957, 917, 828, 797, 788, 757, 734, 635, 617, 563, 503, 480.

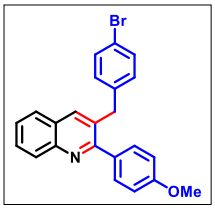


3-(4-chlorobenzyl)-2-(4-methoxyphenyl)quinoline (4.5g): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 70% yield (251 mg, 0.70 mmol) as White solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.07 (d, *J* = 8.4 Hz, 1H), 7.80 (s, 1H), 7.66 (d, *J* = 8.1 Hz, 1H), 7.61 – 7.58 (m, 1H), 7.44 – 7.41 (m, 1H), 7.33 (d, *J* = 8.7 Hz, 2H), 7.12 (d, *J* = 8.4 Hz, 2H), 6.89 (d, *J* = 8.7 Hz, 2H), 6.84 (d, *J* = 8.4 Hz, 2H), 4.03 (s, 2H), 3.77 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.3, 159.9, 146.7, 138.6, 137.3, 132.9, 132.2,

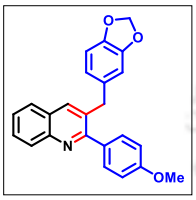


132.2, 130.4, 130.3, 129.4, 129.2, 128.7, 127.4, 127.2, 126.6, 113.9, 55.5, 38.7. **HRMS (ESI):** Calc'd for $C_{23}H_{18}ClNO$ [M +H]$^+$: 360.1155, Found: 360.1149. **IR (ATIR, DCM, cm^{-1}):** 3043, 2929, 2836, 1606, 1512, 1487, 1458, 1420, 1290, 1244, 1174, 1090, 1034, 1015, 956, 835, 802, 734, 702, 636, 530, 480.

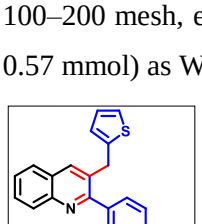
3-(4-bromobenzyl)-2-(4-methoxyphenyl)quinoline (4.5h): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 88% yield (355 mg, 0.88 mmol) as White solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.06 (d, *J* = 8.4 Hz, 1H), 7.80 (s, 1H), 7.66 (d, *J* = 8.1 Hz, 1H), 7.61 – 7.58 (m, 1H), 7.43 (t, *J* = 7.5 Hz, 1H), 7.33 (d, *J* = 8.7 Hz, 2H), 7.27 (d, *J* = 8.4 Hz, 2H), 6.89 (d, *J* = 8.7 Hz, 2H), 6.79 (d, *J* = 8.3 Hz, 2H), 4.02 (s, 2H), 3.77 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.3, 159.9, 146.8, 139.2, 137.2, 133.0, 132.1, 131.7, 130.8, 130.3, 129.4, 129.3, 127.4, 127.2, 126.6, 120.3, 114.0, 55.5, 38.8. **HRMS (ESI):** Calc'd for $C_{23}H_{18}BrNO$ [M +H]$^+$:404.0650, Found: 404.0648. **IR (ATIR, DCM, cm^{-1}):** 3046, 2836, 1607, 1513, 1486, 1419, 1289, 1245, 1174, 1108, 1070, 1035, 1011, 956, 917, 837, 732, 701, 569, 531, 478.



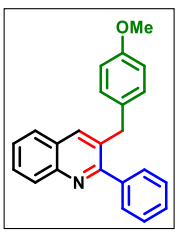
3-(benzo[d][1,3]dioxol-5-ylmethyl)-2-(4-methoxyphenyl)quinoline (4.5i): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 60% yield (222 mg, 0.60 mmol) as brown solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.10 (d, *J* = 8.4 Hz, 1H), 7.84 (s, 1H), 7.67 (d, *J* = 8.1 Hz, 1H), 7.63 – 7.52 (m, 1H), 7.43 (t, *J* = 7.5 Hz, 1H), 7.38 (d, *J* = 8.7 Hz, 2H), 6.91 (d, *J* = 8.7 Hz, 2H), 6.61 (d, *J* = 7.9 Hz, 1H), 6.41 – 6.38 (m, 2H), 5.83 (s, 2H), 3.98 (s, 2H), 3.78 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.2, 160.0, 147.9, 146.4, 146.2, 137.4, 133.9, 132.9, 130.6, 130.5, 129.4, 129.0, 127.5, 127.2, 126.6, 122.1, 113.9, 109.5, 108.4, 101.0, 55.5, 38.9. **HRMS (ESI):** Calc'd for $C_{24}H_{19}NO_3$ [M +H]$^+$: 370.1443, Found: 370.1451.



2-(4-methoxyphenyl)-3-(thiophen-2-ylmethyl)quinoline (4.5j): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 57% yield (189 mg, 0.57 mmol) as White solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.07 (d, *J* = 8.4 Hz, 1H), 7.96 (s, 1H), 7.69 (d, *J* = 8.2 Hz, 1H), 7.60 (t, *J* = 7.7 Hz, 1H), 7.44 – 7.39 (m, 3H), 7.07 (d, *J* = 5.1 Hz, 1H), 6.91 (d, *J* = 8.5 Hz, 2H), 6.88 – 6.77 (m, 1H), 6.58 (d, *J* = 3.1 Hz, 1H), 4.23 (s, 2H), 3.78 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.0, 146.9, 143.2, 137.2, 132.8, 132.1, 130.5, 130.4, 129.5, 129.2, 127.5, 127.3, 127.0, 126.6, 125.8, 124.4, 113.9, 55.5, 33.6. **HRMS (ESI):** Calc'd for **$C_{21}H_{17}NOS$ [M +H]$^+$: 332.1109, Found: 332.1112. IR (ATIR, DCM, cm^{-1}):** 3064, 2928, 2832, 1607, 1576, 1511, 1487, 1421, 1289, 1245, 1175, 1034, 1019, 1000, 837, 797, 755, 698, 634, 572, 535, 481.

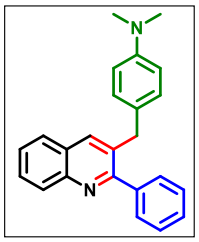


3-(4-methoxybenzyl)-2-phenylquinoline (4.5k):Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 63% yield (204 mg, 0.63 mmol) as White solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.06 (d, *J* = 8.4 Hz, 1H), 7.81 (s, 1H), 7.65 (d, *J* = 8.2 Hz, 1H), 7.58 (t, *J* = 7.6 Hz, 1H), 7.45 – 7.26 (m, 6H), 6.82 (d, *J* = 7.0 Hz, 2H), 6.69 (d, *J* = 8.4 Hz, 2H), 3.97 (s, 2H), 3.68 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.8, 158.2, 146.7, 140.8, 137.0, 133.1, 132.1, 130.1, 129.4, 129.2, 129.0, 128.4, 128.3, 127.7, 127.2,

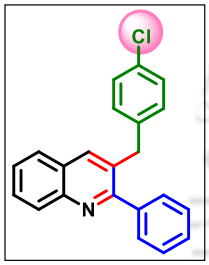


126.6, 114.0, 55.3, 38.4.**HRMS (ESI):** Calc'd for $C_{23}H_{19}NO$ $[M + H]^+$: 326.1545; found = 326.1537. **IR (ATIR, DCM, cm^{-1}):** 3027, 2932, 2826, 1606, 1576, 1550, 1514, 1494, 1474, 1437, 1415, 1247, 1174, 1073, 1018, 921, 830, 722, 604.

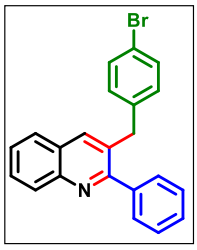
N,N-dimethyl-4-((2-phenylquinolin-3-yl)methyl)aniline (4.5l): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 58% yield (196 mg, 0.58 mmol) as brown solid. **^{1}H NMR (600 MHz, Chloroform-*d*)** δ 8.07 (d, *J* = 8.4 Hz, 1H), 7.84 (s, 1H), 7.67 (d, *J* = 8.1 Hz, 1H), 7.59 (t, *J* = 7.8 Hz, 1H), 7.45 – 7.41 (m, 3H), 7.39 – 7.33 (m, 3H), 6.82 (d, *J* = 8.4 Hz, 2H), 6.59 (d, *J* = 8.3 Hz, 2H), 3.95 (s, 2H), 2.84 (s, 6H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 160.8, 149.1, 146.5, 140.7, 137.1, 133.5, 129.8, 129.3, 129.2, 129.1, 128.4, 128.3, 127.7, 127.3, 126.5, 113.2, 41.0, 38.2. **HRMS (ESI):** Calc'd for $C_{24}H_{22}N_2$ $[M + H]^+$: 339.1861; found = 339.1854. **IR (ATIR, DCM, cm^{-1}):** 3035, 2934. 2896, 1683, 1614, 1520, 1484, 1445, 1415, 1344, 1265, 1163, 1229, 1007, 804, 767, 752, 701.



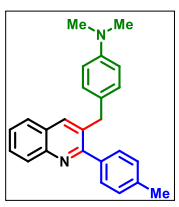
3-(4-chlorobenzyl)-2-phenylquinoline (4.5m): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 58% yield (191 mg, 0.58 mmol) as yellow solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.14 (d, *J* = 8.4 Hz, 1H), 7.91 (s, 1H), 7.77 (d, *J* = 8.1 Hz, 1H), 7.69 (t, *J* = 7.6 Hz, 1H), 7.53 (t, *J* = 7.5 Hz, 1H), 7.44 – 7.42 (m, 5H), 7.19 (d, *J* = 8.3 Hz, 2H), 6.89 (d, *J* = 8.3 Hz, 2H), 4.09 (s, 2H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.8, 146.8, 140.6, 138.5, 137.1, 132.2, 132.1, 130.4, 129.5, 128.9, 128.7, 128.5, 128.4, 127.6, 127.2, 126.8, 38.7. **HRMS (ESI):** Calc'd for $C_{22}H_{16}ClN$ $[M + H]^+$: 330.1050; found = 330.1096. **IR (ATIR, DCM, cm^{-1}):** 3050, 3027, 2931, 1608, 1578, 1548, 1514, 1478, 1456, 1392, 1340, 1266, 1445, 1178, 1072, 1020, 921, 837, 728, 577, 554.



3-(4-bromobenzyl)-2-phenylquinoline (4.5n): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt petroleum ether 5% to 20%) afforded the title compound in 74% yield (276 mg, 0.74 mmol) as White solid. ^{1}H **NMR (500 MHz, Chloroform-*d*)** δ 8.06 (d, *J* = 8.4 Hz, 1H), 7.82 (s, 1H), 7.68 (d, *J* = 8.1 Hz, 1H), 7.61 (t, *J* = 7.7 Hz, 1H), 7.44 (t, *J* = 7.5 Hz, 1H), 7.37 – 7.34 (m, 5H), 7.25 (d, *J* = 8.3 Hz, 2H), 6.76 (d, *J* = 8.2 Hz, 2H), 3.99 (s, 2H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.7, 146.8, 140.6, 139.0, 137.1, 132.00, 131.7, 130.8, 129.5, 129.4, 128.9, 128.5, 128.4, 127.6, 127.2, 126.8, 120.3, 38.7. **HRMS (ESI):** Calc'd for $C_{22}H_{16}BrN$ $[M + NH_4]^+$: 391.0810, Found: 391.0803. **IR (ATIR, DCM, cm^{-1}):** 3023, 2918, 1618, 1594, 1556, 1513, 1486, 1444, 1414, 1330, 1266, 1182, 1157, 1018, 1005, 899, 845, 804, 752, 699, 480.

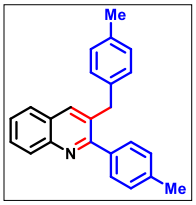


N,N-dimethyl-4-((2-(p-tolyl)quinolin-3-yl)methyl)aniline (4.5o): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 74% yield (276 mg, 0.74 mmol) as brown solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.09 (d, *J* = 8.4 Hz, 1H), 7.82 (s, 1H), 7.65 (d, *J* = 8.1 Hz, 1H), 7.58 (t, *J* = 7.3 Hz, 1H), 7.41 (t, *J* = 7.5 Hz, 1H), 7.36 (d, *J* = 8.0 Hz, 2H), 7.12 (s, 2H), 6.85 (d, *J* = 8.6 Hz, 2H), 6.61 (d, *J* = 8.5 Hz, 2H), 3.97 (s, 2H), 2.85 (s, 6H), 2.35 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.8, 151.3, 149.2, 146.5

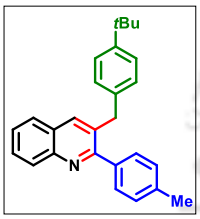


146.4, 138.2, 137.7, 137.1, 133.7, 129.9, 129.1, 129.1, 127.7, 127.2, 126.4, 113.2, 41.0, 38.2, 21.5. **HRMS (ESI):** Calc'd for $C_{25}H_{24}N_2$ $[M + H]^+$: 353.2018, Found: 353.2018. **IR (ATIR, DCM, cm^{-1}):** 3030, 2908, 2799, 1613, 1565, 1518, 1476, 1443, 1411, 1339, 1267, 1226, 1160, 946, 805, 783, 764, 700, 562.

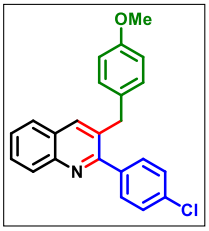
3-(4-methylbenzyl)-2-(p-tolyl)quinoline (4.5p): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 72% yield (233 mg, 0.72 mmol) as White solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.13 (d, *J* = 8.5 Hz, 1H), 7.87 (s, 1H), 7.71 (d, *J* = 8.1 Hz, 1H), 7.65 (t, *J* = 7.7 Hz, 1H), 7.47 (t, *J* = 7.5 Hz, 1H), 7.41 (d, *J* = 7.7 Hz, 2H), 7.25 (d, *J* = 7.7 Hz, 2H), 7.06 (d, *J* = 7.7 Hz, 2H), 6.92 (d, *J* = 7.6 Hz, 2H), 4.09 (s, 2H), 2.41 (s, 3H), 2.31 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.8, 146.7, 138.1, 137.8, 137.1, 137.0, 135.8, 132.9, 129.3, 129.1, 129.0, 129.0, 129.0, 127.6, 127.2, 126.4, 38.7, 21.4, 21.1. **HRMS (ESI):** Calc'd for $C_{24}H_{21}NO$ $[M + H]^+$:324.1752, Found: 324.1770. **IR (ATIR, DCM, cm^{-1}):** 3021, 2918, 1614, 1595, 1556, 1512, 1486, 1416, 1335, 1266, 1184, 1211, 1157, 1016, 1004, 955, 891, 816, 753, 516, 481.



3-(4-(tert-butyl)benzyl)-2-(p-tolyl)quinoline(4.5q): Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 67% yield (244 mg, 0.67 mmol) as White solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.13 (d, *J* = 8.4 Hz, 1H), 7.90 (s, 1H), 7.71 (d, *J* = 8.1 Hz, 1H), 7.66 – 7.62 (m, 1H), 7.46 (t, *J* = 7.5 Hz, 1H), 7.42 – 7.40 (m, 2H), 7.27 – 7.22 (m, 4H), 6.96 (d, *J* = 8.3 Hz, 2H), 4.10 (s, 2H), 2.40 (s, 3H), 1.29 (s, 9H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.9, 149.1, 146.7, 138.0, 137.9, 137.2, 137.1, 132.9, 129.4, 129.1, 129.0, 128.9, 128.7, 127.6, 127.2, 126.4, 125.5, 38.6, 34.5, 31.5, 21.4. **HRMS (ESI):** Calc'd for $C_{27}H_{27}N$ $[M + H]^+$: 366.2222, Found: 366.2222. **IR (ATIR, DCM, cm^{-1}):** 3025, 2959, 2866, 1614, 1595, 1568, 1511, 1490, 1460, 1363, 1266, 1182, 1108, 1094, 831, 788, 752, 730, 616, 563, 480.



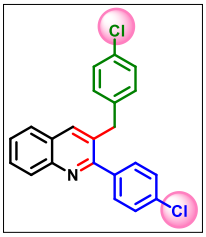
3-(benzo[d][1,3]dioxol-5-ylmethyl)-2-(p-tolyl)quinoline (4.5r): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 66% yield (365 mg, 0.66 mmol) as brown solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.09 (d, *J* = 8.4 Hz, 1H), 7.82 (s, 1H), 7.67 (d, *J* = 8.1 Hz, 1H), 7.59 (t, *J* = 7.4 Hz, 1H), 7.42 (t, *J* = 7.5 Hz, 1H), 7.32 (d, *J* = 7.9 Hz, 2H), 7.18 (d, *J* = 8.3 Hz, 2H), 6.61 (d, *J* = 7.9 Hz, 1H), 6.45 – 6.32 (m, 2H), 5.82 (s, 2H), 3.96 (s, 2H), 2.34 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.7, 147.9, 146.5, 146.1, 138.3, 137.2, 133.9, 132.9, 129.4, 129.2, 129.1, 129.0, 127.6, 127.2, 127.0, 126.6, 122.1, 109.5, 108.3, 101.0, 38.9, 21.4. **HRMS (ESI):** Calc'd for $C_{24}H_{19}NO_2$ $[M + H]^+$: 354.1494, Found: 354.1510.



2-(4-chlorophenyl)-3-(4-methoxybenzyl)quinoline (4.5s): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 58% yield (208 mg, 0.58 mmol) as off white solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.02 (d, *J* = 8.4 Hz, 1H), 7.83 (s, 1H), 7.65 (d, *J* = 8.1 Hz, 1H), 7.58 (t, *J* = 7.6 Hz, 1H), 7.42 (d, *J* = 7.4 Hz, 1H), 7.31 (s, 4H), 6.80 (d, *J* = 8.5 Hz, 2H), 6.69 (d, *J* = 8.6 Hz, 2H), 3.94 (s, 2H), 3.67 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 159.5, 158.2, 146.7, 139.1, 137.3, 134.4, 132.7, 131.8, 130.4, 130.0, 129.4, 129.3, 128.5, 127.7, 127.2, 126.8, 114.1, 55.3, 38.3. **HRMS (ESI):** Calc'd for

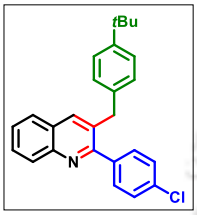
$C_{23}H_{18}ClNO$ [M + H]$^+$: 360.1155, Found: 360.1159. **IR (ATIR, DCM, cm^{-1}):** 3045, 2955, 2835, 1610, 1598, 1510, 1485, 1462, 1264, 1245, 1176, 1084, 1014, 956, 890, 732, 701, 523, 424.

3-(4-chlorobenzyl)-2-(4-chlorophenyl) quinoline (4.5t): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 55% yield (200 mg, 0.55 mmol) as yellowish sticky liquid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.12 (d, *J* = 8.5 Hz, 1H), 7.93 (s, 1H), 7.78 (d, *J* = 8.1 Hz, 1H), 7.71 (t, *J* = 7.6 Hz, 1H), 7.55 (t, *J* = 7.5 Hz, 1H), 7.42 – 7.37 (m, 4H), 7.21 (d, *J* = 8.3 Hz, 2H), 6.90 (d, *J* = 8.3 Hz, 2H), 4.08 (s, 2H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 159.5, 146.9, 139.2, 138.3, 137.4, 134.6, 132.4, 131.8, 130.4, 130.3, 129.7, 129.4, 128.8, 128.7, 127.66, 127.3, 127.0, 38.7.

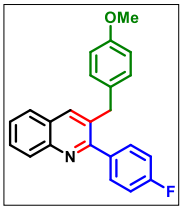


HRMS (ESI): Calc'd for $C_{22}H_{15}Cl_2N$ [M + H]$^+$: 364.0660, Found: 364.0665. **IR (ATIR, DCM, cm^{-1}):** 3053, 2916, 1597, 1486, 1415, 1334, 1269, 1174, 1090, 1011, 957, 916, 891, 837, 801, 754, 657, 618, 592, 481.

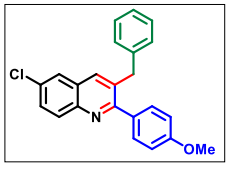
3-(4-(tert-butyl)benzyl)-2-(4-chlorophenyl)quinoline (4.5u): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 56% yield (215 mg, 0.56 mmol) as yellowish sticky liquid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.11 (d, *J* = 8.5 Hz, 1H), 7.97 (s, 1H), 7.77 (d, *J* = 8.1 Hz, 1H), 7.69 (t, *J* = 7.5 Hz, 1H), 7.52 (t, *J* = 7.4 Hz, 1H), 7.43 – 7.39 (m, 4H), 7.26 – 7.22 (m, 2H), 6.92 (d, *J* = 8.1 Hz, 2H), 4.08 (s, 2H), 1.30 (s, 9H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 159.7, 149.4, 146.8, 139.3, 137.5, 136.9, 135.2, 134.5, 132.6, 130.5, 129.4, 128.7, 128.6, 127.7, 127.3, 126.8, 125.6, 38.6, 34.5, 31.5. **HRMS (ESI):** Calc'd for $C_{26}H_{24}ClN$ [M + H]$^+$: 386.1676, Found: 386.1675. **IR (ATIR, DCM, cm^{-1}):** 3028, 2922, 1610, 1590, 1548, 1475, 1443, 1395, 1371, 1363, 1263, 1212, 1184, 917, 913, 902, 819, 737, 566, 480, 460.



2-(4-fluorophenyl)-3-(4-methoxybenzyl) quinoline (4.5v): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 51% yield (175 mg, 0.51 mmol) as brown sticky liquid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.14 (d, *J* = 8.4 Hz, 1H), 7.94 (s, 1H), 7.77 (d, *J* = 8.1 Hz, 1H), 7.69 (t, *J* = 7.8 Hz, 1H), 7.53 (t, *J* = 7.4 Hz, 1H), 7.48 – 7.43 (m, 2H), 7.12 (t, *J* = 8.5 Hz, 2H), 6.89 (d, *J* = 8.2 Hz, 2H), 6.78 (d, *J* = 8.3 Hz, 2H), 4.05 (s, 2H), 3.78 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 163.0 (d, *J* = 245.8), 159.8, 158.2, 146.6, 137.4, 136.7, 133.0, 131.9, 130.9 (d, *J* = 8.2), 130.0, 129.5, 129.2, 127.7, 127.3, 126.8, 115.4 (d, *J* = 21.4), 114.1, 55.4, 38.4. **HRMS (ESI):** Calc'd for $C_{23}H_{18}FNO$ [M + H]$^+$: 344.1451, Found: 344.1451. **IR (ATIR, DCM, cm^{-1}):** 2960, 2835, 1602, 1558, 1509, 1487, 1454, 1439, 1416, 1377, 1335, 1244, 1222, 1176, 1157, 1093, 1031, 1015, 957, 915, 890, 796, 755, 730, 699, 642, 629, 616, 563, 517, 481, 407.

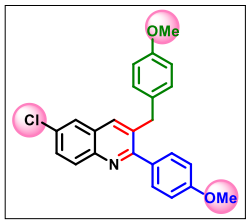


3-benzyl-6-chloro-2-(4-methoxyphenyl)quinoline (4.5y): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 61% yield (219 mg, 0.61 mmol) as white solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.04 (d, *J* = 8.9 Hz, 1H), 7.78 (s, 1H), 7.70 (d, *J* = 2.2 Hz, 1H), 7.58 (dd, *J* = 8.9, 2.2 Hz, 1H), 7.45 (d, *J* = 8.7 Hz, 2H), 7.27 – 7.24 (m, 1H), 7.21 – 7.18 (m, 2H), 7.01 (d, *J* = 7.0 Hz, 2H), 6.97 (d, *J* = 8.7 Hz, 2H), 4.14 (s, 2H), 3.86 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.7, 160.0, 145.2, 139.8, 136.2,



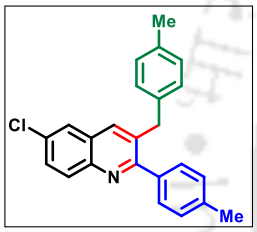
133.8, 132.9, 132.2, 131.0, 130.4, 130.1, 129.1, 128.7, 128.1, 126.5, 125.9, 113.9, 55.5, 39.3. **HRMS (ESI):** Calc'd for $C_{23}H_{18}ClNO$ $[M + H]^+$: 360.1155, Found: 360.1154. **IR (ATIR, DCM, cm^{-1}):** 3056, 3029, 2933, 1607, 1576, 1547, 1513, 1470, 1450, 1396, 1340, 1266, 1445, 1178, 1072, 1019, 920, 836, 729, 574, 558.

6-chloro-3-(4-methoxybenzyl)-2-(4-methoxyphenyl) quinoline (4.5z): Purification by column chromatography



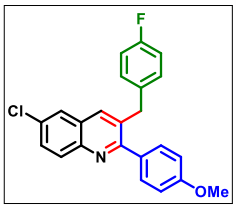
(SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 69% yield (268 mg, 0.69 mmol) as yellow solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.03 (d, *J* = 8.9 Hz, 1H), 7.75 (s, 1H), 7.70 (d, *J* = 2.1 Hz, 1H), 7.58 – 7.56 (m, 1H), 7.45 (d, *J* = 8.7 Hz, 2H), 6.98 (d, *J* = 8.6 Hz, 2H), 6.92 (d, *J* = 8.4 Hz, 2H), 6.80 (d, *J* = 8.6 Hz, 2H), 4.07 (s, 2H), 3.86 (s, 3H), 3.77 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.7, 159.9, 158.3, 145.1, 140.0, 134.3, 132.9, 132.0, 131.8, 130.9, 130.4, 130.1, 130.0, 128.1, 125.8, 114.1, 113.9, 55.5, 55.4, 38.4. **HRMS (ESI):** Calc'd for $C_{24}H_{20}ClNO_2$ $[M + H]^+$: 390.1261, Found: 390.1275. **IR (ATIR, DCM, cm^{-1}):** 3018, 3004, 1607, 1591, 1508, 1472, 1454, 1397, 1379, 1240, 1177, 1072, 1019, 818, 733, 560.

6-chloro-3-(4-methylbenzyl)-2-(p-tolyl)quinoline (4.5aa): Purification by column chromatography (SiO_2, 100–



200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 64% yield (232 mg, 0.64 mmol) as White solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.05 – 8.03 (m, 1H), 7.75 (s, 1H), 7.69 (s, 1H), 7.58 – 7.56 (m, 1H), 7.42 – 7.39 (m, 2H), 7.25 (d, *J* = 7.9 Hz, 2H), 7.06 (d, *J* = 7.4 Hz, 2H), 6.91 (d, *J* = 7.6 Hz, 2H), 4.08 (s, 2H), 2.41 (s, 3H), 2.31 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 161.1, 145.1, 138.3, 137.5, 136.7, 136.1, 136.0, 134.1, 132.1, 131.0, 130.0, 129.4, 129.1, 129.0, 128.9, 128.2, 125.8, 38.7, 21.4, 21.1. **HRMS (ESI):** Calc'd for $C_{24}H_{20}ClNO$ $[M + H]^+$: 358.1363, Found: 358.1350. **IR (ATIR, DCM, cm^{-1}):** 3022, 2917, 1614, 1592, 1548, 1475, 1443, 1395, 1371, 1363, 1263, 1212, 1184, 917, 913, 902, 817, 736, 564, 481, 463.

6-chloro-3-(4-fluorobenzyl)-2-(4-methoxyphenyl)quinoline (4.5ab): Purification by column chromatography



(SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 51% yield (192 mg, 0.50 mmol) as yellow solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.08 (d, *J* = 7.0 Hz, 1H), 7.74 (s, 1H), 7.67 – 7.66 (m, 1H), 7.55 (dd, *J* = 9.0, 2.2 Hz, 1H), 7.36 (d, *J* = 8.4 Hz, 2H), 6.91 (d, *J* = 8.5 Hz, 2H), 6.85 (d, *J* = 7.3 Hz, 4H), 4.03 (s, 2H), 3.77 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 161.7 (d, *J* = 243.5 Hz), 160.0, 136.2, 135.3 (d, *J* = 3.3 Hz), 133.9, 132.5, 132.3 (d, *J* = 9.8 Hz), 130.6, 130.5, 130.4, 128.7, 128.6, 128.1, 125.9, 115.6 (d, *J* = 21.2 Hz), 114.0, 55.5, 38.5. **HRMS (ESI):** Calc'd for $C_{23}H_{17}FClNO$ $[M + H]^+$: 378.1061, Found: 378.1061. **IR (ATIR, DCM, cm^{-1}):** 3047, 3003, 2959, 2933, 1605, 1575, 1506, 1474, 1437, 1414, 1297, 1146, 1072, 1047, 920, 832, 688, 541, 482.

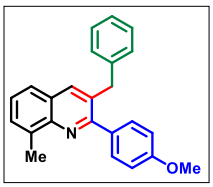
4-((6-chloro-2-phenylquinolin-3-yl)methyl)-N,N-dimethylaniline(4.5ac): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 60% yield (200 mg, 0.60 mmol) as White solid. **^{1}H NMR (600 MHz, Chloroform-*d*)** δ 8.05 (d, *J* = 8.9 Hz, 1H), 7.80 (s, 1H), 7.72 (s, 1H), 7.58 (d, *J* = 8.8 Hz, 2H), 7.51 (d, *J* = 6.8 Hz, 2H), 7.47 – 7.43 (m, 3H), 6.88 (d, *J* = 8.2 Hz, 2H), 6.68 (s, 2H), 4.02 (s, 1H), 2.92 (s, 6H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 161.1, 149.1, 144.9, 140.5, 136.0, 134.7, 132.1, 131.0, 130.0, 129.9, 129.0, 128.5, 128.5, 128.3, 125.9, 113.3, 41.0, 38.2. **HRMS (ESI):** Calc'd for $C_{24}H_{21}ClN$ $[M + H]^+$: 339.1861; found = 339.1854.

6-chloro-3-(4-methylbenzyl)-2-phenylquinoline (4.5ad): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 74% yield (254 mg, 0.74 mmol) as yellow solid. **^{1}H NMR (600 MHz, Chloroform-*d*)** δ 8.13 (d, *J* = 7.8 Hz, 1H), 7.82 (s, 1H), 7.73 (s, 1H), 7.61 (d, *J* = 8.9 Hz, 1H), 7.51 – 7.49 (m, 2H), 7.47- 7.43 (m, 3H), 7.06 (d, *J* = 7.6 Hz, 2H), 6.88 (d, *J* = 7.6 Hz, 2H), 4.07 (s, 2H), 2.31 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 160.8, 144.6, 139.8, 136.5, 136.4, 136.2, 134.2, 132.5, 130.7, 130.4, 129.5, 129.0, 128.7, 128.5, 128.3, 125.9, 38.7, 21.2. **HRMS (ESI):** Calc'd for $C_{23}H_{18}ClN[M+H]^+$**:** 344.1206; found = 344.1199. **IR (ATIR, DCM, cm^{-1}):** 3055, 3027, 3004, 2934, 1608, 1576, 1547, 1516, 1494, 1474, 1453, 1438, 1414, 1340, 1284, 1247, 1178, 1111, 1072, 1030, 920, 836, 729, 574, 483.

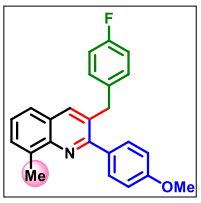
6-chloro-3-(4-chlorobenzyl)-2-phenylquinoline (4.5ae): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 52% yield (189 mg, 0.52 mmol) as yellow solid. **^{1}H NMR** (600 MHz, Chloroform-*d*) δ 8.06 (d, *J* = 8.9 Hz, 1H), 7.80 (s, 1H), 7.75 (s, 1H), 7.61 (d, *J* = 8.9 Hz, 1H), 7.44 (s, 5H), 7.19 (d, *J* = 7.7 Hz, 2H), 6.88 (d, *J* = 7.7 Hz, 2H), 4.08 (s, 2H). **^{13}C NMR** (150 MHz, $CDCl_3$) δ 161.0, 145.2, 140.2, 138.1, 136.1, 133.3, 132.5, 132.4, 131.1, 130.4, 130.4, 128.8, 128.8, 128.6, 128.6, 128.2, 125.9, 38.7. **HRMS (ESI):**Calc'd for $C_{28}H_{19}Cl_2N$ $[M + K]^+$: 478.0532, Found: 478.0491. **IR (ATIR, DCM, cm^{-1}):** 3050, 2962, 1592, 1550, 1489, 1475, 1443, 1395, 1369, 1341, 1263, 1191, 1132, 1089, 1071, 1010, 937, 915, 902, 838, 830, 797, 758, 737, 697, 655, 576, 553, 480.

N,N-dimethyl-4-((8-methyl-2-phenylquinolin-3-yl)methyl)aniline (4.5af): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 71% yield (250 mg, 0.71 mmol) as brown solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.79 (s, 1H), 7.53 (d, *J* = 6.9 Hz, 2H), 7.49 (d, *J* = 8.1 Hz, 1H), 7.42 (d, *J* = 6.8 Hz, 1H), 7.38 – 7.33 (m, 3H), 7.29 (t, *J* = 7.5 Hz, 1H), 6.83 (d, *J* = 8.4 Hz, 2H), 6.60 (d, *J* = 7.9 Hz, 2H), 4.00 (s, 2H), 2.84 (s, 6H), 2.73 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 159.2, 149.3, 145.9, 141.4, 137.4, 137.3, 132.9, 129.8, 129.6, 129.0, 128.4, 128.2, 128.1, 127.6, 126.2, 125.2, 113.0, 40.9, 38.2, 18.1. **HRMS (ESI):** Calc'd for $C_{25}H_{24}N_2[M + H]^+$:353.2018; found = 353.2014.

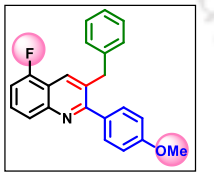
3-benzyl-2-(4-methoxyphenyl)-8-methylquinoline (4.5ag): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 61% yield (207 mg, 0.61 mmol) as off white solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.84 (s, 1H), 7.54 (d, *J* = 8.6 Hz, 3H), 7.49 (d, *J* = 7.9 Hz, 1H), 7.35 (t, *J* = 7.5 Hz, 1H), 7.24 – 7.21 (m, 2H), 7.17 (t, *J* = 7.6 Hz, 1H), 7.03 (d, *J* = 7.3 Hz, 2H), 6.96 (d, *J* = 8.6 Hz, 2H), 4.19 (s, 2H), 3.84 (s, 3H), 2.80 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 159.8, 158.8, 146.0, 140.6, 137.6, 137.4, 133.8, 131.9, 130.9, 129.2, 129.1, 128.6, 127.4, 126.3, 126.1, 125.1, 113.7, 55.5, 39.3, 18.0. **HRMS (ESI):**Calc'd for **$C_{24}H_{21}NO$** $[M + H]^+$: 340.1701, Found: 340.1702. **IR (ATIR, DCM, cm^{-1}):** 3000, 2940, 2835, 1605, 1512, 1489, 1460, 1419, 1245, 1175, 1108, 1030, 1001, 954, 840, 813, 790, 753, 708, 634, 617, 628, 480.



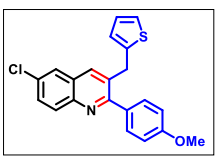
3-(4-fluorobenzyl)-2-(4-methoxyphenyl)-8-methylquinoline (4.5ah): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 53% yield (189 mg, 0.53 mmol) as white solid. **^{1}H NMR (600 MHz, Chloroform-*d*)** δ 7.83 (s, 1H), 7.57 (d, *J* = 8.1 Hz, 1H), 7.51 (d, *J* = 8.5 Hz, 3H), 7.38 (t, *J* = 7.5 Hz, 1H), 7.00 – 6.90 (m, 6H), 4.16 (s, 2H), 3.86 (s, 3H), 2.80 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 161.5 (d, *J* = 242.9 Hz), 159.7, 158.7, 146.0, 137.5, 137.3, 136.1 (d, *J* = 3.2 Hz), 133.6, 131.8, 130.8, 130.4 (d, *J* = 7.7 Hz), 129.3, 127.2, 126.2, 125.1, 115.3 (d, *J* = 21.0 Hz), 113.6, 55.5, 38.5, 18.1. **HRMS (ESI):** Calc'd for $C_{24}H_{20}FNO$ $[M + H]^+$: 358.1607, Found: 358.1606. **IR (ATIR, DCM, cm^{-1}):** 3041, 2956, 2836, 1606, 1567, 1507, 1478, 1440, 1412, 1375, 1337, 1265, 1245, 1220, 1170, 1157, 1108, 1075, 1033, 1015, 892, 859, 831, 807, 781, 760, 734, 561, 483, 464.



3-benzyl-5-fluoro-2-(4-methoxyphenyl) quinoline (4.5ai): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 61% yield (209 mg, 0.61 mmol) as brown solid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.22 (s, 1H), 7.98 (d, *J* = 8.0 Hz, 1H), 7.60 (q, *J* = 7.8 Hz, 1H), 7.45 (d, *J* = 8.3 Hz, 2H), 7.26 – 7.23 (m, 2H), 7.20 (t, *J* = 7.5 Hz, 2H), 7.01 – 6.96 (m, 4H), 4.19 (s, 2H), 3.86 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 161.5, 160.0, 157.7 (d, *J* = 253 Hz), 147.6 (d, *J* = 2.9 Hz), 139.9, 133.1 (d, *J* = 2.4 Hz), 132.9, 130.4 (d, *J* = 4.1 Hz), 130.4, 129.0, 128.7, 128.6 (d, *J* = 8.9 Hz), 126.5, 125.2 (d. *J* = 4.0 Hz), 118.3 (d, *J* = 15.8 Hz), 113.95, 109.9 (d, *J* = 19.1 Hz), 55.54, 39.46. **^{19}F NMR (471 MHz, Chloroform-*d*)** δ -123.22. **HRMS (ESI):** Calc'd for $C_{23}H_{18}FNO$ $[M + H]^+$: 344.1451, Found: 344.1484.

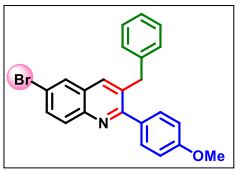


6-chloro-2-(4-methoxyphenyl)-3-(thiophen-2-ylmethyl) quinoline (4.5aj): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 64% yield (234 mg, 0.64 mmol) as brown solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.11 (d, *J* = 8.4 Hz, 1H), 7.98 (s, 1H), 7.70 (d, *J* = 8.2 Hz, 1H), 7.61 (t, *J* = 7.6 Hz, 1H), 7.44 –7.40 (m, 2H), 7.09–7.06 (m, 1H), 6.91 (d, *J* = 8.1 Hz, 2H), 6.83 – 6.82 (m, 1H), 6.60 – 6.58 (m, 1H), 4.24 (s, 2H), 3.78 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.1, 159.9, 146.6, 143.09, 137.4, 132.1, 130.5, 129.6, 129.1, 127.5, 127.3, 127.0, 126.7, 125.8, 124.4, 114.0, 55.5, 33.6. **HRMS (ESI):**Calc'd

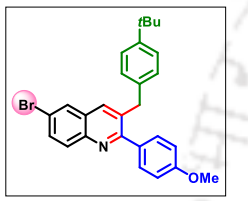


for $C_{21}H_{17}NOS$ [M + H]$^+$: 332.1109, Found: 332.1112.**IR (ATIR, DCM, cm^{-1}):** 3061, 2928, 2835, 1606, 1576, 1511, 1487, 1421, 1289, 1245, 1175, 1034, 1019, 1000, 837, 797, 755, 698, 634, 572, 535, 481.

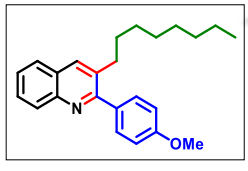
3-benzyl-6-bromo-2-(4-methoxyphenyl) quinoline (4.5ak): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 81% yield (326 mg, 0.81 mmol) as white solid. **^{1}H NMR (600 MHz, Chloroform-*d*)** δ 7.93 (d, *J* = 8.9 Hz, 1H), 7.82 (s, 1H), 7.71 (s, 1H), 7.65 (dd, *J* = 8.9, 2.0 Hz, 1H), 7.39 (d, *J* = 8.6 Hz, 2H), 7.20 – 7.18 (m, 2H), 7.15 -7.13 (m, 1H), 6.94 (d, *J* = 7.4 Hz, 2H), 6.91 (d, *J* = 8.6 Hz, 2H) 4.08 (s, 2H), 3.79 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 160.8, 160.0, 145.2, 139.7, 136.2, 133.8, 132.7, 130.9, 130.4, 129.2, 129.1, 128.7, 128.6, 126.6, 120.3, 113.9, 55.5, 39.2. **HRMS (ESI):** Calc'd for $C_{23}H_{18}BrNO$[M + H]$^+$:404.0650; found = 404.0638. **IR (ATIR, DCM, cm^{-1}):** 3055, 3027, 2934, 1608, 1576, 1547, 1516, 1474, 1453, 1396, 1340, 1264, 1247, 1178, 1072, 1019, 920, 836, 729, 574, 557.



6-bromo-3-(4-(tert-butyl) benzyl)-2-(4-methoxyphenyl) quinoline (4.5al): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 69% yield (317 mg, 0.69 mmol) as white solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.91 (d, *J* = 8.9 Hz, 1H), 7.80 – 7.79 (m, 1H), 7.71 (s, 1H), 7.62 (dd, *J* = 9.0, 2.1 Hz, 1H), 7.39 (d, *J* = 8.7 Hz, 2H), 7.20 – 7.16 (m, 2H), 6.90 – 6.85 (m, 4H), 4.03 (s, 2H), 3.77 (s, 3H), 1.22 (s, 9H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.8, 160.1, 149.4, 145.2, 136.7, 136.2, 134.1, 132.7, 132.6, 130.9, 130.5, 129.2, 128.8, 128.8, 128.6, 125.6, 120.2, 113.9, 55.5, 38.7, 34.5, 31.5. **HRMS (ESI):** Calc'd for $C_{27}H_{26}BrNO$ [M + H]$^+$: 460.1276, Found: 460.1267. **IR (ATIR, DCM, cm^{-1}):** 3057, 3031, 1665, 1614, 1594, 1580, 1493, 1446, 1395, 1311, 1261, 1177, 1148, 1074, 929, 887, 802, 751, 736, 714, 696, 647, 614, 588, 557, 526, 502.



2-(4-methoxyphenyl)-3-octylquinoline (4.5am): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 50% yield (123 mg, 0.50 mmol) as sticky brown liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.10 (d, *J* = 8.4 Hz, 1H), 8.01 (s, 1H), 7.79 (d, *J* = 8.1 Hz, 1H), 7.65 (t, *J* = 7.7 Hz, 1H), 7.52–7.49 (m, 3H), 7.01 (d, *J* = 8.0 Hz, 2H), 3.88 (s, 3H), 2.78 (t, *J* = 7.8 Hz, 2H), 1.56 –1.50 (m, 2H), 1.28 –1.19 (m, 10H), 0.86 (t, *J* = 7.0 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.5, 159.7, 146.6, 135.8, 134.42, 133.7, 130.3, 129.3, 128.8, 127.7, 127.3, 127.0, 126.3, 113.9, 55.5, 33.1, 32.0, 30.7, 29.4, 29.4, 29.3, 22.8, 14.2. **HRMS (ESI):** Calc'd for $C_{24}H_{29}NO$ [M + H]$^+$: 348.2327, Found: 348.2327. **IR (ATIR, DCM, cm^{-1}):** 2923, 2853, 1609, 1511, 1488, 1460, 1420, 1291, 1244, 1173, 1107, 1036, 1001, 834, 755, 480.



3-decyl-2-(4-methoxyphenyl) quinoline (4.5an): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 51% yield (191 mg, 0.51 mmol) as sticky liquid. **^{1}H NMR (600 MHz, Chloroform-*d*)** δ 8.08 (d, *J* = 7.7 Hz, 1H), 7.96 (s, 1H), 7.72 (d, *J* = 8.0 Hz, 1H), 7.59 (t, *J* = 8.1 Hz, 1H), 7.45 – 7.43 (m, 3H), 6.94 (d, *J* = 8.6 Hz, 2H), 3.80 (s, 3H), 2.71 (t, *J* = 7.8 Hz, 2H), 1.49 – 1.44 (m, 2H), 1.23 – 1.12 (m, 14H), 0.80 (t, *J* = 7.0 Hz, 3H).

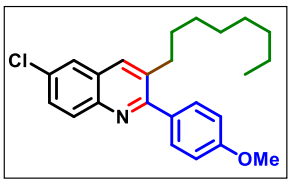
^{13}C NMR (150 MHz, $CDCl_3$) δ 160.3, 159.7, 146.1, 136.2, 134.5, 130.3, 129.0, 129.0, 127.6, 127.0, 126.5, 113.8, 55.5, 33.0, 32.1, 30.7, 29.8 (2 C), 29.7, 29.6, 29.5, 29.4, 22.8, 14.3. **HRMS (ESI):** Calc'd for $C_{26}H_{33}NO$ [M+ H]$^+$: 398.2460, Found: 398.2474. **IR (ATIR, DCM, cm^{-1}):** 2922, 2852, 1608, 1512, 1488, 1459, 1420, 1291, 1244, 1174, 1107, 1037, 1001, 954, 911, 839, 795, 752, 637, 617, 574, 536, 480.

3-dodecyl-2-(4-methoxyphenyl) quinoline (4.5ao): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 51% yield (205 mg, 0.51 mmol) as white solid. **^{1}H NMR (400 MHz, Chloroform-*d*)** δ 8.10 (d, *J* = 8.4 Hz, 1H), 8.00 (s, 1H), 7.78 (d, *J* = 8.0 Hz, 1H), 7.66 – 7.62 (m, 1H), 7.51 – 7.48 (m, 3H), 7.02 – 6.99 (m, 2H), 3.87 (s, 3H), 2.78 (t, *J* = 7.6 Hz,2H), 1.57 – 1.50 (m, 2H), 1.31 -1.20 (m, 18H), 0.87 (t, *J* = 6.6 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.5, 159.7, 146.5, 135.8, 134.4, 133.6, 130.2, 129.3, 128.8, 127.7, 127.0, 126.3, 113.8, 55.5, 33.1, 32.1, 30.7, 29.8, 29.8, 29.7, 29.6, 29.5, 29.4, 29.4, 22.8, 14.3. **HRMS (ESI):** Calc'd for $C_{28}H_{37}NO$ [M + H]$^+$: 404.2953; found = 404.2966.**I R (ATIR, DCM, cm^{-1}):** 2920, 2853, 1608, 1583, 1513, 1497, 1487, 1467, 1420, 1288, 1445, 1174, 1108, 1034, 1001, 839, 821, 790, 755, 724, 617, 477.

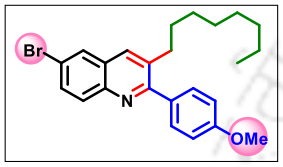
3-hexadecyl-2-(4-methoxyphenyl) quinoline (4.5ap): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 55% yield (252 mg, 0.55 mmol) as white solid.**^{1}H NMR (600 MHz, Chloroform-*d*)** δ 8.10 (d, *J* = 8.4 Hz, 1H), 8.00 (s, 1H), 7.78 (d, *J* = 7.8 Hz, 1H), 7.65 – 7.63 (m, 1H), 7.51 – 7.48 (m, 3H), 7.00 (d, J = 8.7 Hz, 2H), 3.87 (s, 3H), 2.78 (t, *J* = 7.7 Hz, 2H), 1.56 – 1.51 (m, 2H), 1.30 – 1.19 (m, 26H), 0.87 (t, *J* = 6.9 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 160.5, 159.7, 146.6, 135.8, 134.4, 133.7, 130.3, 129.3, 128.81, 127.7, 127.3, 127.0, 126.3, 113.9, 55.5, 33.1, 32.1, 30.7, 29.8, 29.8, 29.8, 29.7, 29.6, 29.5, 29.5, 29.4, 22.8, 14.2. **HRMS (ESI):** Calc'd for$C_{32}H_{45}NO$ [M + H]$^+$: 460.3579; found = 460.3594. **IR (ATIR, DCM, cm^{-1}):** 2915, 2848, 1609, 1585, 1513, 1488, 1465, 1421, 1303, 1246, 1174, 1035, 831, 809, 738, 721, 589, 552.

2-(4-methoxyphenyl)-3-octadecylquinoline (4.5aq): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 57% yield (278 mg, 0.57 mmol) as green solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.10 (d, *J* = 8.4 Hz, 1H), 8.00 (s, 1H), 7.78 (d, *J* = 8.0 Hz, 1H), 7.66 – 7.62 (m, 1H), 7.51 – 7.48 (m, 3H), 7.00 (d, *J* = 8.6 Hz, 2H), 3.87 (s, 3H), 2.91 – 2.66 (t, *J* = 7.6 Hz, 2H), 1.56 – 1.50 (m, 2H), 1.29 – 1.20 (m, 30H), 0.87 (t, *J* = 6.6 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.5, 159.7, 146.6, 135.8, 134.4, 133.7, 130.3, 129.4, 128.8, 127.7, 127.0, 126.3, 113.9, 55.5, 33.1, 32.1, 30.7, 29.8, 29.8, 29.8, 29.6, 29.5, 29.5, 29.4, 22.84, 14.3. **HRMS (ESI):** Calc'd for$C_{34}H_{49}NO$ [M + H]$^+$: 488.3892; found = 488.3878. **IR (ATIR, DCM, cm^{-1}):** 2921, 2851, 1607, 1581, 1513, 1499, 1488, 1462, 1420, 1288, 1445, 1174, 1108, 1034, 1001, 839, 821, 789, 755, 722, 617, 478.

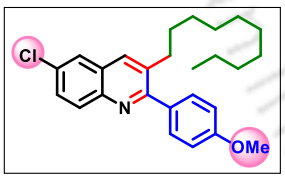
6-chloro-2-(4-methoxyphenyl)-3-octylquinoline (4.5ar): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 47% yield (179 mg, 0.47 mmol) as pale yellow solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.98 (d, *J* = 8.9 Hz, 1H), 7.83 (s, 1H), 7.68 – 7.67 (m, 1H), 7.50 – 7.47 (m, 1H), 7.41 (d, *J* = 8.6 Hz, 2H), 6.93 (d, *J* = 8.6 Hz, 2H), 3.79 (s, 3H), 2.70 (t, *J* = 7.8 Hz, 2H), 1.47 – 1.41 (m, 2H), 1.18 – 1.11 (m, 10H), 0.78 (t, *J* = 6.9 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.7, 159.9, 144.8, 135.5, 134.9, 133.0, 131.9, 130.8, 130.2, 129.7, 128.2, 125.6, 113.9, 55.5, 33.0, 31.9, 30.6, 29.4, 29.3, 29.2, 22.7, 14.2. **HRMS (ESI):**Calc'd for$C_{24}H_{28}ClNO$ [M + H]$^+$: 382.1938, Found: 382.1938. **IR (ATIR, DCM, cm^{-1}):** 2954, 2924, 2853, 1607, 1576, 1550, 1514, 1484, 1474, 1339, 1299, 1245, 1173, 1108, 1037, 1002, 918, 828, 735, 688, 578, 481.



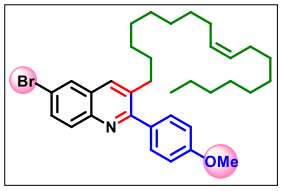
6-bromo-2-(4-methoxyphenyl)-3-octylquinoline (4.5as): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 53% yield (225 mg, 0.53 mmol) as white solid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.92 (d, *J* = 8.9 Hz, 1H), 7.86 – 7.84 (m, 2H), 7.64 – 7.61 (m, 1H), 7.41 (d, *J* = 8.6 Hz, 2H), 6.93 (d, *J* = 8.6 Hz, 2H), 3.78 (s, 3H), 2.71 (t, *J* =8 Hz, 2H), 1.47 – 1.42 (m, 2H), 1.17 – 1.12 (m, 10H), 0.78 (t, *J* = 7.1 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.8, 159.9, 144.9, 135.5, 134.9, 133.0, 132.4, 130.9, 130.3, 129.0, 128.8, 120.2, 113.9, 55.5, 33.1, 31.9, 30.6, 29.4, 29.3, 29.2, 22.8, 14.2. **HRMS (ESI):** Calc'd for.$C_{24}H_{28}BrNO$ [M + H]$^+$: 426.1433, Found: 426.1419. **IR (ATIR, DCM, cm^{-1}):** 2923, 2853, 1606, 1513, 1446, 1373, 1337, 1292, 1245, 1174, 1108, 1058, 1037, 1002, 913, 829, 789, 755, 670, 629, 561, 481.



6-chloro-3-decyl-2-(4-methoxyphenyl) quinoline (4.5at): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 50% yield (205 mg, 0.50 mmol) as white solid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.01 (d, *J* = 8.7 Hz, 1H), 7.86 (s, 1H), 7.70 – 7.69 (m, 1H), 7.52 – 7.49 (m, 1H), 7.42 (d, *J* = 8.5 Hz, 2H), 6.94 (d, *J* = 8.5 Hz, 2H), 3.80 (s, 3H), 2.71 (t, J = 7.7 Hz, 2H), 1.48 – 1.42 (m, 2H), 1.22 – 1.12 (m, 14H), 0.80 (t, *J* = 6.7 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.6, 160.0, 144.6, 135.6, 135.2, 132.1, 130.7, 130.3, 129.9, 128.2, 125.7, 114.0, 55.5, 33.0, 32.0, 30.6, 29.7, 29.6, 29.4, 29.4, 22.8, 14.2. **HRMS (ESI):** Calc'd for$C_{26}H_{32}ClNO$ [M + H]$^+$: 410.2251, Found: 410.2261. **IR (ATIR, DCM, cm^{-1}):** 2923, 2852, 1608, 1577, 1513, 1461, 1419, 1289, 1245, 1173, 1072, 1038, 838, 736, 557.

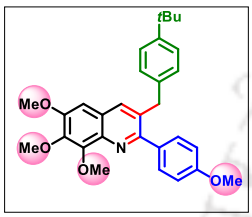


(Z)-6-bromo-2-(4-methoxyphenyl)-3-(octadec-9-en-1-yl) quinoline (4.5au): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 41% yield (231 mg, 0.41 mmol) as white solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.92 (d, *J* = 8.8 Hz, 1H), 7.87 – 7.84 (m, 2H), 7.63 (dd, *J* = 8.9, 2.0 Hz, 1H), 7.41 (d, *J* = 8.6 Hz, 2H), 6.93 (d, *J* = 8.6 Hz, 2H), 5.30 – 5.22 (m, 2H), 3.80 (s, 3H), 2.71 (t, *J* =7.7, 2H), 1.93 – 1.86 (m, 5H), 1.46 – 1.42 (m, 2H), 1.24 – 1.14 (m, 21H), 0.79 (t, *J* = 6.6 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.8, 160.0, 135.5, 135.0, 132.4, 130.9, 130.6, 130.4, 130.3, 130.1, 129.9, 129.0, 128.8, 120.2, 113.9, 55.5, 33.1, 32.7, 32.0, 30.6, 29.9, 29.8, 29.7, 29.6, 29.4, 29.4, 29.3, 27.4, 27.3,



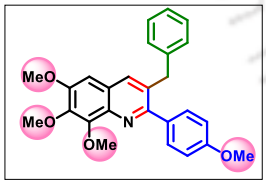
22.8, 14.2. **HRMS (ESI):** Calc'd for$C_{34}H_{46}BrNO$ $[M + H]^+$: 564.2851, Found: 564.2852. **IR (ATIR, DCM, cm^{-1}):** 2922, 2851, 1606, 1576, 1548, 1514, 1484, 1469, 1485, 1388, 1248, 1174, 1108, 1059, 1020, 1038, 826, 670, 481.

2-(4-methoxyphenyl)-8-methyl-3-octylquinoline (4.5av): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 49% yield (177 mg, 0.49 mmol) as white solid. **^{1}H NMR (600 MHz, Chloroform-*d*)** δ 7.89 (s, 1H), 7.54 – 7.50 (m, 3H), 7.41 (d, *J* = 6.8 Hz, 1H), 7.30 (t, *J* = 7.8 Hz, 1H), 6.94 (d, *J* = 8.4 Hz, 2H), 3.80 (s, 3H), 2.74 (t, *J* = 8.0, 2H), 2.72 (s, 3H), 1.48 – 1.43 (m, 2H), 1.18 – 1.10 (m, 10H), 0.78 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 159.6, 158.71, 145.5, 137.2, 136.2, 133.9, 133.8, 130.7, 128.9, 127.4, 126.0, 124.9, 113.3, 55.4, 33.0, 32.0, 30.8, 29.5, 29.4, 29.3, 22.8, 18.2, 14.3. **HRMS (ESI):** Calc'd for.$C_{25}H_{31}NO$ $[M + H]^+$:362.2484, Found: 362.2453. **IR (ATIR, DCM, cm^{-1}):** 2925, 2854, 1677, 1600, 1510, 1462, 1770, 1310, 1256, 1170, 1112, 1031, 834, 604.

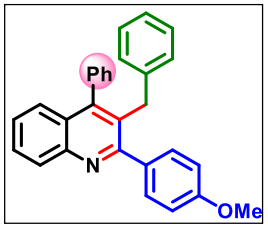


3-(4-(tert-butyl)benzyl)-6,7,8-trimethoxy-2-(4-methoxyphenyl)quinoline (4.5aw): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 64% yield (301 mg, 0.64 mmol) as brown solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.74 (s, 1H), 7.51 (d, *J* = 8.4 Hz, 2H), 7.28 – 7.25 (m, 2H), 6.99 – 6.94 (m, 4H), 6.77 (s, 1H), 4.20 (s, 3H), 4.12 (s, 2H), 4.02 (s, 3H), 3.94 (s, 3H), 3.85 (s, 3H), 1.30 (s, 9H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 159.7, 157.0, 153.1, 149.2, 148.1, 144.0, 138.3, 137.6, 136.1, 133.8, 132.0, 130.9, 128.8, 125.5, 125.0, 113.6, 100.5, 62.3, 61.6, 56.1, 55.5, 38.6, 34.5, 31.5. **HRMS (ESI):** Calc'd for$C_{30}H_{33}NO_4$ $[M + H]^+$: 472.2488, Found: 472.2490. **IR (ATIR, DCM, cm^{-1}):** 2948, 2831, 1609, 1557, 1514, 1484, 1460, 1414, 1378, 1361, 1290, 1241, 1203, 1157, 1110, 1037, 1000, 958, 911, 802, 762, 695, 567, 509.

3-benzyl-6,7, 8-trimethoxy-2-(4-methoxyphenyl)quinoline (4.5ax): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 57% yield (236 mg, 0.57 mmol) as brown solid. **^{1}H NMR (600 MHz, Chloroform-*d*)** δ 7.72 (s, 1H), 7.51 (d, *J* = 7.8 Hz, 2H), 7.27 – 7.24 (m, 2H), 7.19 (t, *J* = 7.2 Hz, 1H), 7.05 (d, *J* = 7.4 Hz, 2H), 6.95 (d, *J* = 7.8 Hz, 2H), 6.77 (s, 1H), 4.21 (s, 3H), 4.15 (s, 2H), 4.02 (s, 3H), 3.94 (s, 3H), 3.85 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 159.6, 156.8, 153.1, 147.9, 144.0, 140.5, 138.1, 136.2, 133.4, 131.8, 130.8, 129.1, 128.6, 126.3, 124.9, 113.6, 100.4, 62.3, 61.6, 56.0, 55.4, 39.1. **HRMS (ESI):** Calc'd for$C_{30}H_{33}NO_4$ $[M + Na]^+$: 494.2307, Found, 494.2331. **IR (ATIR, DCM, cm^{-1}):** 2950, 2834, 1610, 1555, 1513, 1478, 1461, 1419, 1377, 1362, 1294, 1243, 1203, 1154, 1110, 1039, 1000, 958, 911, 803, 762, 693, 561, 502.

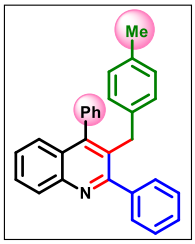


3-benzyl-2-(4-methoxyphenyl)-4-phenylquinoline (4.5ay): Purification by column chromatography (SiO_2, 100 – 200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 61% yield (245 mg, 0.61 mmol) as white solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.11 (d, *J* = 8.4 Hz, 1H), 7.60 – 7.56 (m, 1H), 7.30 – 7.26 (m, 7H), 7.10 – 7.08 (m, 2H), 6.93 – 6.92 (m, 3H), 6.78 (d, *J* = 8.4 Hz, 2H), 6.5 – 6.51 (m, 2H), 3.90 (s, 2H), 3.72 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 161.3, 159.6, 148.9, 146.7, 141.0, 137.2, 134.0,

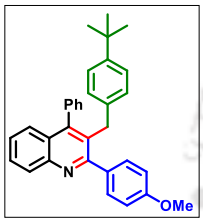


130.2, 129.8, 129.5, 129.5, 129.1, 128.4, 128.4, 128.0, 127.9, 127.4, 126.4, 126.4, 125.6, 113.7, 55.5, 36.3. **HRMS (ESI):** Calc'd for.$C_{29}H_{23}NO$ $[M + H]^+$: 402.1858, Found: 402.1859. **IR (ATIR, DCM, cm^{-1}):** 3474, 3346, 3055, 1614, 1578, 1547, 1480, 1445, 1291, 1246, 1158, 1073, 936, 919, 751, 697, 642, 612, 526, 481.

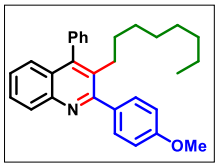
3-(4-methylbenzyl)-2,4-diphenylquinoline (4.5az): Purification by column chromatography (SiO_2, 100 – 200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 67% yield (245 mg, 0.67 mmol) as brown liquid. **^{1}H NMR (400 MHz, Chloroform-*d*)** δ 8.12 (d, *J* = 8.4 Hz, 1H), 7.62 – 7.58 (m, 1H), 7.35 – 7.30 (m, 7H), 7.27 – 7.23 (m, 3H), 7.14 – 7.11 (m, 2H), 6.73 (d, *J* = 7.9 Hz, 2H), 6.38 (d, *J* = 7.9 Hz, 2H), 3.89 (s, 2H), 2.13 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 161.7, 148.8, 146.6, 141.4, 137.7, 137.1, 135.0, 129.9, 129.6, 129.1, 128.8, 128.6, 128.4, 128.4, 128.2, 128.2, 128.0, 127.9, 127.5, 126.5, 126.5, 35.8, 21.0. **HRMS (ESI):** Calc'd for $C_{29}H_{23}N$ $[M + H]^+$: 386.1909, Found: 386.1920.



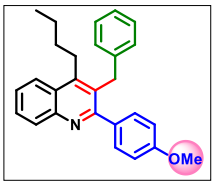
3-(4-(tert-butyl) benzyl)-2-(4-methoxyphenyl)-4-phenylquinoline (4.5aaa): Purification by column chromatography (SiO_2, 100 – 200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 72% yield (329 mg, 0.72 mmol) as white solid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.15 (d, *J* = 7.6 Hz, 1H), 7.60 (t, *J* = 7.1 Hz, 1H), 7.33 – 7.29 (m, 5H), 7.26 (d *J* = 8.5 Hz, 2H), 7.10 – 7.08 (m, 2H), 6.93 (d, *J* = 8.1 Hz, 2H), 6.41 (d, *J* = 8.1 Hz, 2H), 3.92 (s, 2H), 3.75 (s, 3H), 1.15 (s, 9H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 161.2, 159.7, 148.5, 137.9, 137.2, 130.5, 130.3, 129.6, 129.1, 128.4, 128.1, 127.9, 127.5, 126.4, 126.4, 124.8, 113.7, 55.5, 35.9, 34.4, 31.5. **HRMS (ESI):** Calc'd for $C_{33}H_{31}NO$ $[M + H]^+$: 458.2484, Found: 458.2488. **IR (ATIR, DCM, cm^{-1}):** 3059, 2658, 2867, 1607, 1572, 1547, 1513, 1484, 1463, 1442, 1394, 1352, 1289, 1247, 1175, 1108, 1073, 1029, 1005, 964, 912, 828, 764, 742, 702, 615, 606, 547, 455.



2-(4-methoxyphenyl)-3-octyl-4-phenylquinoline (4.5aab): Purification by column chromatography (SiO_2, 100 – 200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 39% yield (165 mg, 0.39 mmol) as white solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.07 (d, *J* = 8.4 Hz, 1H), 7.54 (t, *J* = 7.5 Hz, 1H), 7.45 – 7.38 (m, 5H), 7.27 (t, *J* = 8.1 Hz, 1H), 7.24 – 7.22 (m, 3H), 6.93 (d, *J* = 8.5 Hz, 2H), 3.80 (s, 3H), 2.50 – 2.47 (m, 2H), 1.14 – 1.05 (m, 4H), 1.02 – 0.96 (m, 2H), 0.93 – 0.88 (m, 2H), 0.81 – 0.79 (m, 4H), 0.75 (t, *J* = 7.3 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 161.0, 159.6, 147.6, 146.1, 137.7, 134.4, 132.4, 130.2, 129.7, 129.4, 128.6, 128.5, 127.7, 127.5, 126.2, 126.2, 113.8, 55.5, 31.8, 30.4, 30.3, 29.5, 28.9, 28.7, 22.7, 14.2. **HRMS (ESI):** Calc'd for$C_{30}H_{33}NO$ $[M + H]^+$: 424.2640, Found: 424.2630.

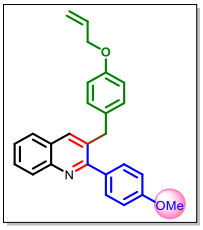


3-benzyl-4-butyl-2-(4-methoxyphenyl)quinoline (4.5aac): Purification by column chromatography (SiO_2, 100 – 200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 46% yield (175 mg, 0.46 mmol) as White solid. **^{1}H NMR (600 MHz, Chloroform-*d*)** δ 8.17 (d, *J* = 8.1 Hz, 1H), 8.03 (d, *J* = 8.4 Hz, 1H), 7.68 (t, *J* = 7.5 Hz, 1H), 7.55 (t, *J* = 7.5 Hz, 1H), 7.33 (d, *J* = 7.6 Hz, 2H), 7.21 (t, *J* = 7.2 Hz, 2H), 7.16 (t, *J* = 7.0 Hz, 1H), 6.95 (d, *J* = 7.4 Hz, 2H), 6.87 (d, *J* = 7.7 Hz, 2H), 4.23 (s, 2H), 3.81 (s, 3H), 3.03 – 3.00 (m, 2H), 1.55 – 1.50 (m, 2H), 1.46 – 1.40 (m, 2H),



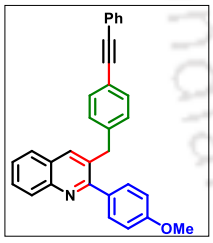
0.90 (t, *J* = 7.1 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 161.3, 159.6, 148.3, 146.9, 140.8, 134.2, 130.4, 130.1, 128.8, 128.8, 128.6, 128.2, 126.8, 126.3, 126.1, 123.8, 113.7, 55.5, 35.7, 32.7, 29.0, 23.5, 14.0. **HRMS (ESI):** Calc'd for $C_{27}H_{27}NO$ $[M + Na]^+$: 404.1990, Found: 404.1984. **IR (ATIR, DCM, cm^{-1}):** 3026, 2956, 2928, 2866, 1669, 1605, 1577, 1509, 1454, 1376, 1347, 1293, 1246, 1177, 1107, 1030, 867, 834, 743, 699, 623, 575, 523, 464.

3-(4-(allyloxy) benzyl)-2-(4-methoxyphenyl) quinoline (4.5aad): Purification by column chromatography (SiO_2, 100 – 200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 43% yield (164 mg, 0.43 mmol) as White cryatalline solid.



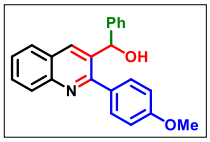
^{1}H NMR (500 MHz, $CDCl_3$) δ 8.12 (d, *J* = 8.4 Hz, 1H), 7.88 (s, 1H), 7.73 (d, *J* = 8.2 Hz, 1H), 7.66 (t, *J* = 7.7 Hz, 1H), 7.49 (t, *J* = 7.5 Hz, 1H), 7.44 (d, *J* = 8.7 Hz, 1H), 6.97 (d, *J* = 8.6 Hz, 1H), 6.92 (d, *J* = 8.5 Hz, 1H), 6.80 (d, *J* = 8.6 Hz, 1H), 6.08 – 6.01 (m, 1H), 5.40 (d, *J* = 17.2 Hz, 1H), 5.27 (d, *J* = 10.6 Hz, 1H), 4.50 (d, *J* = 5.3 Hz, 1H), 4.08 (s, 2H), 3.86 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 160.5, 159.8, 157.2, 146.8, 137.0, 133.5, 133.4, 133.1, 132.5, 130.4, 130.1, 129.3, 129.1, 127.6, 127.2, 126.4, 117.8, 114.9, 113.9, 69.0, 55.5, 38.5. **HRMS (ESI):** Calc'd for $C_{26}H_{23}NO_2$ $[M + H]^+$: 382.1807, Found: 382.1765. **IR (ATIR, DCM, in cm^{-1}):** 2924, 2837, 1607, 1508, 1487, 1458, 1418, 1294, 1241, 1175, 1108, 1022, 999, 926, 834, 798, 754, 617, 568, 532, 481.

2-(4-methoxyphenyl)-3-(4-(phenylethynyl) benzyl) quinoline (4.5aae): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 20%) afforded the title compound in 36% yield (153 mg, 0.36 mmol) as brown solid.

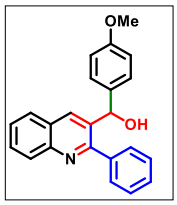


^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.13 (d, *J* = 8.4 Hz, 1H), 7.90 (s, 1H), 7.74 (d, *J* = 8.0 Hz, 1H), 7.67 (t, *J* = 8.2 Hz, 1H), 7.52 – 7.50 (m, 3H), 7.43 –7.40 (m, 4H), 7.34 – 7.31 (m, 3H), 6.98 (d, *J* = 8.1, 2H),6.96 (d, *J* = 8.7, 2H), 4.16 (s, 2H), 3.85 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 160.5, 159.9, 146.9, 140.6, 137.2, 133.2, 132.2, 131.9, 131.7, 130.3, 129.4, 129.3, 129.1, 128.5, 128.3, 127.5, 127.2, 126.5, 123.4, 121.3, 113.9, 89.4, 89.4, 55.5, 39.3. **HRMS (ESI):** Calc'd for $C_{31}H_{23}NO$ $[M + H]^+$: 426.1858; found = 426.1841. **IR (ATIR, DCM, cm^{-1}):** 2928, 2835, 1608, 1512, 1485, 1417, 1247, 1176, 1116, 1041, 839, 755, 690.

(2-(4-methoxyphenyl)quinolin-3-yl)(phenyl) methanol (4.9a): Purification by column chromatography (SiO_2, 100 – 200 mesh, eluent: AcOEt/ petroleum ether 10% to 25%) afforded the title compound in 90% yield (61 mg, 0.18 mmol) as white solid. Reaction is carried out in 0.2 mmol scale.



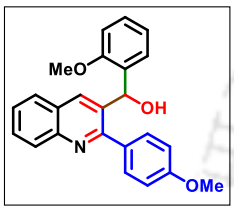
^{1}H NMR (600 MHz, DMSO-d_6) δ 8.45 (s, 1H), 8.0 (d, *J* = 7.9 Hz, 1H), 7.98 (d, *J* = 8.5 Hz, 1H), 7.73 (t, *J* = 8.3 Hz, 1H), 7.57 (t, *J* = 7.5 Hz, 1H), 7.44 (d, *J* = 8.7 Hz, 2H), 7.21 (t, *J* = 7.4 Hz, 2H), 7.16 (t, *J* = 7.3 Hz, 1H), 7.05 (d, *J* = 7.3 Hz, 2H), 7.02 (d, *J* = 8.6 Hz, 2H) 6.15 (d, *J* = 4.4 Hz, 1H), 6.03 (d, *J* = 4.3 Hz, 1H), 3.83 (s, 3H). **^{13}C NMR (150 MHz, DMSO-d6)** δ 159.3, 158.4, 146.4, 144.4, 137.0, 135.0, 133.5, 130.5, 129.6, 128.6, 128.1, 127.9, 126.9, 126.6, 126.5, 113.5, 70.7, 55.3, 55.2. **HRMS (ESI):** Calc'd for $C_{23}H_{19}NO_2$ $[M + H]^+$: 342.1494; found = 342.1487. **IR (ATIR, DCM, cm^{-1}):** 3392, 3060, 2836, 1608, 1515, 1490, 1453, 1421, 1289, 1246, 1176, 1155, 1035, 845, 757, 699, 482.

(4-methoxyphenyl)(2-phenylquinolin-3-yl) methanol (4.9b): Purification by column chromatography (SiO_2, 100 – 200 mesh, eluent: AcOEt/ petroleum ether 10% to 25%) afforded the title compound in 84% yield (57 mg, 0.17 mmol) as white solid. Reaction is carried out in 0.2 mmol scale. 

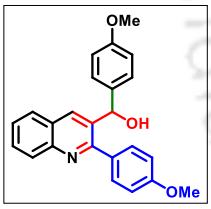
^{1}H NMR (500 MHz, DMSO-d_6) δ 8.52 (s, 1H), 8.05 (d, *J* = 8.2 Hz, 1H), 7.99 (d, *J* = 8.4 Hz, 1H), 7.75 (t, *J* = 8.3 Hz, 1H), 7.61 (t, *J* = 7.5 Hz, 1H), 7.47 – 7.42 (m, 5H), 6.90 (d, *J* = 8.6 Hz, 2H), 6.75 (d, *J* = 8.7 Hz, 2H), 6.03 (d, *J* = 3.8 Hz, 1H), 5.92 (d, *J* = 3.1 Hz, 1H), 3.67 (s, 3H). **^{13}C NMR (125 MHz, DMSO-d_6)** δ 158.7, 158.2, 146.3, 140.2, 137.2, 136.3, 134.5, 129.6, 128.9, 128.6, 128.1, 128.0, 127.9, 127.9, 127.1, 126.7, 113.4, 70.3, 55.0. **HRMS (ESI):** Calc'd for $C_{23}H_{19}NO_2$ $[M+H]^+$: 342.1494; found = 342.1508.

(2-methoxyphenyl)(2-(4-methoxyphenyl) quinolin-3-yl) methanol (4.9c): Purification by column chromatography (SiO_2, 100 – 200 mesh, eluent: AcOEt/ petroleum ether 10% to 25%) afforded the title compound in 80% yield (59 mg, 0.16 mmol) as white solid. Reaction is carried out in 0.2 mmol scale.

^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.29 (s, 1H), 8.13 (d, *J* = 8.5 Hz, 1H), 7.80 (d, *J* = 8.1 Hz, 1H), 7.68 (t, *J* = 7.7 Hz, 1H), 7.50 (t, *J* = 7.5 Hz, 1H), 7.41 (d, *J* = 8.7 Hz, 2H), 7.23 (d, *J* = 7.6 Hz, 1H), 7.14 (d, *J* = 7.5 Hz, 1H), 6.90 – 6.88 (m, 3H), 6.79 (d, *J* = 8.2 Hz, 1H), 6.34 (s, 1H), 3.82 (s, 3H), 3.64 (s, 3H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 159.7, 159.56, 156.6, 147.2, 135.3, 134.9, 132.9, 131.6, 130.4, 129.6, 129.2, 129.0, 127.8, 127.8, 127.4, 126.4, 120.7, 113.7, 110.6, 68.2, 55.5, 55.3. **HRMS (ESI):** Calc'd for.$C_{24}H_{21}NO_3$ $[M+H]^+$: 372.1600; found = 372.1603.

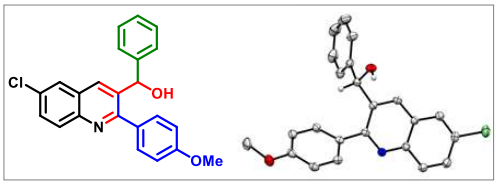


(4-methoxyphenyl)(2-(4-methoxyphenyl) quinolin-3-yl)methanol (4.9d): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 10% to 25%) afforded the title compound in 95% yield (71 mg, 0.19 mmol) as white solid. Reaction is carried out in 0.2 mmol scale. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.39 (s, 1H), 8.04 (d, *J* = 8.9 Hz, 1H), 7.85 (s, 1H), 7.63 – 7.61 (m, 1H), 7.28 – 7.26 (m, 3H), 6.98 (d, *J* = 8.1 Hz, 2H), 6.91 (d, *J* = 7.8 Hz, 2H), 6.76 (d, *J* = 8.1 Hz, 2H), 6.05 (s, 1H), 3.85 (s, 3H), 3.77 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.1, 159.4, 159.4, 145.5, 136.7, 134.9, 133.7, 132.4, 132.3, 130.9, 130.6, 130.3, 128.6, 128.0, 126.5, 114.0, 113.9, 72.4, 55.5, 55.4. **HRMS (ESI):** Calc'd for $C_{24}H_{21}NO_3$ $[M+H]^+$: 372.1600; found = 372.1593.

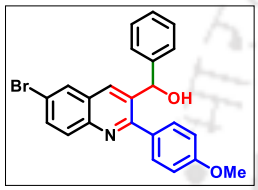


Benzo[d][1,3]dioxol-5-yl(2-(4-methoxyphenyl)quinolin-3-yl)methanol (4.9e): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 10% to 25%) afforded the title compound in 85% yield (66 mg, 0.17 mmol) as brown sticky liquid. Reaction is carried out in 0.2 mmol scale. **^{1}H NMR (500 MHz, DMSO-d_6)** δ 8.45 (s, 1H), 8.02 (d, *J* = 8.1 Hz, 1H), 7.97 (d, *J* = 8.4 Hz, 1H), 7.73 (t, *J* = 7.6 Hz, 1H), 7.58 (t, *J* = 7.2, 1H), 7.43 (d, *J* = 8.6 Hz, 2H), 7.03 (d, *J* = 8.6 Hz, 2H), 6.71 (d, *J* = 8 Hz, 1H) 6.63 – 6.62 (m, 1H), 6.40 (dd, *J* = 8.0, 1.1 Hz, 1H), 6.05 (d, *J* = 4.3 Hz, 1H), 5.93 – 5.92 (m, 3H), 3.89 (s, 3H). **^{13}C NMR (125 MHz, DMSO-d_6)** δ 159.3, 158.3, 147.1, 146.3, 146.0, 138.5, 137.1, 134.7, 132.5, 130.4, 129.6, 128.5, 127.9, 126.9, 126.4, 119.9, 113.5, 107.7, 107.0, 100.8, 70.4, 55.2. **HRMS (ESI):** Calc'd for $C_{24}H_{19}NO_4$ $[M+H]^+$: 386.1392; found = 386.1373.

(6-chloro-2-(4-methoxyphenyl)quinolin-3-yl)(phenyl) methanol (4.9f): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 10% to 25%) afforded the title compound in 75% yield (56 mg, 0.15 mmol) as white solid. Reaction is carried out in 0.2 mmol scale. **^{1}H NMR (500 MHz, DMSO-d6)** δ 8.50 (s, 1H), 8.20 – 8.19 (m, 1H), 7.99 (d, *J* = 8.9 Hz, 1H), 7.73 (dd, *J* = 8.9, 2.2 Hz, 1H), 7.43 (d, *J* = 8.5 Hz, 2H), 7.22 – 7.14 (m, 3H), 7.02 (d, *J* = 8.3 Hz, 4H), 6.18 (d, *J* = 4.1 Hz, 1H), 6.03 (d, *J* = 4.1 Hz, 1H), 3.82 (s, 3H).**^{13}C NMR (125 MHz, DMSO-d6)** δ 159.4, 158.7, 144.7, 144.1, 138.1, 134.2, 132.1, 130.7, 130.6, 130.4, 130.1, 128.0, 127.7, 126.9, 126.6, 126.5, 113.5, 70.6, 55.2. **HRMS (ESI):** Calc'd for $C_{23}H_{18}ClNO_2$ $[M + H]^+$: 376.1104; found = 376.1106. **IR (ATIR, DCM, cm^{-1}):** 3063, 2926, 2852, 1619, 1606, 1514, 1493, 1477, 1453, 1438, 1345, 1248, 1176, 1109, 1076, 1028, 1004, 831, 699.

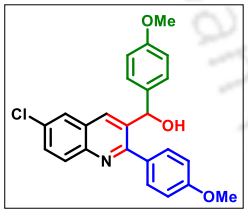


(6-bromo-2-(4-methoxyphenyl)quinolin-3-yl)(phenyl) methanol (4.9g): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 10% to 25%) afforded the title compound in 78% yield (66 mg, 0.156 mmol) as brown solid. Reaction is carried out in 0.2 mmol scale**.**



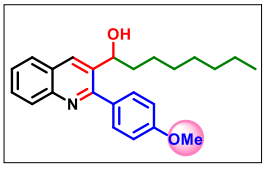
^{1}H NMR (500 MHz, DMSO-d$_6$) δ 8.5 (s, 1H), 8.34 – 8.33 (m, 1H), 7.91 (d, *J* = 8.9 Hz, 1H), 7.85 – 7.82 (m, 1H), 7.42 (d, *J* = 8.5 Hz, 2H), 7.21 – 7.14 (m, 3H), 7.02 – 7.00 (m, 4H), 6.18 (d, *J* = 4.1 Hz, 1H), 6.02 (d, *J* = 4.1 Hz, 1H), 3.82 (s, 3H). **^{13}C NMR (125 MHz, DMSO-d$_6$)** δ 164.6, 164.2, 150.1, 149.3, 143.3, 139.4, 137.8, 137.4, 136.0, 135.6, 135.1, 133.5, 133.3, 132.2, 131.8, 124.6, 118.7, 75.8, 60.5. **HRMS (ESI):** Calc'd for $C_{23}H_{18}BrNO_2$ $[M +H]^+$: 422.0579; found = 422.0553.

(6-chloro-2-(4-methoxyphenyl) quinolin-3-yl)(4-methoxyphenyl) methanol (4.9h):



Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 10% to 25%) afforded the title compound in 88% yield (72 mg, 0.176 mmol) as yellow solid. Reaction is carried out in 0.2 mmol scale. **^{1}H NMR (500 MHz, DMSO-*d*$_6$)** δ 8.52 (s, 1H), 8.20 – 8.19 (m, 1H), 7.99 (d, *J* = 9.0 Hz, 1H), 7.73 (dd, *J* = 9.0, 2.2 Hz, 1H), 7.40 (d, *J* = 8.5 Hz, 2H), 7.02 (d, *J* = 8.6 Hz, 2H), 6.93 (d, *J* = 8.6 Hz, 2H), 6.77 (d, *J* = 8.6 Hz, 2H), 6.06 (d, *J* = 4.1 Hz, 1H), 5.96 (d, *J* = 4.1 Hz, 1H), 3.83 (s, 3H), 3.68 (s, 3H). **^{13}C NMR (125 MHz, CDCl$_3$)** δ 159.9, 159.4, 159.3, 145.4, 136.9, 135.0, 133.8, 132.3, 132.2, 130.8, 130.6, 130.3, 128.5, 128.0, 126.5, 114.0, 113.8, 72.2, 55.5, 55.4. **HRMS (ESI):** Calc'd for $C_{24}H_{20}ClNO_3$ $[M +H]^+$: 406.1210; found = 406.1201. **IR (ATIR, DCM, cm^{-1}):** 3310, 1608, 1578, 1510, 1478, 1348, 1248, 1176, 1073, 1034, 1017, 935, 831, 788, 690, 639, 580, 565.

1-(2-(4-methoxyphenyl)quinolin-3-yl)octan-1-ol (4.9i): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 10% to 25%) afforded the title compound in 54% yield (39 mg, 0.11 mmol) as yellow liquid. Reaction is carried out in 0.2 mmol scale. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.38 (s, 1H), 8.11 (d, *J* = 8.5 Hz, 1H), 7.85 (d, *J* = 8.1 Hz, 1H), 7.69 (t, *J* = 7.7 Hz, 1H), 7.53 (t, *J* = 7.5 Hz, 1H), 7.45–7.43 (m, 2H), 6.98 – 6.96 (m, 2H), 5.02 (t, *J* = 6.2 Hz, 1H), 3.86 (s, 3H), 1.70 –1.66 (m, 2H), 1.33–1.10 (m, 10H), 0.85 (t, *J* = 7.1 Hz, 3H). **^{13}C NMR (125**

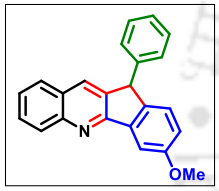


MHz, $CDCl_3$) δ 159.9, 158.8, 147.1, 136.9, 133.9, 132.8, 130.4, 129.6, 129.3, 127.7, 127.6, 126.5, 114.0, 70.2, 55.5, 38.9, 31.9, 29.3, 29.2, 26.0, 22.7, 14.2. **HRMS (ESI):** Calc'd for $C_{26}H_{33}NO_2$ $[M + H]^+$: 364.2277; found = 364.2275.

1-(2-(4-methoxyphenyl) quinolin-3-yl)octadecan-1-ol (4.9i): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 10% to 25%) afforded the title compound in 65% yield (65 mg, 0.13 mmol) as white solid. Reaction is carried out in 0.2 mmol scale.

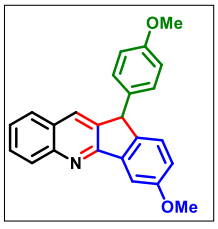
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.37 (s, 1H), 8.11 (d, *J* = 8.4 Hz, 1H), 7.83 (d, *J* = 8.1 Hz, 1H), 7.68 (t, *J* = 7.7 Hz, 1H), 7.53 (t, *J* = 7.5 Hz, 1H), 7.42 – 7.39 (m, 2H), 6.96 – 6.93 (m, 2H), 5.00 (t, *J* = 6.0 Hz, 1H), 3.85 (s, 3H), 1.69 – 1.64 (m, 2H), 1.32 – 1.14 (m, 30H), 0.88 (t, *J* = 6.9 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 159.8, 158.8, 147.1, 137.0, 133.9, 132.7, 130.4, 129.6, 129.2, 127.7, 127.6, 126.5, 113.9, 70.1, 55.5, 38.9, 32.1, 29.8(7C), 29.7, 29.7, 29.6, 29.5, 29.3, 26.0, 22.8, 14.2. **HRMS (ESI):** Calc'd for $C_{34}H_{49}NO_2$ $[M + H]^+$:504.3842; found = 504.3841.

3-methoxy-11-phenyl-11H-indeno [1,2-b]quinoline (4.10a): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 10%) afforded the title compound in 92% yield (30 mg, 0.092 mmol) as white solid. Reaction is carried out in 0.1 mmol scale.



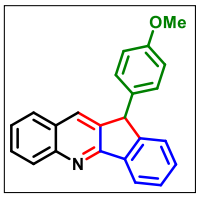
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.22 (d, *J* = 8.5 Hz, 1H), 8.16 (d, *J* = 8.4 Hz, 1H), 7.89 (s, 1H), 7.70 – 7.65 (m, 2H), 7.44 (t, *J* = 7.4 Hz, 1H), 7.32 – 7.27 (m, 3H), 7.15 (d, *J* = 6.9 Hz, 2H), 7.07 (dd, *J* = 8.5, 2.0 Hz, 1H), 6.88 (s, 1H), 5.17 (s, 1H), 3.83 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 162.3, 161.2, 151.8, 148.5, 141.3, 139.8, 132.7, 131.4, 129.2, 129.1, 128.9, 128.5, 128.1, 127.4, 127.4, 125.5, 123.3, 115.1, 110.6, 55.7, 51.8. **HRMS (ESI):** Calc'd for $C_{23}H_{17}NO$ $[M + H]^+$:324.1388; found = 324.1388. **IR (ATIR, DCM, cm^{-1}):** 3034, 2928, 2837, 1726, 1608, 1585, 1555, 1510, 1498, 1460, 1431, 1394, 1384, 1350, 1247, 1177, 1094, 1074, 1031, 924, 827, 735, 687, 577, 481.

3-methoxy-11-(4-methoxyphenyl)-11H-indeno [1,2-b]quinoline (4.10b): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 10% to 25%) afforded the title compound in 89% yield (32 mg, 0.091 mmol) as yellow solid. Reaction is carried out in 0.1 mmol scale.



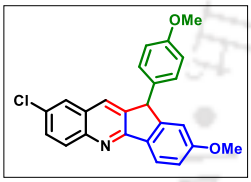
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.18 (d, *J* = 8.5 Hz, 1H), 8.08 (d, *J* = 9.0 Hz, 1H), 7.77 (s, 1H), 7.67 – 7.66 (m, 1H), 7.59 (dd, *J* = 9.0, 2.2 Hz, 1H), 7.07 – 7.04 (m, 4H), 6.86 – 6.83 (m, 3H), 5.11 (s, 1H), 3.83 (s, 3H), 3.79 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 162.6, 161.5, 159.0, 152.2, 146.8, 141.1, 132.8, 132.2, 130.9, 130.4, 130.3, 129.8, 129.4, 128.0, 126.8, 123.3, 115.2, 114.5, 110.4, 55.7, 55.4, 51.0. **HRMS (ESI):** Calc'd for $C_{23}H_{17}NO$ $[M + H]^+$: 354.1494; found = 354.1504. **IR (ATIR, DCM, cm^{-1}):** 2963, 2926, 2856, 1718, 1606, 1491, 1464, 1399, 1274, 1243, 1109, 1089, 1030, 815, 755, 543, 481, 416.

11-(4-methoxyphenyl)-11H-indeno[1,2-b]quinoline (4.10c): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 10%) afforded the title compound in 81% yield (26 mg, 0.081 mmol) as white solid. Reaction is carried out in 0.1 mmol scale. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.31 (d, *J* = 7.6 Hz, 1H), 8.21 (d, *J* = 8.4 Hz, 1H), 7.97 (s, 1H), 7.74 (d, *J* = 8.1 Hz, 1H), 7.69 (t, *J* = 7.6 Hz, 1H), 7.53 – 7.44 (m, 3H), 7.38 (d, *J* = 7.5 Hz, 1H), 7.06 (d, *J* = 8.4 Hz, 2H), 6.84 (d, *J* = 8.4 Hz, 2H), 5.20 (s, 1H), 3.78 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 161.3, 159.0, 150.0, 148.5, 140.1, 139.8, 133.2, 131.8, 130.7, 129.5, 129.3, 129.2, 128.2, 128.1, 127.9, 125.9, 125.8, 122.1, 114.5, 55.4, 51.1. **HRMS (ESI):** Calc'd for $C_{23}H_{17}NO$ $[M+H]^+$:324.1388; found = 324.139. **IR (ATIR, DCM, cm^{-1}):** 3032, 2925, 2836, 1720, 1608, 1584, 1553, 1509, 1497, 1462, 1438, 1396, 1380, 1349, 1248, 1173, 1092, 1076, 1033, 922, 826, 736, 685, 578, 482.



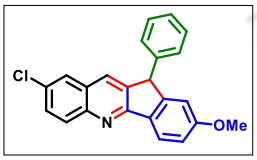
8-chloro-2-methoxy-11-(4-methoxyphenyl)-11H-indeno [1,2-b]quinoline (4.10d): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 10% to 25%) afforded the title compound in 83% yield (32 mg, 0.083 mmol) as yellow solid. Reaction is carried out in 0.1 mmol scale.

^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.18 (d, *J* = 8.5 Hz, 1H), 8.07 (d, *J* = 9.0 Hz, 1H), 7.77 (s, 1H), 7.66 – 7.65 (m, 1H), 7.59 (dd, *J* = 9.0, 2.3 Hz, 1H), 7.06 – 7.03 (m, 3H), 6.86 – 6.83 (m, 3H), 5.10 (s, 1H), 3.82 (s, 3H), 3.79 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 162.6, 161.5, 159.0, 152.2, 146.8, 141.0, 132.8, 132.2, 130.9, 130.4, 130.3, 129.8, 129.4, 128.0, 126.8, 123.3, 115.24, 114.5, 110.4, 55.7, 55.4, 51.0. **HRMS (ESI):** Calc'd for $C_{24}H_{18}ClNO_2$ $[M+H]^+$:388.1104; found = 388.1122.



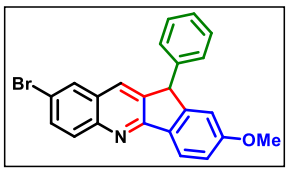
8-chloro-2-methoxy-11-phenyl-11H-indeno [1,2-b]quinoline (4.10e): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 10% to 25%) afforded the title compound in 74% yield (27 mg, 0.074 mmol) as yellow solid. Reaction is carried out in 0.1 mmol scale.

^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.19 (d, *J* = 8.5 Hz, 1H), 8.08 (d, *J* = 8.9 Hz, 1H), 7.79 (s, 1H), 7.67 – 7.66 (m, 1H), 7.60 (dd, *J* = 8.9, 2.3 Hz, 1H), 7.33– 7.27 (m, 3H), 7.14 – 7.12 (m, 2H), 7.07 (dd, *J* = 8.5, 2.1 Hz, 1H), 6.88 – 6.87 (m, 1H), 5.17 (s, 1H), 3.83 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 162.6, 161.5, 151.8, 146.9, 140.9, 140.7, 132.4, 131.0, 130.4, 130.4, 129.9, 129.1, 128.4, 128.0, 127.5, 126.8, 123.4, 115.3, 110.6, 55.7, 51.8. **HRMS (ESI):** Calc'd for $C_{23}H_{16}ClNO$ $[M+H]^+$:358.0999; found = 358.0994. **IR (ATIR, DCM, cm^{-1}):** 3027, 2924, 1852, 1732, 1608, 1563, 1495, 1453, 1441, 1438, 1396, 1379, 1349, 1322, 1267, 1189, 1134, 1108, 1092, 1076, 1035, 923, 827, 798, 733, 699, 669, 553, 430.



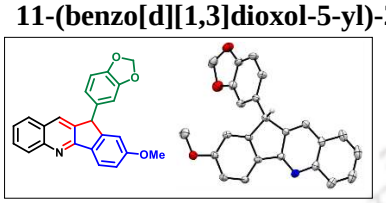
8-bromo-2-methoxy-11-phenyl-11H-indeno [1,2-b]quinoline (4.10f): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 80% yield (32 mg, 0.080 mmol) as white solid. Reaction is carried out in 0.1 mmol scale.

^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.19 (d, *J* = 8.5 Hz, 1H), 8.01 (d, *J* = 8.9 Hz, 1H), 7.86 - 7.84 (m, 1H), 7.78 (s, 1H), 7.72 (dd, *J* = 8.9, 2.2 Hz, 1H), 7.32 – 7.28 (m, 3H), 7.13 (d, *J*= 7.1 Hz, 2H), 7.07 (dd, *J* = 8.5, 2.1 Hz, 1H), 6.88 – 6.87 (m, 1H), 5.17 (s, 1H), 3.83 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 162.6, 161.6, 151.9, 147.2, 140.9, 140.7, 132.4, 132.4, 130.6, 130.3, 130.1, 129.1, 128.5, 128.4, 127.5, 123.4, 119.0, 115.3, 110.6, 55.7, 51.8.

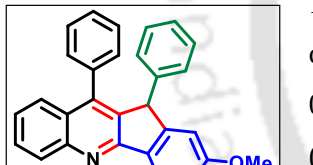


HRMS (ESI): Calc'd for $C_{23}H_{16}BrNO$ $[M+H]^+$: 402.0494; found = 402.0482.

11-(benzo[d][1,3]dioxol-5-yl)-2-methoxy-11H-indeno[1,2-b]quinoline (4.10g): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 10% to 25%) afforded the title compound in 77% yield (29 mg, 0.077 mmol) as white solid. Reaction is carried out in 0.1 mmol scale. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.20 (d, *J* = 8.4 Hz, 1H), 8.15 (d, *J* = 8.4 Hz, 1H), 7.89 (s, 1H), 7.71 (d, *J* = 7.9 Hz, 1H), 7.67 (t, *J* = 7.4 Hz, 1H), 7.44 (t *J* = 7.4 Hz, 1H) 7.06 (d, *J* =7.2, 1H), 6.88 (s, 1H), 6.78 (s, 2H), 6.42 (s, 1H), 5.91 – 5.90 (m, 2H), 5.08 (s, 1H), 3.84 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 162.4, 161.1, 151.9, 148.5, 148.3, 147.0, 139.8, 135.0, 132.6, 131.4, 129.2, 128.9, 128.1, 127.3, 125.5, 123.3, 121.9, 115.1, 110.5, 108.6, 108.4, 101.2, 55.7, 51.4. **HRMS (ESI):** Calc'd for $C_{24}H_{17}NO_3$ $[M+H]^+$:368.1287; found = 369.1326. **IR (ATIR, DCM, cm^{-1}):** 2922, 2856, 1728, 1604, 1501, 1486, 1440, 1398, 1251, 1083, 1036, 929, 797, 752, 539.

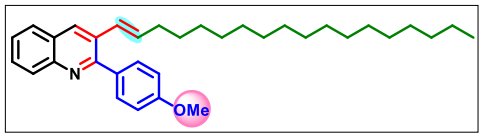


2-methoxy-10,11-diphenyl-11H-indeno[1,2-b]quinoline (4.10h): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 10% to 25%) afforded the title compound in 61% yield (25 mg, 0.061 mmol) as white solid. Reaction is carried out in 0.1 mmol scale.**^{1}H NMR (600 MHz, Chloroform-*d*)** δ 8.79 (d, *J* = 8.3 Hz, 1H), 8.47 (d, *J* = 7.9 Hz, 1H), 8.28 (d, *J* = 8.4 Hz, 1H), 7.78 – 7.76 (m, 1H), 7.72 – 7.69 (m, 1H), 7.51 (t, *J* = 7.7 Hz, 1H), 7.40 – 7.35 (m, 4H), 7.00 – 6.92 (m, 3H), 6.81 (d, *J* = 8.6 Hz, 2H), 6.63 (d, *J* = 6.9 Hz, 2H), 5.42 (s, 1H), 3.81 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 159.8, 157.7, 150.8, 148.7, 145.6, 139.7, 139.2, 139.1, 133.1, 131.1, 130.7, 130.6, 129.1, 129.0, 128.3, 128.1, 127.8, 126.7, 126.6, 125.6, 124.5, 123.9, 123.8, 55.5, 54.4. **HRMS (ESI):** Calc'd for $C_{29}H_{21}NO$ $[M+H]^+$: 400.1701; found = 400.1725.

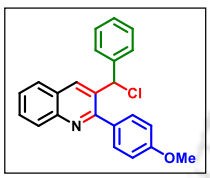


(E)-2-(4-methoxyphenyl)-3-(oct-1-en-1-yl)quinoline (4.11a): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 10%) afforded the title compound in 91% yield (32 mg, 0.091 mmol) as brown solid. Reaction is carried out in 0.1 mmol scale. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.20 (s, 1H), 8.09 (d, *J* = 8.4 Hz, 1H), 7.80 (d, *J* = 8.0 Hz, 1H), 7.65 – 7.62 (m, 3H), 7.48 (t, *J* = 7.5 Hz, 1H), 7.01 (d, *J* = 8.7 Hz, 2H), 6.50 (d, *J* = 15.7 Hz, 1H), 6.30 – 6.24 (m,1H), 3.89 (s, 3H), 2.21 (q, *J* = 6.8 Hz, 2H), 1.51 – 1.55 (m, 3H), 1.38 – 1.29 (m, 5H), 0.90 (t, *J* = 6.8 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.0, 158.3, 147.3, 134.0, 133.1, 133.0, 131.3, 130.8, 129.3, 129.09, 128.4, 127.5, 127.4, 126.4, 113.7, 55.5, 33.3, 31.9, 29.3, 29.0, 22.8, 14.2. **HRMS (ESI):** Calc'd for $C_{24}H_{27}NO$ $[M+H]^+$: 346.2171; found = 346.2170.

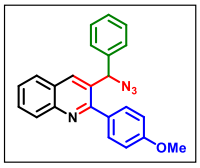
(E)-2-(4-methoxyphenyl)-3-(octadec-1-en-1-yl) quinoline (4.11b): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 10%) afforded the title compound in 95% yield (46 mg, 0.095 mmol) as white solid. Reaction is carried out in 0.1 mmol scale. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.21 (s, 1H), 8.09 (d, *J* = 8.4 Hz, 1H), 7.81 (d, *J* = 8.0 Hz, 1H), 7.66 –7.63 (m, 3H), 7.49 (t, *J* = 7.5 Hz, 1H), 7.01 (d, *J* = 8.7 Hz, 2H), 6.50 (d, *J* = 15.7 Hz, 1H), 6.31 – 6.25 (m, 1H), 3.88 (s, 3H), 2.22 (q, *J* = 6.8 Hz, 2H), 1.51-1.45 (m, 2H), 1.38 –1.26 (m, 26H), 0.88 (t, *J* = 6.9 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.0, 158.3, 147.3, 134.1, 133.1, 133.0, 131.3, 130.8, 129.4, 129.1, 128.4, 127.6, 127.4, 126.4, 113.7, 55.5, 33.3, 32.1, 29.7, 29.8, 29.8, 29.7, 29.5, 29.4, 29.4, 22.8, 14.3. **HRMS (ESI):** Calc'd for $C_{34}H_{47}NO$ $[M+H]^+$: 486.3736; found = 486.3731. **IR (ATIR, DCM, cm^{-1}):** 2921, 2851, 1645, 1607, 1576, 1555, 1514, 1484, 1465, 1418, 1407, 1303, 1290, 1246, 1173, 1108, 1040, 1022, 970, 911, 838, 787, 753, 738, 633, 616, 554, 478.



3-(chloro(phenyl)methyl)-2-(4-methoxyphenyl)quinoline (4.12a): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 87% yield (47 mg, 0.13 mmol) as white solid. Reaction is carried out in 0.15 mmol scale.**^{1}H NMR (600 MHz, Chloroform-*d*)** δ 8.5 (s, 1H), 8.13 (d, *J* = 8.5 Hz, 1H), 7.85 (d, *J* = 8.0 Hz, 1H), 7.74 – 7.71 (m, 1H), 7.56 – 7.53 (m, 1H), 7.41 (d, *J* = 8.7 Hz, 2H), 7.30 – 7.24 (m, 5H), 6.97 (d, *J* = 8.7 Hz, 2H), 6.45 (s, 1H), 3.86 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 160.1, 158.5, 147.4, 140.7, 137.5, 133.3, 132.1, 130.4, 130.3, 129.4, 128.7, 128.2, 127.9, 127.9, 127.3, 126.9, 114.1, 60.8, 55.5. **HRMS (ESI):** Calc'd for $C_{23}H_{18}ClNO$ $[M+H]^+$: 360.1155; found = 360.116. **IR (ATIR, DCM, cm^{-1}):** 3058, 2929, 2836, 1607, 1575, 1556, 1514, 1487, 1453, 1421, 1340, 1291, 1245, 1174, 1155, 1108, 1077, 1033, 1019, 1001, 843, 795, 754, 733, 696, 638, 615, 569, 537, 498.

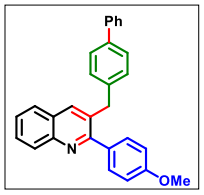


3-(azido(phenyl)methyl)-2-(4-methoxyphenyl)quinoline (4.12b): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 71% yield (52 mg, 0.14 mmol) as white solid. Reaction is carried out in 0.2 mmol scale. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.34 (s, 1H), 8.13 (d, *J* = 8.4 Hz, 1H), 7.88 (d, *J* = 8.3 Hz, 1H), 7.75 – 7.72 (m, 1H), 7.57 (t, *J* = 7.5 Hz, 1H), 7.29 – 7.25 (m, 5H), 7.09 – 7.06 (m, 2H), 6.95 (d, *J* = 8.7 Hz, 2H), 6.01 (s, 1H), 3.86 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.0, 159.3, 147.4, 138.8, 135.8, 132.3, 131.8, 130.3, 130.2, 129.4, 128.8, 128.4, 127.9, 127.8, 127.2, 126.9, 114.1, 65.1, 55.6. **HRMS (ESI):** Calc'd for $C_{23}H_{18}N_4O$ $[M+H]^+$: 367.1559; found = 367.1560.



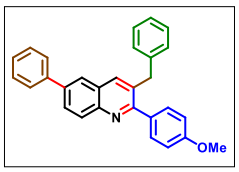
3-([1,1'-biphenyl]-4-ylmethyl)-2-(4-methoxyphenyl)quinoline (4.13): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 10%) afforded the title compound in 62% yield (62 mg, 0.155mmol) as white solid. Reaction is carried out in 0.25 mmol scale.

^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.13 (d, *J* = 8.4 Hz, 1H), 7.96 (s, 1H), 7.76 (d, *J* = 8.0 Hz, 1H), 7.68 (t, *J* = 8.2 Hz, 1H), 7.57 (d, *J* = 7.3 Hz, 2H), 7.51 – 7.47 (m, 5H), 7.43 (t, *J* = 7.7 Hz, 2H), 7.33 (t, *J* = 8.1 Hz, 1H), 7.10 (d, *J* = 6.9 Hz, 2H), 6.98 (d, *J* = 6.9 Hz, 2H), 4.20 (s, 2H), 3.87 (s, 3H).**^{13}C NMR (150 MHz, $CDCl_3$)** δ 160.5, 159.9, 146.9, 140.9, 139.4, 139.3, 137.3, 133.3, 132.6, 130.5, 129.5, 129.4, 129.3, 128.9, 127.6, 127.3, 127.2, 127.1, 126.5, 113.9, 55.6, 39.0.



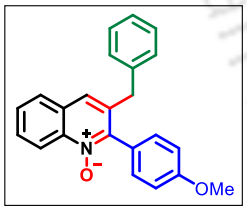
HRMS (ESI): Calc'd for$C_{29}H_{23}NO$ [M + H]$^+$: 402.1858; found = 402.1857.

3-benzyl-2-(4-methoxyphenyl)-6-phenylquinoline (4.19): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 20%) afforded the title compound in 70% yield (70 mg, 0.175 mmol) as white solid. Reaction is carried out in 0.25 mmol scale.**^{1}H NMR (600 MHz, Chloroform-*d*)** δ 8.18 (d, *J* = 8.6 Hz, 1H), 7.94 – 7.92 (m, 3H), 7.71 (d, *J* = 7.1 Hz, 2H), 7.49 – 7.47 (m, 4H), 7.38 (t, *J* = 7.3 Hz, 1H), 7.27 – 7.25 (m, 3H), 7.20 (t, *J* = 6.5 Hz, 1H), 7.05 (d, *J* = 7.2 Hz, 2H), 6.98 (d, *J* = 7.6 Hz, 2H), 4.17 (s, 1H), 3.87 (s, 3H).**^{13}C NMR (150 MHz, $CDCl_3$)** δ 160.5, 159.9, 146.3, 140.7, 140.2, 139.2, 137.4, 133.3, 133.1, 130.5, 129.8, 129.2, 129.1, 129.0, 128.7, 127.7, 127.7, 127.5, 126.4, 124.9, 113.9, 55.6, 39.4. **HRMS (ESI):** Calc'd for $C_{29}H_{23}NO$ [M + H]$^+$: 402.1858; found = 402.1863. **IR (ATIR, DCM, cm^{-1}):** 3028, 2933, 2835, 1607, 1577, 1515, 1486, 1420, 1408, 1335, 1290, 1245, 1175, 1108, 1075, 1036, 840, 753, 698, 616, 569, 481.



3-benzyl-2-(4-methoxyphenyl) quinoline 1-oxide (4.16): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 10% to 25%) afforded the title compound in 86% yield (88 mg, 0.26 mmol) as brown liquid. Reaction is carried out in 0.3 mmol scale.

^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.69 (d, *J* = 9.2 Hz, 1H), 7.92 – 7.82 (m, 1H), 7.74 (s, 1H), 7.62 (d, *J* = 9.2 Hz, 1H), 7.47 (s, 1H), 7.26 – 7.20 (m, 5H), 7.00 (d, *J* = 7.9 Hz, 2H), 6.95 (d, *J* = 7.2 Hz, 2H), 3.88 (s, 2H), 3.84 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 160.2, 148.3, 138.9, 138.3, 136.7, 134.8, 131.0, 130.6, 129.8, 129.0, 128.7, 128.0, 126.8, 126.4, 124.1, 122.3, 114.4, 55.4, 39.5. **HRMS (ESI):** Calc'd for $C_{23}H_{19}NO_2$ [M +H]$^+$: 342.1494; found = 342.1495. **IR (ATIR, DCM, cm^{-1}):** 3052, 2838, 1708, 1610, 1563, 1519, 1478, 1454, 1439, 1318, 1299, 1247, 1175, 1079, 1080, 1019, 999, 914, 886, 857, 823, 731, 698, 676, 562.



4.21. References:

[1] a) M. Maji, D. Panja, I. Borthakura, S. Kundu, *Org. Chem. Front*. **2021**, *8*, 2673 –2709; b) Hülsey, H. Yang, N. Yan, *ACS Sustainable Chem. Eng*. **2018**, *6*, 5694−5707.

[2] a) G. R. Tombo, H. Blaser, G. Brooks, T. Roberts, *Pesticide Chemistry and Bioscience*; RSC: Cambridge, **1999**; b) A. Loudet, K. Burgess, *Chem. Rev*. **2007**, *107*, 4891–4932.

[3] a) M. E. Doyle, J. M. Egan, *Pharmacol. Rev*. **2003**, *55*, 105–131; b) M. T. Khan, H. Top, *Heterocycl. Chem*. **2007**, *11*, 213.

[4] J. Marco-Contelles, R. Leon, M. G. Lopez, A. G. Garcı, M. Villarroya, *Eur. J. Med. Chem*. **2006**, *41*, 1464.

[5] Z. Wang, Y. Wang, B. Wang, W. Li, L. Huang, X. J. Li, *Med. Chem*. 2015, **58**, 8616.

[6] A. A. Joshi, C. L. Viswanathan, *Bioorg. Med. Chem. Lett*. 2006, **16**, 2613.

[7] J. Marco-Contelles, R. Léon, M. G. López, A. G. García, M. Villarroya, *Eur. J. Med. Chem*. **2006**, *41*, 1464.

[8] J. J. Qin, M. L. Wu, Y. Shu, X. R. Gao, J. J. Zhang, X. Y. Dong, J. Y. Ji, Y. X. Zhang, L. Zhou, Q. Zhang, F. Ding, *Toxicol. Lett*. **2015**, *238*, 70.

[9] a) T. Arai, N. Yokoyama, *Angew. Chem., Int. Ed*. **2008**, *47*, 4989−4992; b) M. M. Biddle, M. Lin, K. A. Scheidt, *J. Am. Chem. Soc*. **2007**, *129*, 3830.

[10] a) X. Zhang, J. Huang, *Chem. Commun*. 2010, **46**, 6042−6044; b) W. Li, W. Lin, J. Wang and X. Guan, *Org. Lett*., **2013**, *15*, 1768.

[11] K. Ilina, M. Henary, *Chem. Eur. J*. **2021**, *27*, 4230 –4248.

[12] a) A. Mukherjee, D. Milstein, *ACS Catal*. **2018**, *8*, 11435; b) T. Irrgang, R. Kempe, *Chem. Rev*. **2019**, *119*, 2524–2549; c) B. G. Reed-Berendt, D. E. Latham, M. B. Dambatta, L. C. Morrill, *ACS Cent. Sci*. **202**1, *7*, 570–585.

[13] M. Maji, I. Borthakur, S. Guria, S. Singha, S. Kundu, *J. Catal*. **2021**, *402*, 37–51.

[14] a) S. N. R. Donthireddy, V. K. Pandey, A. Rit, *J. Org. Chem*. **2021**, *86*, 6994; b) A. Singh, A. Maji, M. Joshi, A. R. Choudhury, K. Ghosh, *Dalton Trans*. **2021**, *50*, 8567; c) M. K. Barman, A. Jana and B. Maji, *Adv. Synth. Catal*. **2018**, *360*, 3233.

[15] a) A. Mondal, R. Sharma, D. Pal, D. Srimani, *Eur. J. Org. Chem*. **2021**, *2021*, 3690–3720; b) A. Maji, S. Gupta, M. Maji, S. Kundu, *J. Org. Chem*. **2022**, *87*, 8 351–8367.

[16] a) M. J. Climent, A. Corma and S. Iborra, *Chem. Rev*. **2011**, *111*, 1072 – 1133; b) C. Vaxelaire, P. Winter and M. Christmann, *Angew. Chem. Int. Ed*. **2011**, *50*, 3605 – 3607; c) L. Albrecht, H. Jiang and K. A. Jorgensen, *Angew. Chem*. **2011**, *123*, 8642 – 8660; *Angew. Chem. Int. Ed*. **2011**, *50*, 8492 – 8509.

[17] S. S. Gawali, B. K. Pandia, C. Gunanathan, *Org. Lett*. **2019**, *21*, 3842–3847.

[18] a) T. Liu, L. Wang, K. Wu, Z. Yu, *ACS Catal*. **2018**, *8*, 7201–7207; b) O. El-Sepelgy, E. Matador, A. Brzozowska, M. Rueping, *ChemSusChem* **2019**, *12*, 3099-3102;

[19] a) J. Schörgenhumer, A. Zimmermann, M. Waser, *Org. Process Res. Dev*. 2**018**, *22*, 862-870; b) K. Paudel, B. Pandey, S. Xu, D. K. Taylor, D. L. Tyer, C. L. Torres, S. Gallagher, L. Kong, K. Ding, *Org. Lett*. **2018**, *20*, 4478-4481;

[20] S. Genç, S. Gülcemal, S. Günnaz, B. Çetinkaya, D. Gülcemal, *J. Org. Chem*. **2020**, 85, 9139-9152; f) A. Kaithal, L.-L. Gracia, C. Camp, E. A. Quadrelli, W. Leitner, *J. Am. Chem. Soc*. **2019**, *141*, 17487-17492.

[21] a) N. Deibl, R. Kempe, *Angew. Chem., Int. Ed*. **2017**, *56*, 1663−1666; b) R. Fertig, F. L,-Künstler, T. Irrgang, R. Kempe, *Nat. Commun*. **202**3, *14*, 595; c) M. Mastalir, M. Glatz, E. Pittenauer, G. Allmaier, K. Kirchner, *J. Am. Chem. Soc*. **2016**, *138*, 15543−15546.

[22] B. Chen, L. Chng, J. Yang, Y. Wei, J. Yang, J. Y. Ying, *Chem Cat Chem* **2013**, *5*, 277–283.

[23] a) S. Fu, Z. Shao, Y. Wang, Q. Liu, *J. Am. Chem. Soc*. **2017**, *139*,11941–11948; b) S. Elangovan, J. Neumann, J.-B. Sortais, K. Junge, C. Darcel, M. Beller, *Nat.Commun*. **2016**, *7*, 12641; c) Z. Shao, Y. Li, C. Liu, W. Ai, S.-P. Luo, Q. Liu, *Nat. Commun*. **2020**, *11*, 591; d) Y. Wang, Z. Shao, K. Zhang, Q. Liu, *Angew. Chem. Int. Ed*. **2018**, *57*, 15143–15147; *Angew. Chem.* **2018**, *130*, 15363–15367.

[24] a) Y. Wang, L. Zhu, Z. Shao, G. Li, Y. Lan, Q. Liu, *J. Am. Chem. Soc*. **2019**, *141*, 17337–17349; b) W. Yang,T. Y. Kalavalapalli, A. M. Krieger, T. A. Khvorost, I. Y. Chernyshov, M. Weber, E. A. Uslamin, E. A. Pidko, G. A. Filonenko, *J. Am. Chem. Soc*. **2022**, *144*, 8129–8137.

[25] a) Y. Zhao, D. G. Truhlar, *J. Chem. Phys*. **2006**, *125*, 194101; b) Gaussian 16, Revision B.01, M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, G. Scalmani, V. Barone, G. A. Petersson, H. Nakatsuji, X. Li, M. Caricato, A. V. Marenich, J. Bloino, B. G. Janesko, R. Gomperts, B. Mennucci, H. P. Hratchian, J. V. Ortiz, A. F. Izmaylov, J. L. Sonnenberg, D. Williams-Young, F. Ding, F. Lipparini, F. Egidi, J. Goings, B. Peng, A. Petrone, T. Henderson, D. Ranasinghe, V. G. Zakrzewski, J. Gao, N. Rega, G. Zheng, W. Liang, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, T. Vreven, K. Throssell, J. A. Montgomery, Jr., J. E. Peralta, F. Ogliaro, M. J. Bearpark, J. J. Heyd, E. N. Brothers, K. N. Kudin, V. N. Staroverov, T. A. Keith, R. Kobayashi, J. Normand, K. Raghavachari, A. P. Rendell, J. C. Burant, S. S. Iyengar, J. Tomasi, M. Cossi, J. M. Millam, M. Klene, C. Adamo, R. Cammi, J. W. Ochterski, R. L. Martin, K. Morokuma, O. Farkas, J. B. Foresman, and D. J. Fox, Gaussian, Inc. Wallingford CT, **2016**.

[26] a) X. B. LAN, Z. Ye, M. Huang, J. Liu, Y. Liu, Z. Ke, *Org. Lett*. **2019**, *21*, 8065–8070; b) A. Mondal, D. Pal, H.J. Phukan, M. Roy, S. Kumar, S. Purkayastha, A.K. Guha, D. Srimani, *ChemSusChem*, **2024**, e202301138.

[27] a) A. Luque-Urrutia, M. Solà, D. Milstein, A. Poater, *J. Am, Chem. Soc*. **2019**, *141*, 2398–2403; b) K. Das, A. Mondal, D. Pal, H. K. Srivastav, D. Srimani, *Organometallics* **2019**, *38*, 1815−1825; c) S. Thiyagarajan, R. V. Sankar, P. K. Anjalikrishna, C. H. Suresh, C. Gunanathan, *ACS Catal*. **2022**, *12*, 2191−2204; d) D. H. Nguyen, X. Trivelli, F. Capet, J.-F. Paul, F. Dumeignil, R. M. Gauvin, *ACS Catal*. **2017**, *7*, 2022–2032; e) S. Elangovan, C. Topf, S. Fischer, H. Jiao, A. Spannenberg, W. Baumann, R. Ludwig, K. Junge, M. Beller, *J. Am. Chem. Soc*. **2016**, 1*38*, 8809–8814.

[28] a). Burg, M. Gicquel, S. Breitenlechner, A. Pçthig, T. Bach, *Angew. Chem. Int. Ed*. **2018**, *57*, 2953; *Angew. Chem.* **2018**, *130*, 3003; c) L. Tanwar, J. Bçrgel, T. Ritter, *J. Am. Chem. Soc*. **2019**, *141*, 17983–17988; b) M. S. Chen, M. C. White, *Science* **2007**, *318*, 783.

[29] a) A. Thakur, A. K. Dhiman, Sumit, R. Kumar, U. Sharma, *J. Org. Chem*. **2021**, *86*, 6612−6621; b) R. Sharma, I. Kumar, R. Kumar, U. Sharma, *Adv. Synth. Catal*. **2017**, *359*, 3022–3028.

[30] J. R. Carney, B. R. Dillon, L. Campbell, S. P. Thomas, *Angew. Chem. Int. Ed*. **2018**, *57*, 10620–10624; *Angew. Chem*. **2018**, *130*, 10780–10784.

[31] a) Y. Wang, L. Zhu, Z. Shao, G. Li, Y. Lan, Q. Liu, *J. Am. Chem. Soc*. **2019**, 141, 17337–17349; b) W. Yang, T. Y. Kalavalapalli, A. M. Krieger, T. A. Khvorost, I. Y. Chernyshov, M. Weber, E. A. Uslamin, E. A. Pidko, G. A. Filonenko, *J. Am. Chem. Soc*. **2022**, *144*, 8129–8137.

[32] Y. Zhao, D. G. Truhlar, *J. Chem. Phys*. **2006**, *125*, 194101;

4.22. Selected ^{1}H & ^{13}C NMR copies of the compounds:

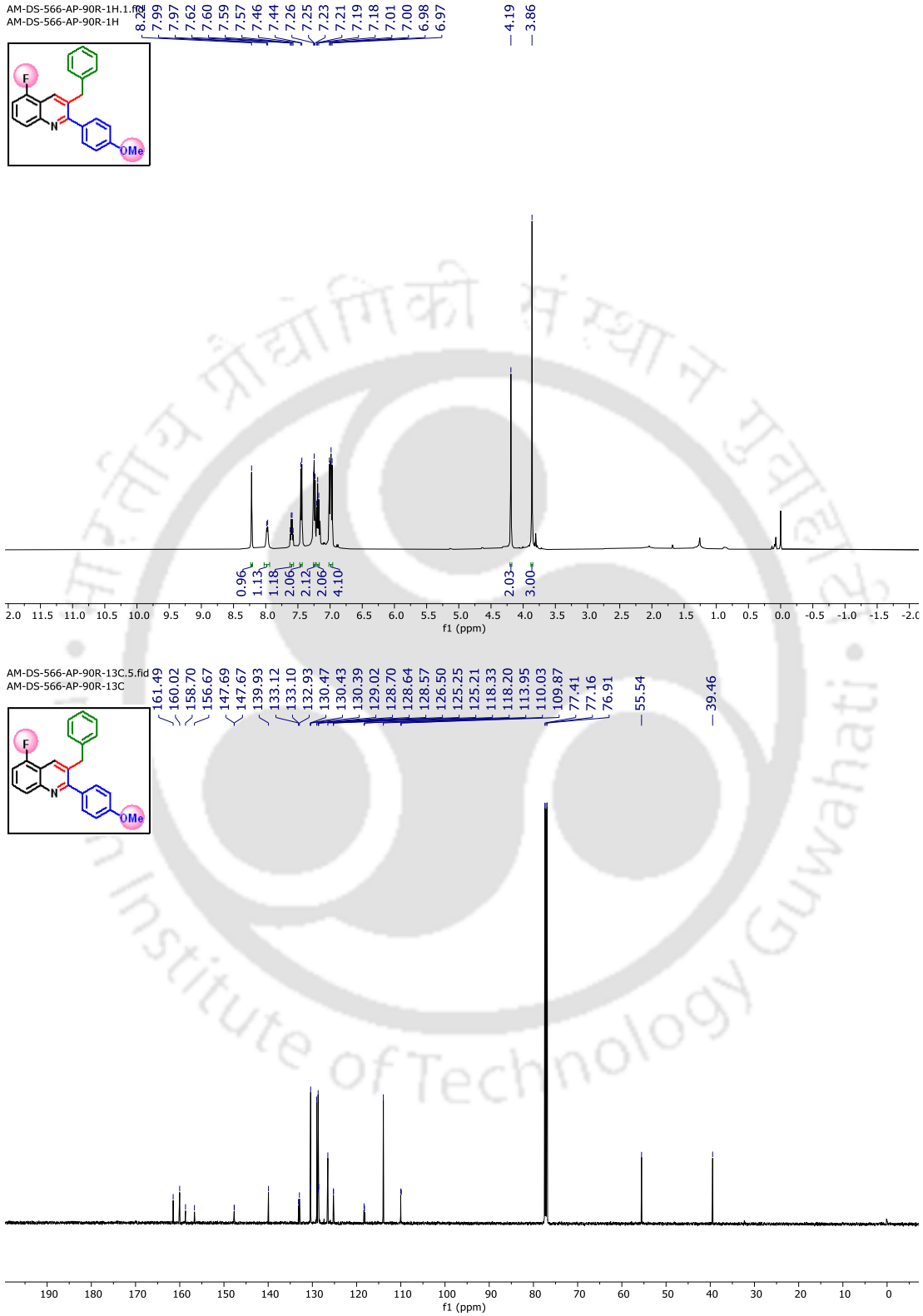


Figure 4.21. ^{1}H (500 MHz) and^{13}C {^{1}H} (125 MHz) NMR Spectrum **3-benzyl-5-fluoro-2-(4-methoxyphenyl)quinoline (4.5ai)** in $CDCl_3$.

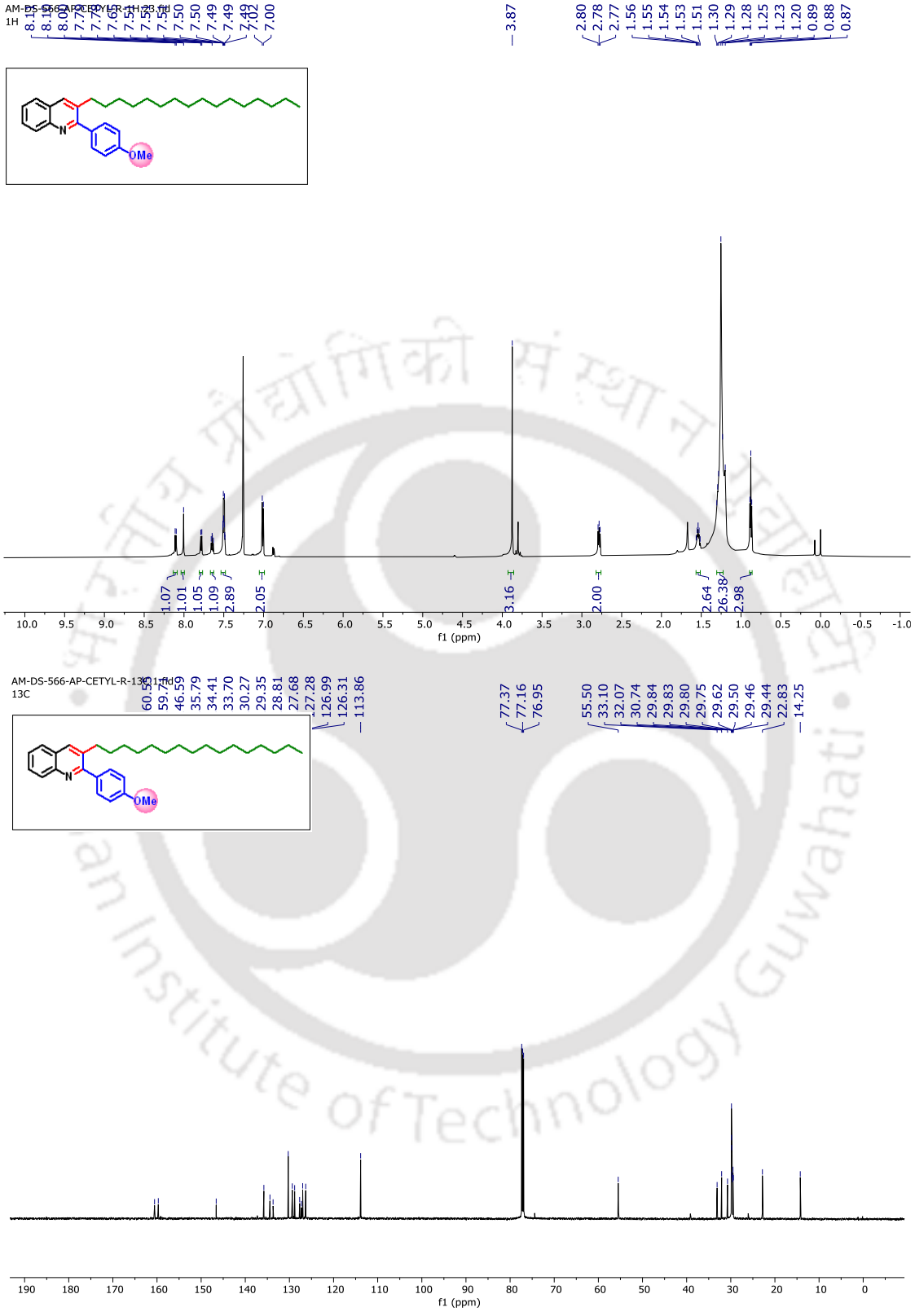


Figure 4.22. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **3-hexadecyl-2-(4-methoxyphenyl)quinoline(4.5ap)** in $CDCl_3$.

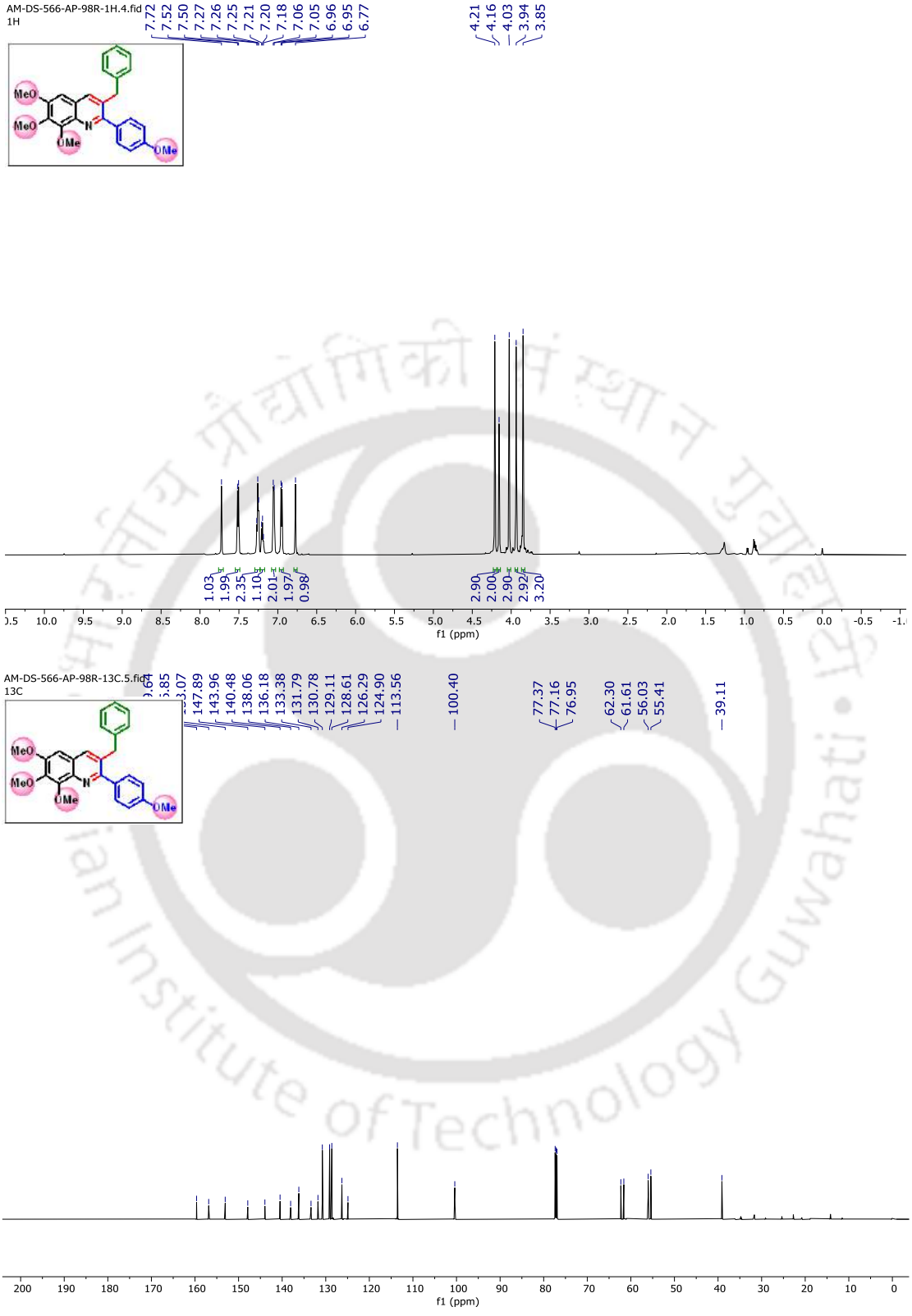


Figure 4.23. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **3-benzyl-6,7,8-trimethoxy-2-(4-methoxyphenyl)quinoline (4.5ax)** in $CDCl_3$.

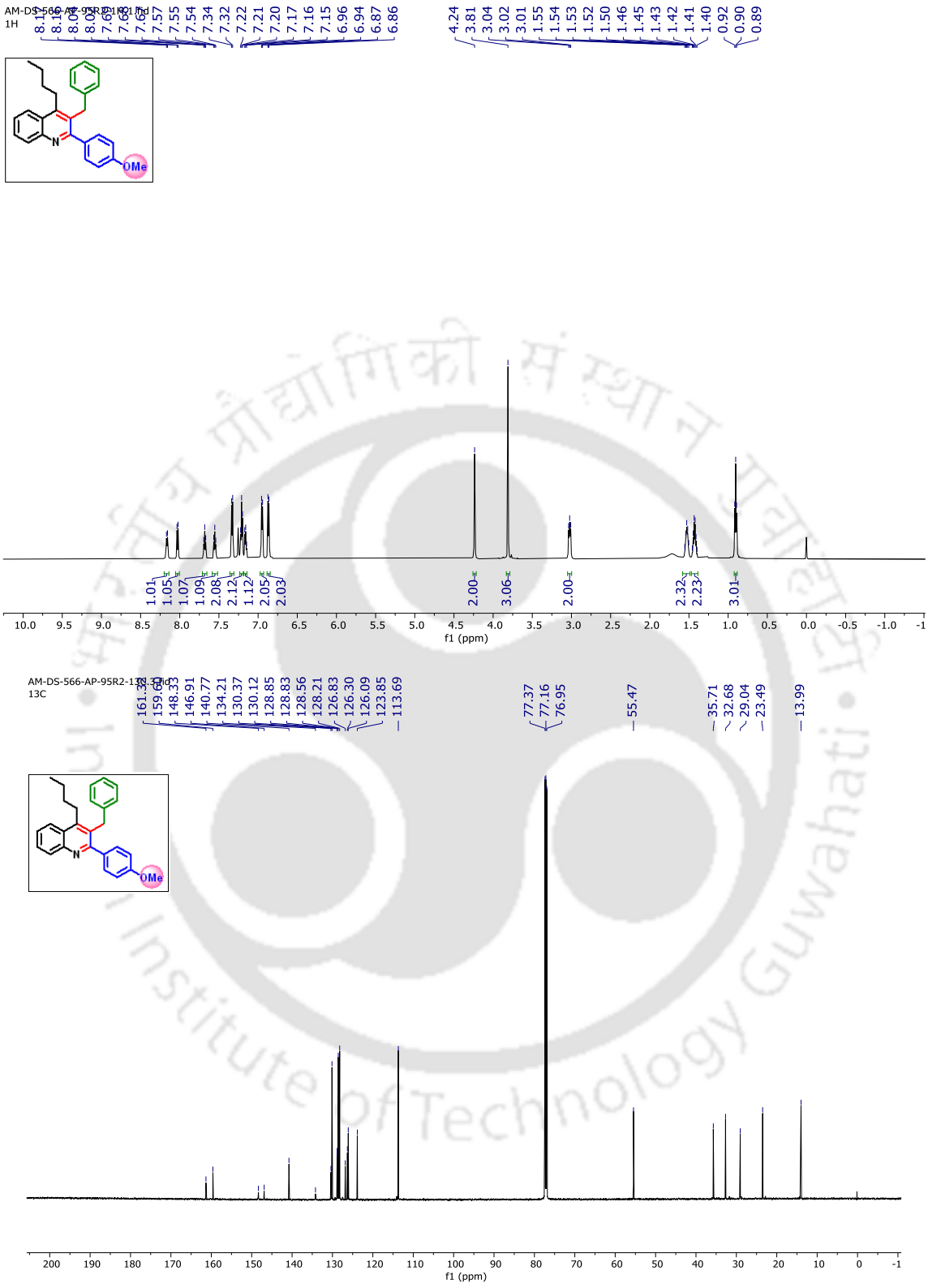


Figure 4.24. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **3-benzyl-4-butyl-2-(4-methoxyphenyl)quinoline (4.5aac)** in $CDCl_3$.

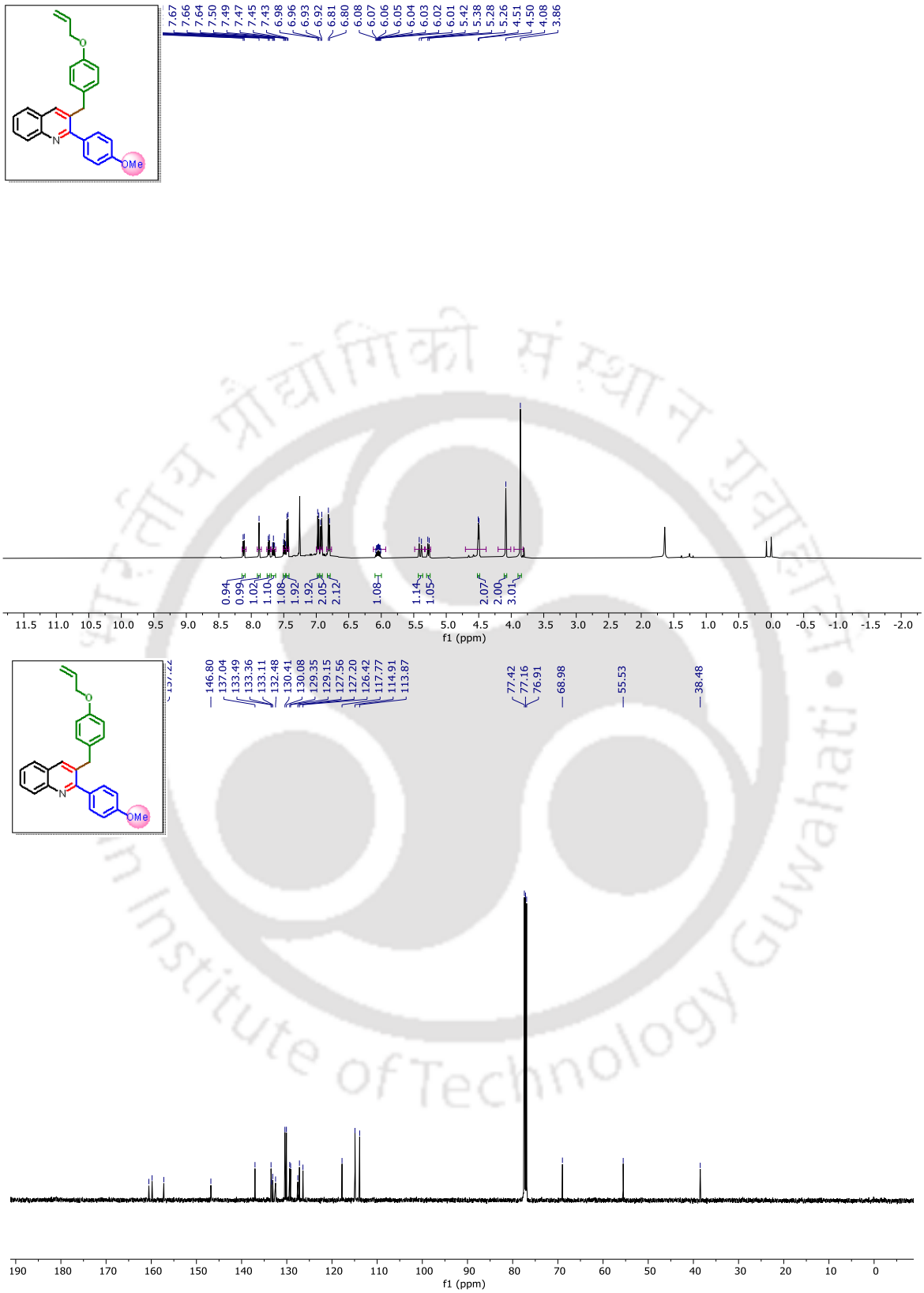


Figure 4.25. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **3-(4-(allyloxy)benzyl)-2-(4-methoxyphenyl)quinoline (4.5aad)** in $CDCl_3$.

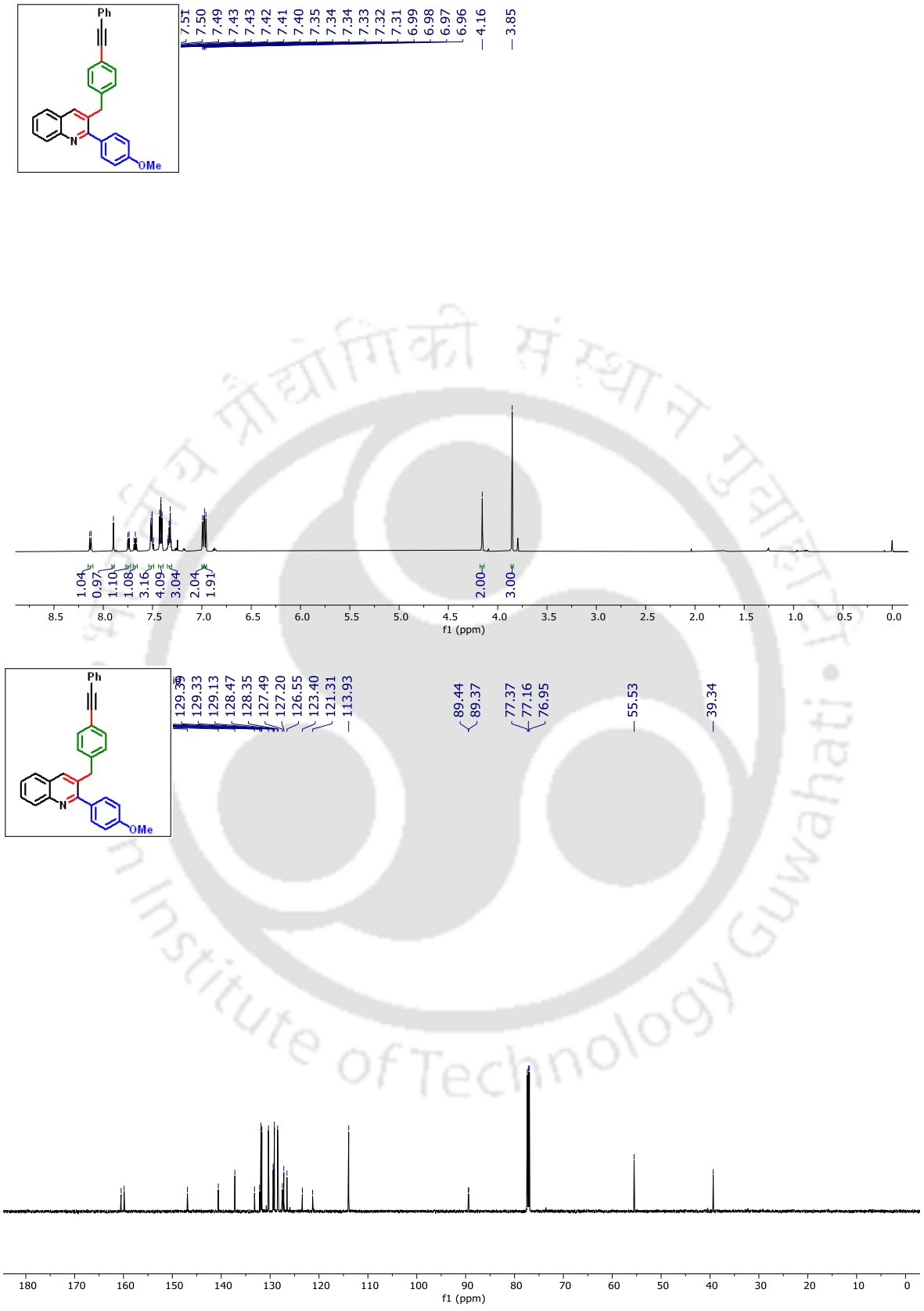


Figure 4.26. ^{1}H (500 MHz) and$^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **2-(4-methoxyphenyl)-3-(4-(phenylethynyl)benzyl)quinoline(4.5aae)** in $CDCl_3$.

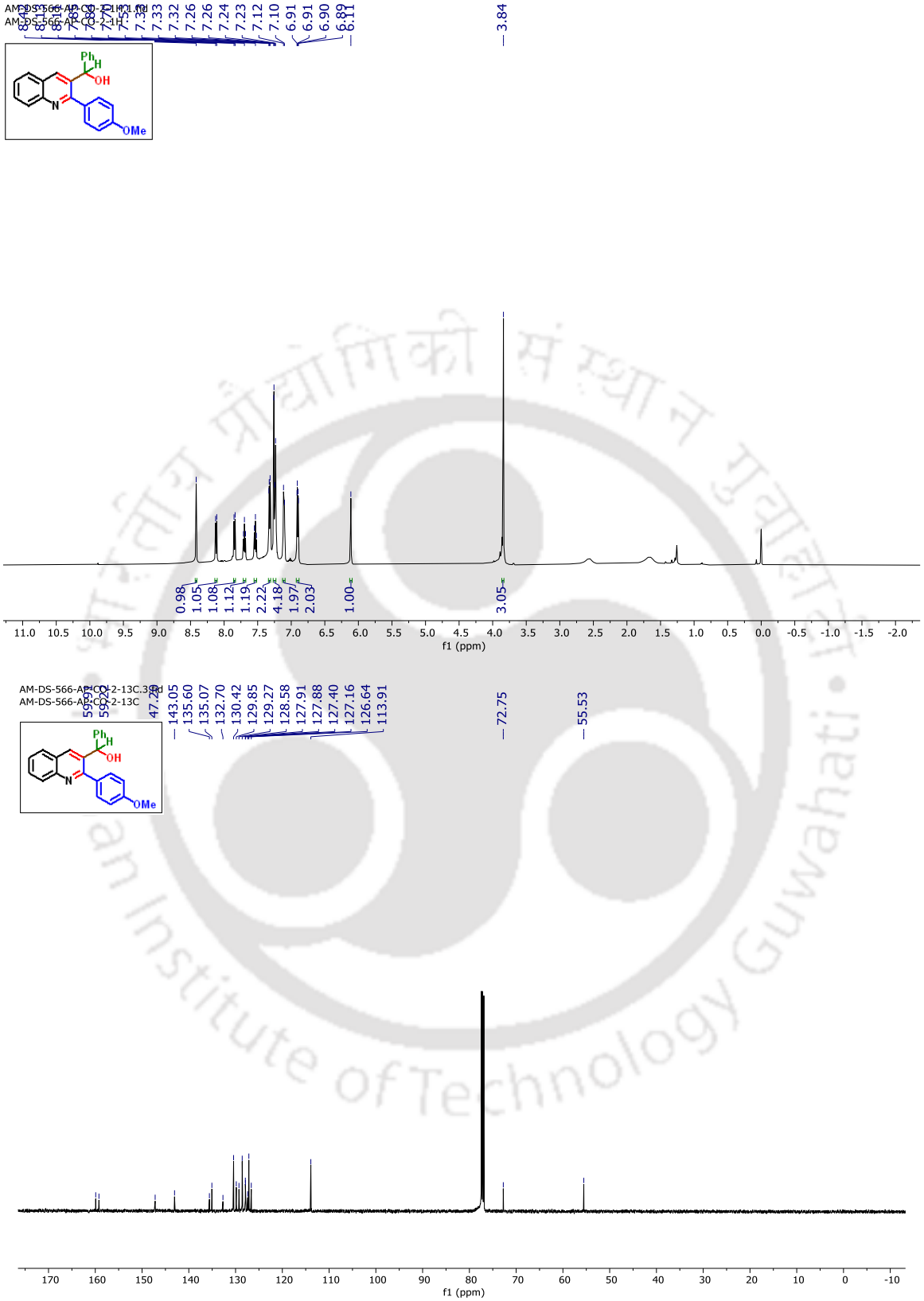


Figure 4.27. ^{1}H (500 MHz) and$^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **(2-(4-methoxyphenyl)quinolin-3-yl)(phenyl)methanol(4.9a)** in $CDCl_3$.

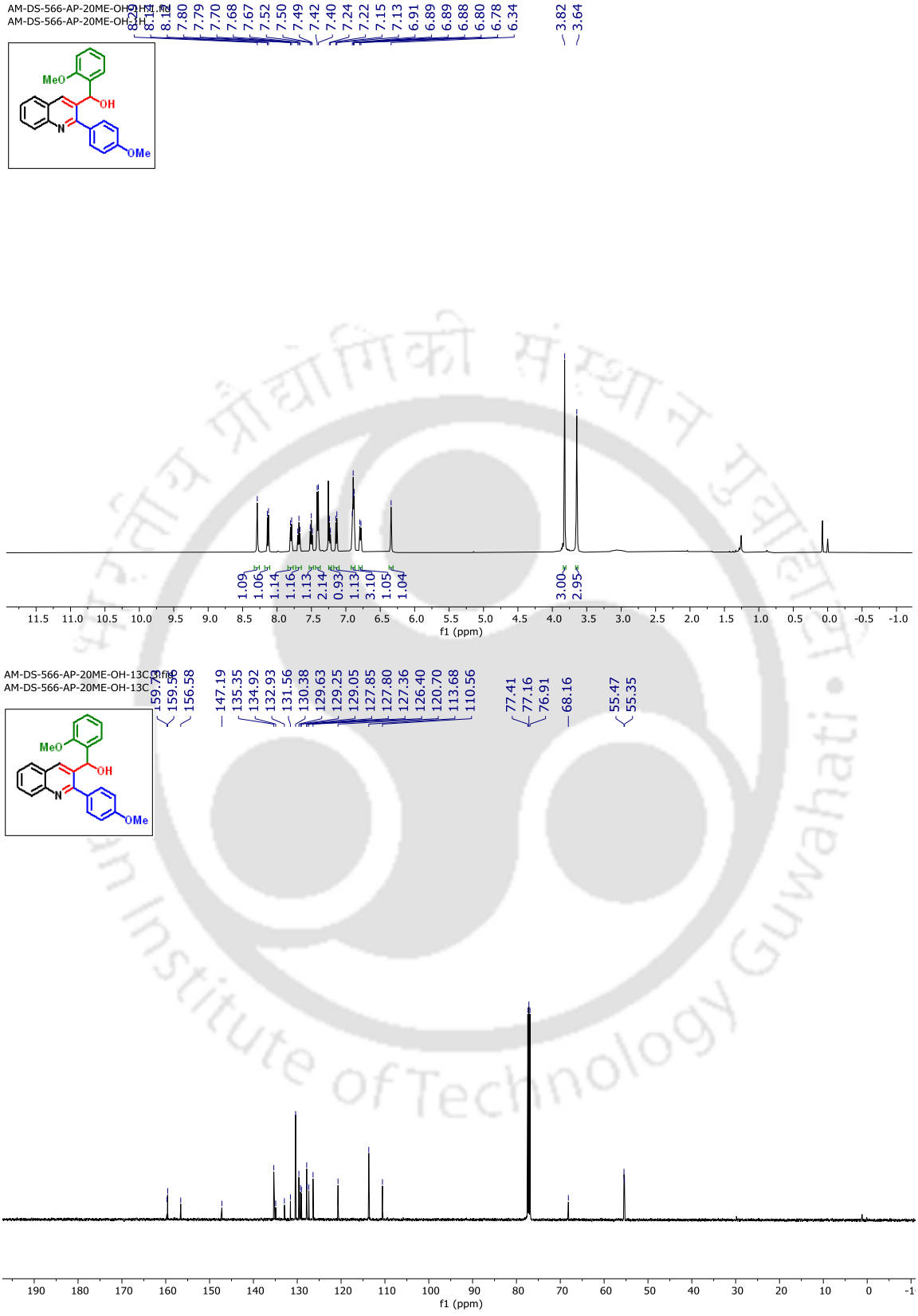


Figure 4.28. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **(2-methoxyphenyl)(2-(4-methoxyphenyl)quinolin-3-yl)methanol (4.9c)** in $CDCl_3$.

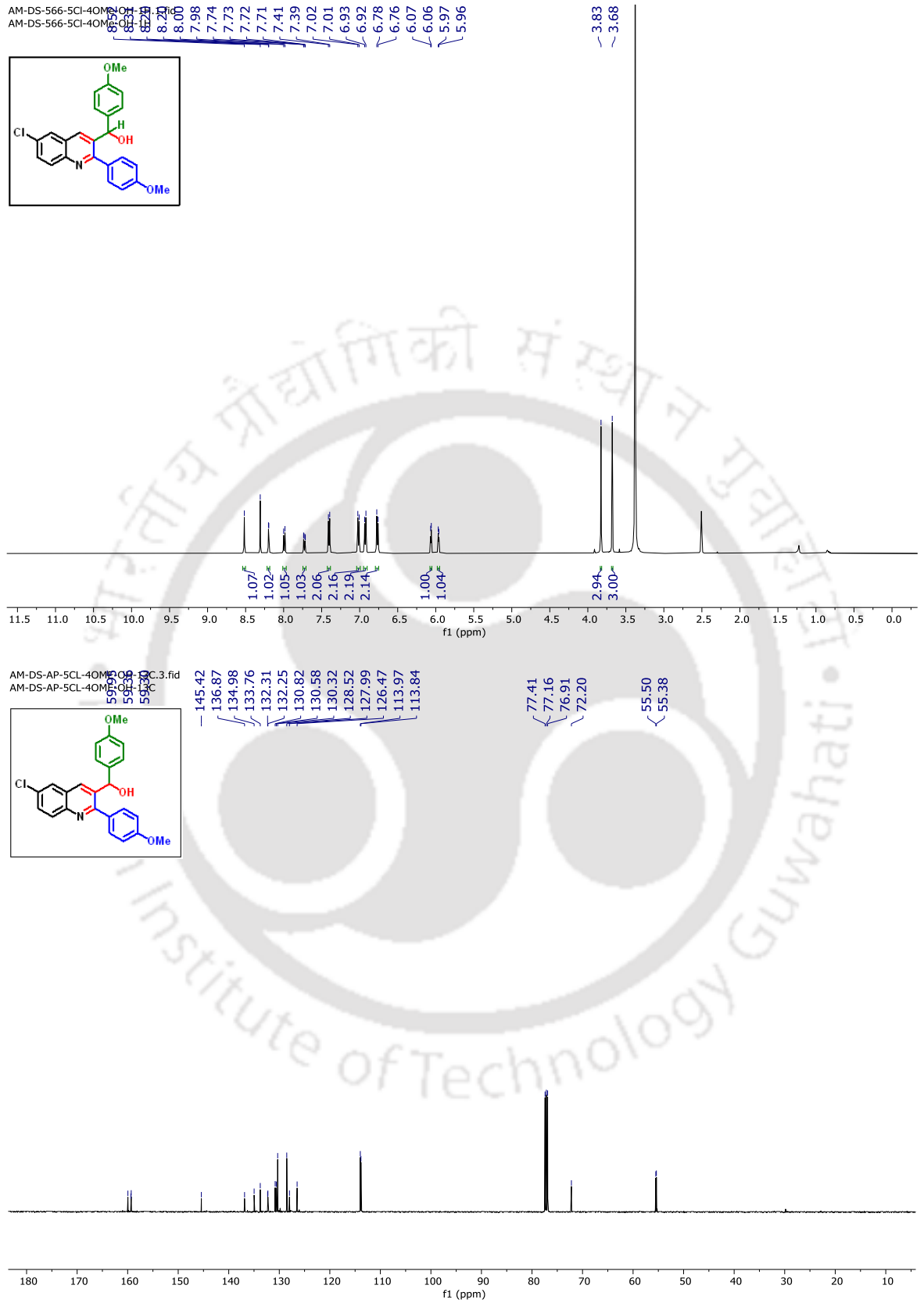


Figure 4.29. ^{1}H (500 MHz) in DMSO-d6 and^{13}C {^{1}H} (125 MHz) in $CDCl_3$ NMR Spectrum **(6-chloro-2-(4-methoxyphenyl) quinolin-3-yl)(4-methoxyphenyl) methanol (4.9h).**

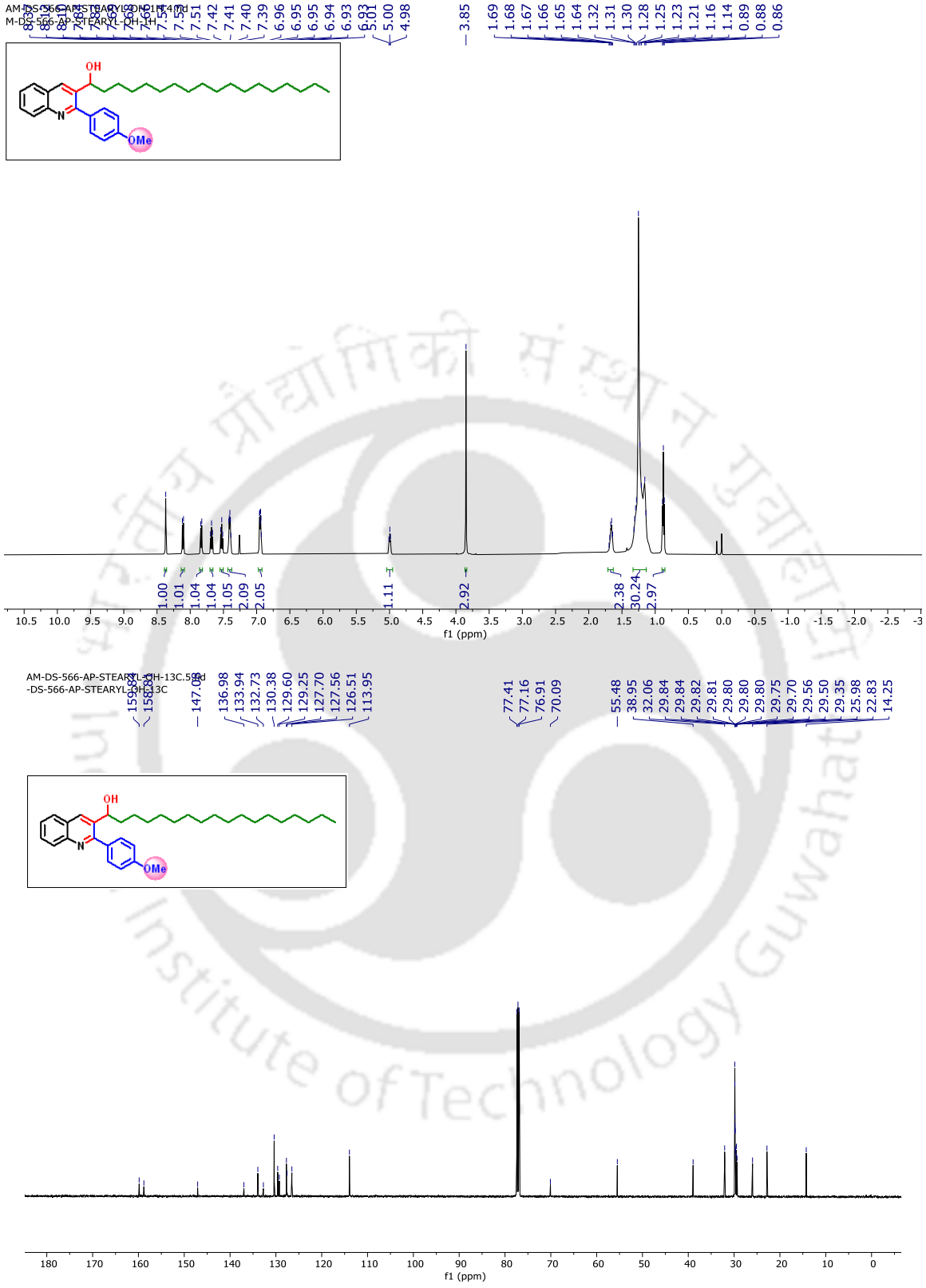


Figure 4.30. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **1-(2-(4-methoxyphenyl)quinolin-3-yl)octadecan-1-ol (4.9j)** in $CDCl_3$.

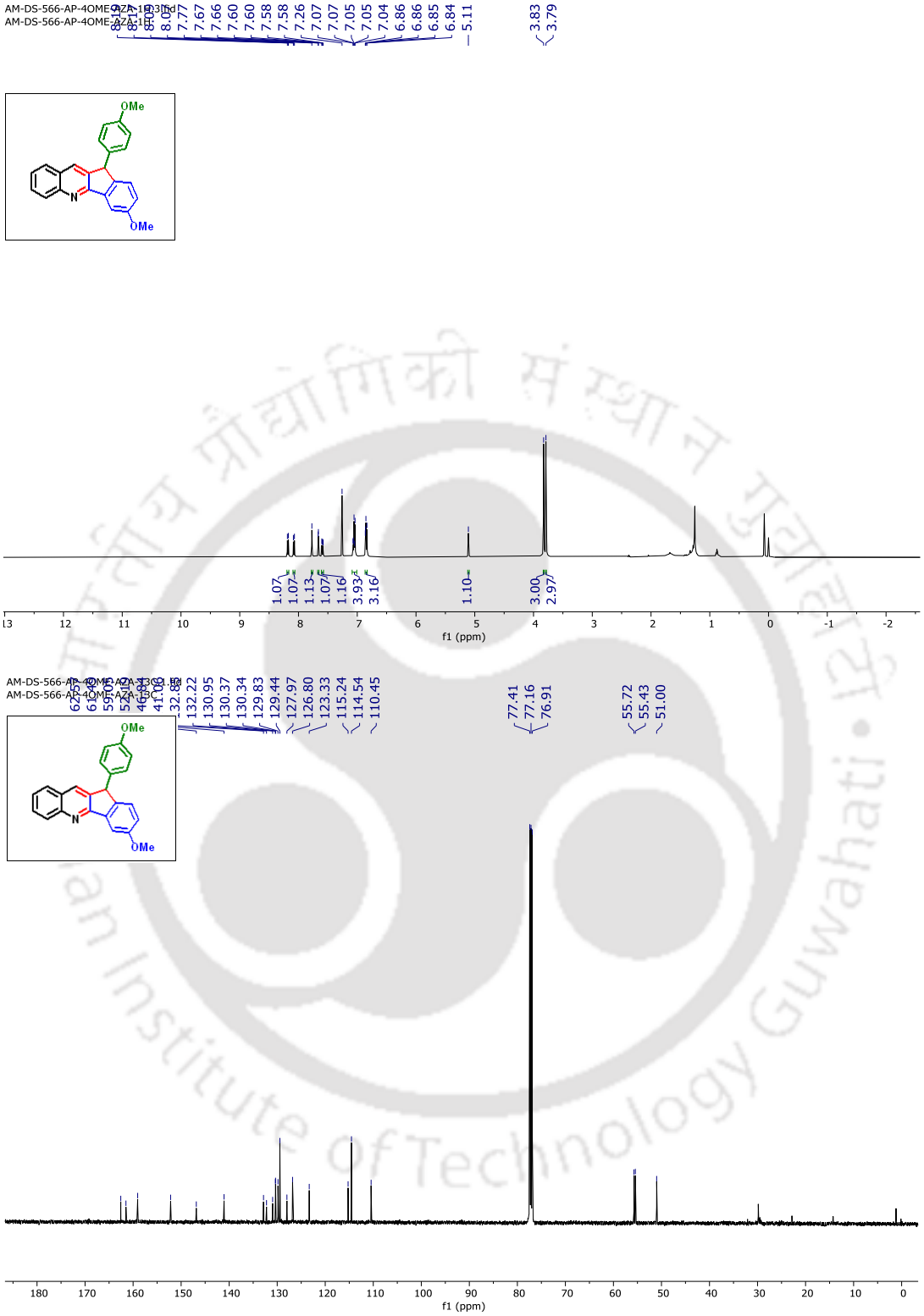


Figure 4.31. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **3-methoxy-11-(4-methoxyphenyl)-11H-indeno[1,2-b]quinoline(4.10b)**in $CDCl_3$.

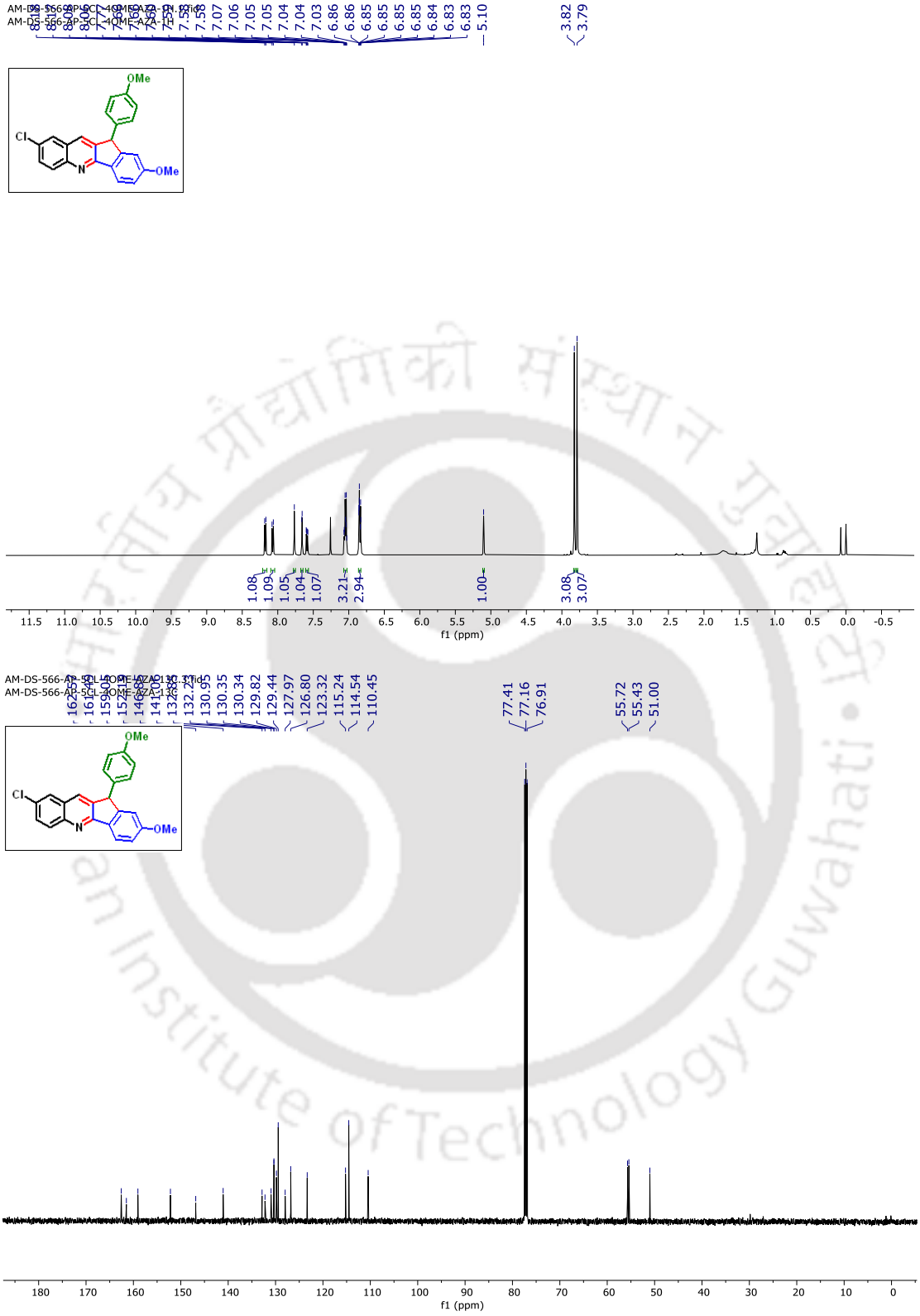


Figure 4.32. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **8-chloro-2-methoxy-11-(4-methoxyphenyl)-11H-indeno[1,2-b]quinoline(4.10d)** in $CDCl_3$.

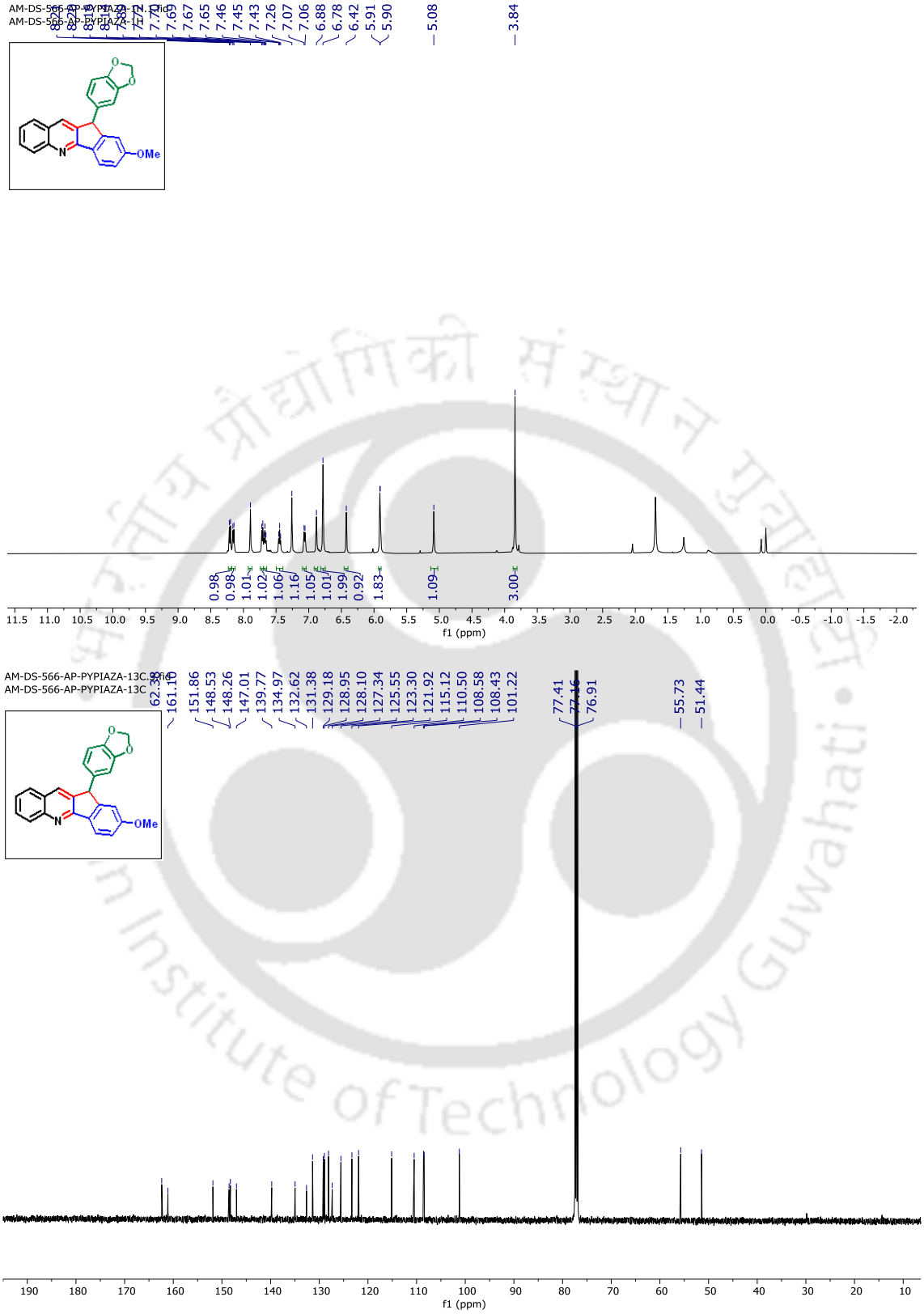


Figure 4.33. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **11-(benzo[d][1,3]dioxol-5-yl)-2-methoxy-11H-indeno[1,2-b]quinoline (4.10g)** in $CDCl_3$.

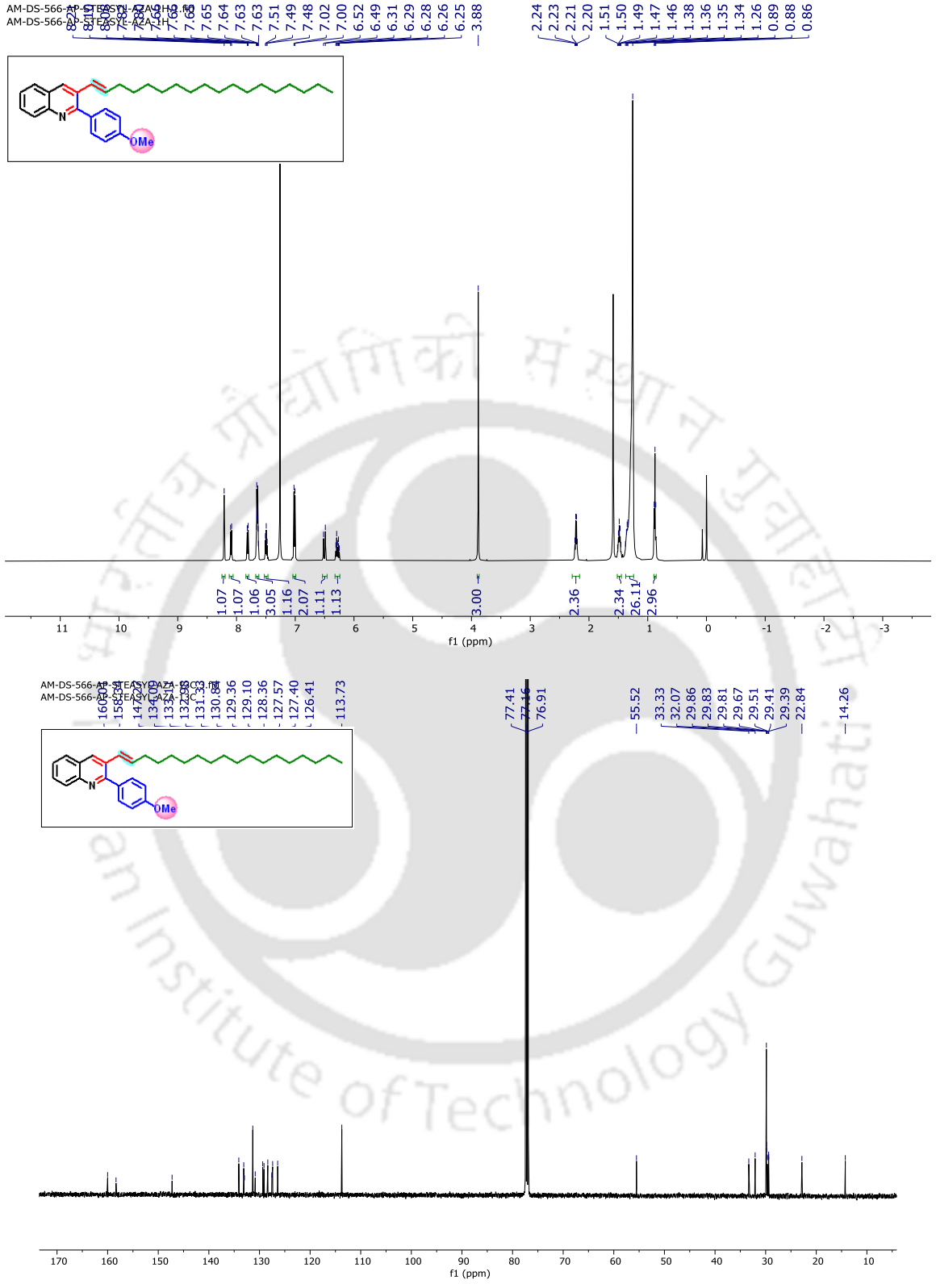


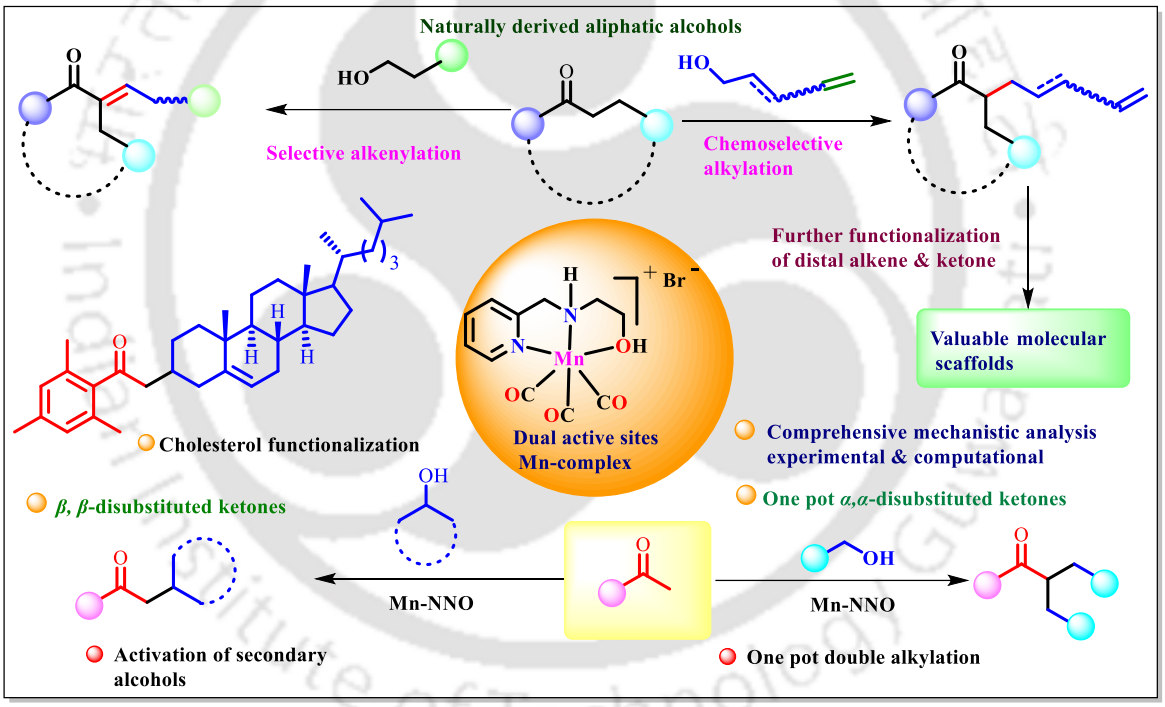
Figure 4.34. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **(E)-2-(4-methoxyphenyl)-3-(octadec-1-en-1-yl)quinoline (4.11b)** in $CDCl_3$.

4.23. Important crystal parameters of Mn-22 and Mn-23:

	Mn-22	**Mn-23**
Empirical formula	C_{19} H_{14} Br Cl_3Mn N_3 O_3	C_{17} H_{18} Br Mn N_2 O_3 S
Formula weight	573.53	465.24
Temperature, T	297 K	273 K
Crystal system	triclinic	'monoclinic'
Space group	'P -1'	'-P 2yn'
Unit cell dimensions	a=10.216(2)Å, α=101.979(5)° b= 15.023(3)Å, β= 105.397(5)° c= 16.540(3)Å, γ= 03.709(5)°	a= 7.262(3)Å, α=90° b=9.096(9)Å, β=3.387(13)° c= 13.785(6)Å, γ=90°
Volume, V (Å3)	2276.3(8)	1908.4(15)
Z	4	4
Index ranges	-12 ≤ h ≤ 12, -17 ≤ k ≤ 17, -19 ≤ l ≤ 19	-8 ≤ h ≤ 8, -22 ≤ k ≤ 22, -16 ≤ l ≤ 16
Final R indices [I>2sigma(I)]	R1 = 0.0446(6022), wR2= 0.1239(7998)	R1=0.0462(2793), wR2(reflections)= 0.1239(3360)
R indices (all data)	R1= 0.0712, WR2= 0.0967	R1= 0.058786, wR2= 0.1083

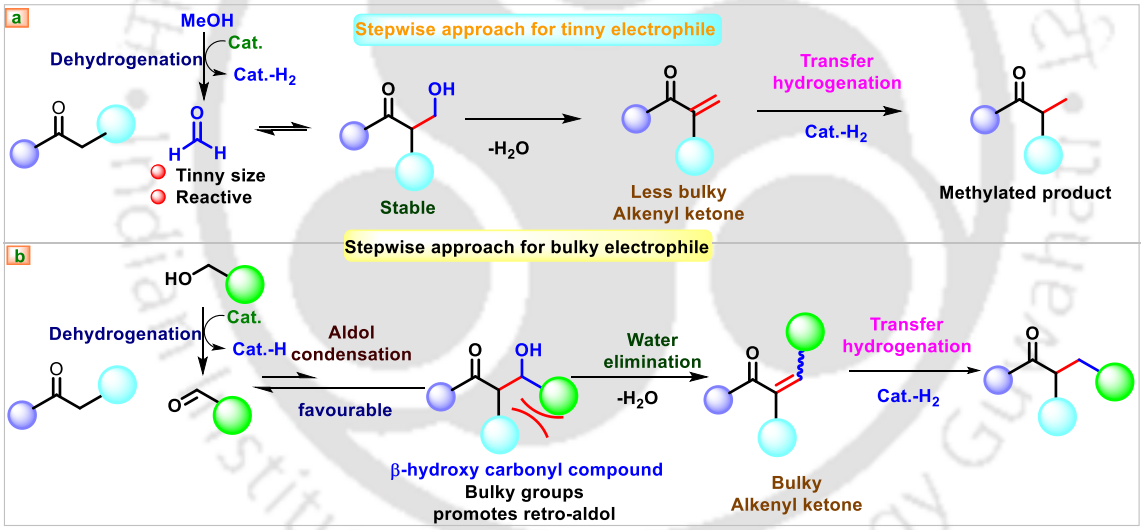
CHAPTER 5

Engineering of a Sterically Less Hindered Bifunctional Mn(I) Complex for Chemoselective $C(sp^3)$-$C(sp^3)$ Bond Formation and its Strategic Applications



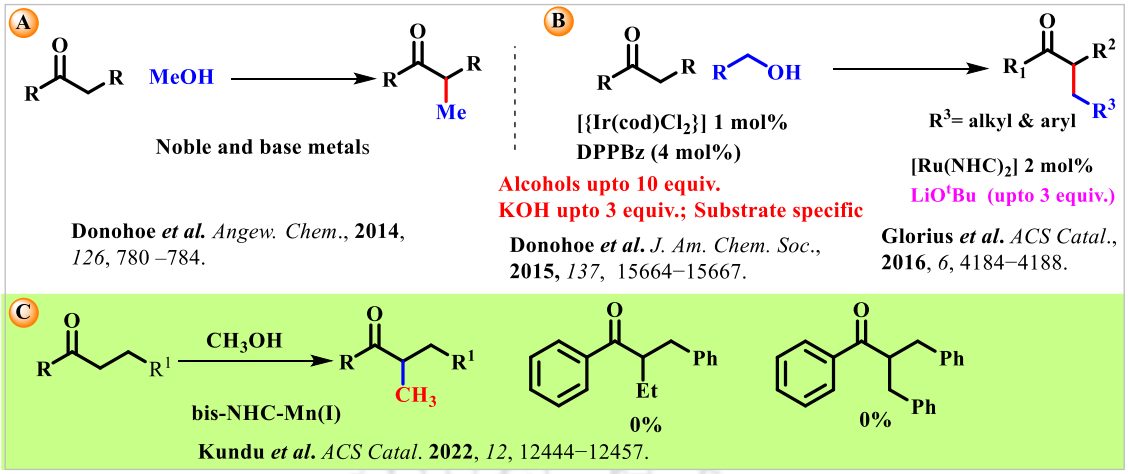
Manuscript under preparation

5.1. Introduction: The BH-mediated construction of C-C bond started with dehydrogenation of alcohol to corresponding carbonyl compound followed by aldol-condensation to form *β*-hydroxy carbonyl compound. Next, the aldol-adducts delivers the *α, β*-unsaturated ketone which via transfer hydrogenation furnishes the desired product.[1] The outcome of the product formation in dehydrogenative transformations is not necessarily determined by the enthalpy required to convert the alcohol to the corresponding electrophilic equivalent, the reactivity of the generated electrophiles also plays a crucial role. For instance, even though the dehydrogenation enthalpy of methanol to formaldehyde is quite high compared to other aliphatic alcohols, BH-mediated alkylation of bulky *α*-branched carbonyl compounds is mostly reported to methylation.[2] The tinny size and highly reactive nature of formaldehyde favors the formation of aldol-adduct whereas steric hindrance renders the intermediate aldol-adduct unstable and promotes the retro-aldol process for bulky electrophiles.[3] Thus, alkylation of bulky *α*-branched ketones with long chain aliphatic alcohols requires more stringent condition and/or large excess of alcohol, which often creates selectivity issue by reducing the keto-group of the branch ketone. The bulky interactions schematically depicted in **Scheme 5.1** as suggested by Donohoe *et al.*[3]



Scheme 5.1. Schematic approached for *α*-functionalization of branched ketones-(a) using methanol; (b) longer alcohols rather than methanol.

5.2. Literature reports: Donohoe and coworkers demonstrated an iridium catalysed BH technique to address this above issue by taking ortho-substituted phenyl ketones.[3] Later on, Glorious[4] reported slight improved protocol using expensive in situ generated Ru-carbene complex using 2-3 equivalent of LiO^tBu. Recently, the use of first-row transition metal complex for dehydrogenative transformation exhibited a significant surge due to their non-toxic and inexpensive nature. In 2023, Kundu's group[5] reported NHC-manganese complex catalysed *α*-methylation of various *α*-branched ketones via challenging methanol. However, their protocol failed to install ethyl and even benzyl group (low enthalpy of dehydrogenation).



Scheme 5.2. Literature reports on *α*-functionalization of branched ketones with alcohols.

Thus, the development of an efficient catalyst for the BH-mediated synthesis of bulky *α, α´* and *β, β´*-disubstituted ketones which can be utilized under relatively milder conditions would be highly challenging and is of high importance. The problem associated with retro-aldol process in the BH mediated synthesis of *α, α´*-bulky disubstituted ketones could be addressed by quick transformation of aldol-adduct to the corresponding *α, β*-unsaturated ketone or stabilizing the unstable *β*-hydroxy ketone intermediate and then fast selective transfer hydrogenation of bulky alkenyl ketone intermediate to *α, α´*-bulky disubstituted ketones would be crucial to shift the equilibrium towards the desired product. However, the steric encumbrance at the site of metal-ligand cooperativity allows the small molecule to enter rather than sterically bulky substrates.[6] Therefore, designing of a highly active catalyst with a sterically less hindered metal-ligand cooperative site, which can easily accommodate bulky unstable *β*-hydroxy ketone could be essential to achieve this goal. Moreover, coupling of various essential oil derived alkenyl alcohols with *α*-branched ketones keeping the unsaturation intact would be extremely impactful, as this would lead to the formation of remote site unsaturated of ketone, which are found in various natural products and biologically relevant molecules.[7]

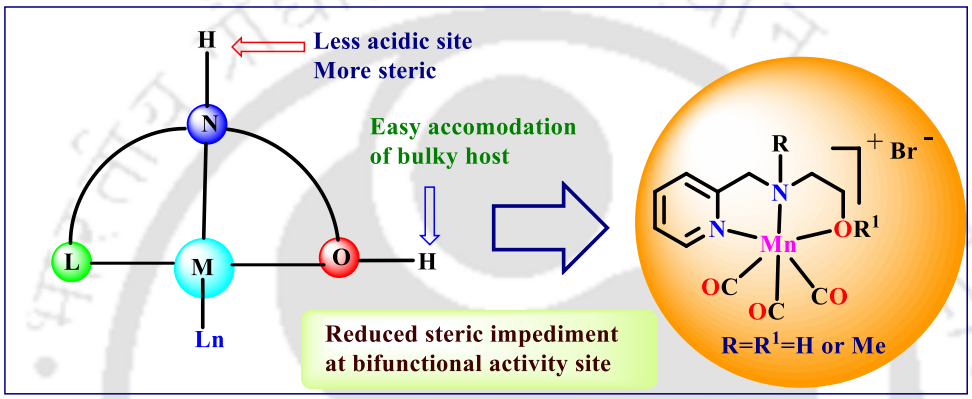
5.3. Present approach: In this chapter, NNO-ligand-derived Mn(I) complexes were synthesised and well characterized with IR, HRMS, NMR, SC-XRD, etc. The catalytic applicability of these complexes has been explored in the functionalization of bulky *α*-branched ketones with various naturally derived long-chain saturated and unsaturated aliphatic alcohols. Thorough investigations of the catalytic system suggested that sterically less hindered hydroxyl bifunctional site host bulky substrates or intermediates, which helps to overcome the reversibility of the retro-aldol step and hydrogenation of highly branched *α, β*-unsaturated intermediates in this transformation. Notably, this present catalytic system also highlighted a new method for direct one pot synthesis of *α, α´*-disubstituted ketones and *β, β´*-disubstituted ketones. The current protocol offers many advantages

in terms of chemo-selectivity, green chemistry matrices, scalability, and synthetic and biological applicability.

5.3. Results and discussion:

5.3.1. Designing and synthesis of Mn(I)-complexes:

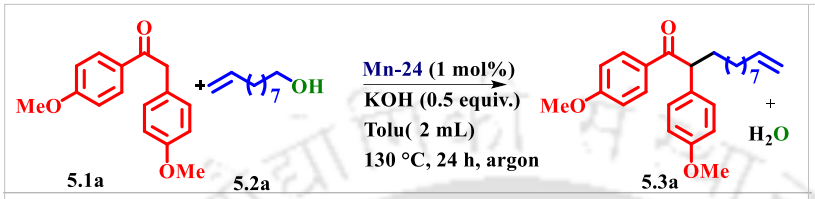
Rationally designed ligands and corresponding complexes have been synthesised to fulfil the hypothesis related to *α*-functionalization of *α*-branched ketones. The synthetic procedures of ligands and corresponding complexes are mentioned in experimental section **5.15**.



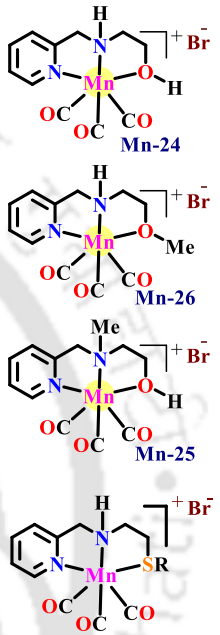
Investigation was started using distally unsaturated oil derived alcohols as an alkylating partners to unsaturated branched ketones synthesis. Keeping the unsaturation intact during the catalysis is challenging task due to chain walking process. Therefore, as a test ground of this survey desoxyanisoin (**5.1a**) and 9-decen-1-ol (**5.2a**) were chosen as a model substrate. When the of 1:1.2 mixture of **5.1a** and **5.2a** were heated at 130 °C for 24 hours in presence of 1 mol% **Mn-24**, 40 mol% KO^{t}Bu in toluene solvent under argon 60% of desired distally unsaturated branch ketones (**5.3a**) were isolated (Table 5.1, entry 1). Keeping other reaction parameter constant only changing the base to NaO^{t}Bu slightly reduced the product yields but on moved to same mol% of KOH gave improved yields of the desired product and increasing KOH concentration to 50 mol% yields of the product was increased to 79% (Table 5.1, entry 2 & 3). However further increase of KOH loading gave similar yields (Table 5.1, entry 8). NaOH showed inferior results than KOH under same conditions. Starting materials were recovered in absence of catalyst and base under identical reaction conditions, which clearly indicated that presence of both, are very crucial for this transformation. Role of both functionalities at ligand scaffold was also tested. When **Mn-25** and **Mn-26** were introduced instead of **Mn-24**, 66%, 40% yields of the desired products were isolated which indicates that presence of hydroxyl functionality is more important than amino functionality and presence of both functionalities make this catalytic system is more effective (Table 5.1, entry 10 & 11). Previously developed catalysts (**Mn-6**, **Mn-17**, **Mn-20** & **Mn-21**) unable to deliver the

products under similar reaction conditions (Table 5.1, entry 12 & 13). Reduced yields of the target product were observed when the catalyst loading, reaction duration, and temperature were decreased (Table 5.1, entry 15 & 17). Weak carbonate and phosphate bases failed to deliver the product (Table 5.1, entry 18). On increasing the alcohol concentration, similar result was produced but result was decreased on reducing the alcohol concentration (Table 5.1, entry 19).

Table 5.1. Optimization table for Mn-catalysed distally unsaturated branch ketones synthesis. [a,b]



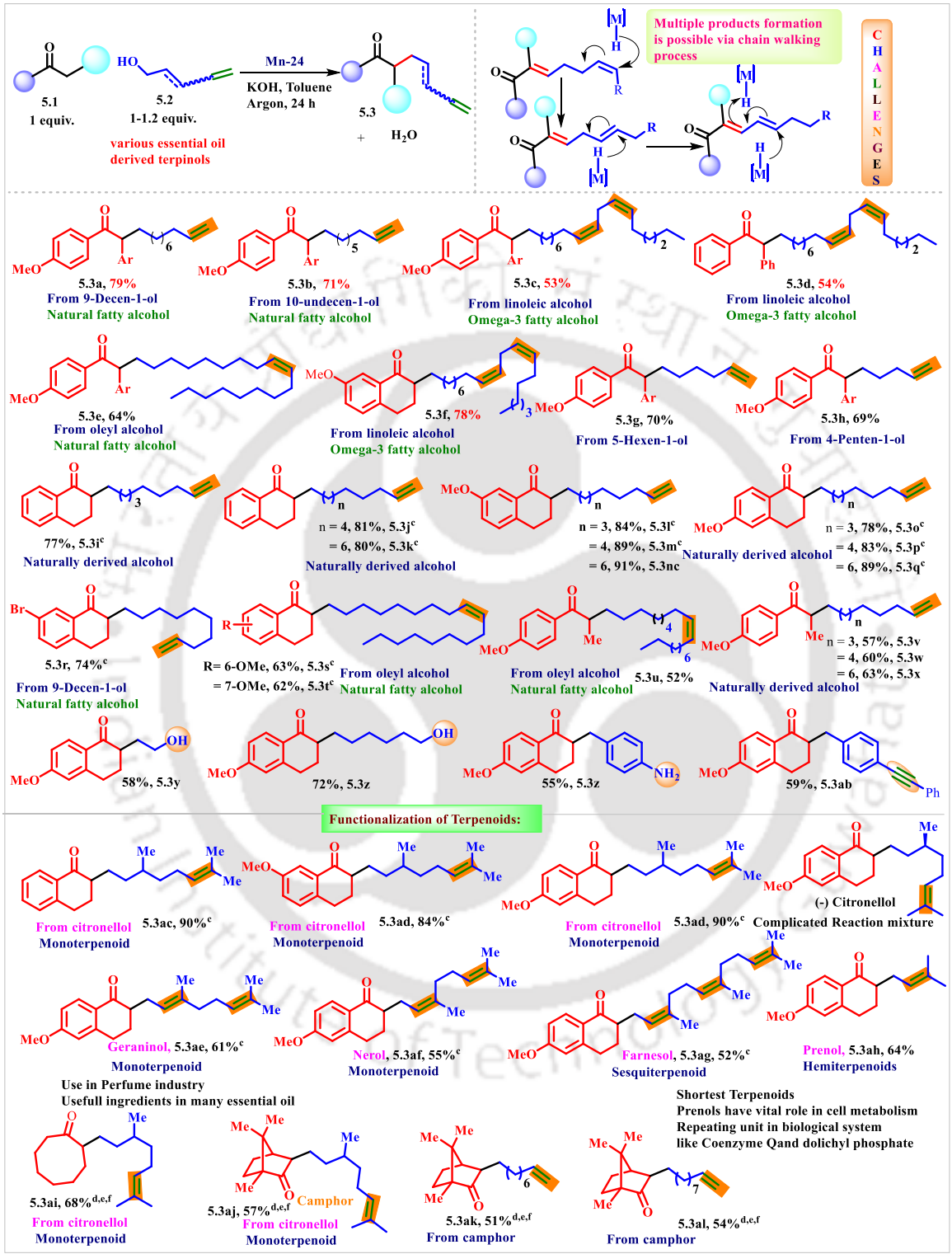
Entry	Deviation from above	5.3a % Yield [b]
1	KO^{t}Bu (0.4 equiv.)	60
2	NaO^{t}Bu (0.4 equiv.)	54
3	KOH (0.4 equiv.)	65
4	NaOH (0.5 equiv.)	41
5	No variation	79
6	Without Mn-24	S.M.R
7	Without KOH	S.M.R
8	KOH (0.6 equiv.)	80
9	Time: 36 h	80
10	Mn-25	66
11	Mn-26	40
12	Mn-17	10
13	Mn-6, Mn-20 & Mn-21	S.M.R
14	Xylene	77
15	Mn-24 (0.6 mol%)	58
16	Mn-24 (1.6 mol%)	80
17	Temperature: 100 °C	10
18	K_2CO_3, Cs_2CO_3 & K_3PO_4	S.M.R
19	5.2a: 1.0 & 1.4 equiv.	67 & 81



[a]**Reaction conditions: 5.1a** (1 mmol), **5.2a** (1-1.4 mmol), Base (0.4-1.0 mmol), **Mn-24** (0.6-1.6 mol %), Under argon, S.M. R=Starting materials recovered, [b]Isolated yields.

5.3.2. Substrate paradigm: After achieving the optimal reaction conditions, the generality of the discovered protocol was investigated. Delightfully, wide range of unsaturated alcohols and terpinols chemo-selectively participate functionalization with branch ketones to afford desired products **5.3a**-**5.3aj** up to in 93% isolated yields. At first, under established reactions conditions, desoxyanisoin (**5.1a**) was introduced, gratifyingly; unactivated 8-Nonen-1-ol and 9-Decen-1-ol chemo selectively reacted with desoxyanisoin providing good to excellent yields of the corresponding distally unsaturated ketones products (**5.3a** & **5.3b**). Two internal double bond at distal position of linonyl alcohol also intact and underwent smooth chemoselective *α*-

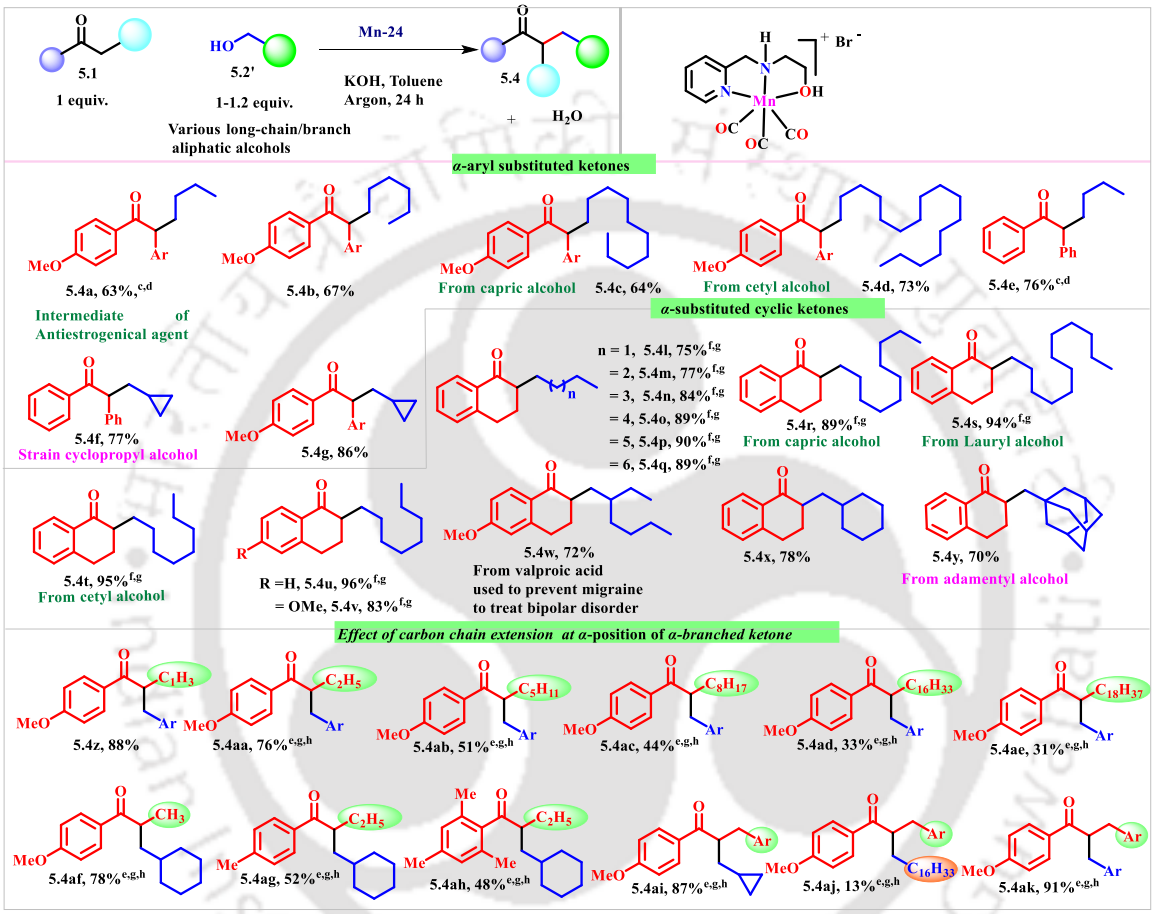
functionalization of bulky ketones in good isolated yields under standard reaction conditions (**5.3c**, **5.3d** & **5.3f**).



[a]**Reaction conditions: 5.1**(1 mmol), **5.2** (1-1.5 mmol), KOH (0.4-1.0 mmol), **Mn-24** (1-3 mol%), Toluene (2 mL), Temperature 130 °C, 15 h, [b]Isolated yields, [c]Mn-loading: 0.5 mol% & KOH: 0.3 equiv., [d]Alcohol: 1.5 equiv., [e]Mn loading: 3 mol%, [f]KOH: 0.8 equiv.

Very recently, Krische,[8a] Patel[8a] and others[8c] constructed various important organic scaffolds and installed different moieties at remote positions utilizing chain walking or chain isomerization process of distal double bond. Thus, there is a substantial chance of isomerization of double bonds and hence keeping the unsaturation intact at a specific position is a challenging task in borrowing hydrogen catalysis especially when shorter chain alkenyl alcohols like 4-penten-1-ol and 5-hexen-1-ol are used as alkylating agent. Next, the scope of 4-penten-1-ol and 5-hexen-1-ol was scrutinized to check the feasibility of developed protocol for challenging chemoselective alkylation. Delightfully, 70% & 78% yields of the desired ketone products were isolated and 20% unreacted ketone recovered, no hydrogenated side products were observed (**5.3g** & **5.3h**). Catalyst efficiency was also tested for different tetralone derivatives with various alkenyl alcohols. Delightedly, reaction with oil derived 8-Nonen-1-ol, 9-Decen-1-ol and 10-Undecen-1-ol and tetralone, 6-methoxy tetralone, 7-methoxy tetralone were all viable in high yields (**5.3i-5.3r**, 77%-89%). Notable, labile bromo substituted tetralone was well tolerated in the catalytic system to deliver **5.3r** in 74% yields. Furthermore, naturally derived oleyl alcohol, which contain cis double bond at C-9 position also successfully, reacted with tetralone and 4´-Methoxypropiophenone, furnished desired α, α´-branch ketone derivatives with good yields (**5.3s-5.3u**). Interestingly, distally unsaturated alcohols such as 8-nonen-1-ol, 9-decen-1-ol and 10-undecen-1-ol smoothly underwent dehydrogenation process and chemoselectively coupled with open chain ketone 4´-methoxypropiophenone to deliver 55-62% yields (**5.3v-5.3w**) of the corresponding products. A novel approach in chemoselective functionalization, employing various *α*-substituted ketones with distally unsaturated alcohols, delivered outstanding catalytic performance. Furthermore, alcohols containing other reactive functional groups such as free hydroxyl, unprotected primary amine and alkyne also persisted, affording good yields of branched ketone alkylated products (**5.3y-5.3ab**). Next, different direct naturally derived, natural flavourings and biologically important terpenols[9] were subjected under current catalytic system. In 2012, U.S alone announced $5.3 billion per year for terpenoids extraction and its functionalization.[10] Due to these great demands, there is an urge to develop sustainable catalytic methods for activating biomass terpenols holds immense economic promise, catering to the growing market while reducing ecological footprint. Recently, Chen group[11] established an elegant redox divergent protocol using $[\eta^3\text{-allylPdCl}]_2$ precatalyst and various additive as a cocatalyst for α-functionalization of tetralones with terpenols. Thus, the application of **Mn-24** catalyst was tested for terpenols activation and functionalization of various bulky ketones (**5.3ac-5.3ad**). Delightedly, various *α*-citrilated tetralone derivatives were furnished in 84%-90% yields under (**5.3ac-5.3ad**). But enantiomerically pure citranellol formed complicated reaction mixture under the optimized conditions. Very recently, Pd and Fe-precatalysts were discovered for the synthesis of terpenylated oxindole.[12] Next, more challenging long chain terpenol such as C10-geraneol, nerol and C15-farnesol were introduced with 7-methoxy tetralone. Delightfully, **Mn-24** catalysed protocol successfully delivered geraneol, nerol and farnesol

functionalized 6-methoxy tetralone (**5.3ae-5.3ag**) was isolated in good yields. Prenol (C5) is the shortest terpenoid in the terpenoids family also found to be compatible under standard conditions and gave 64% corresponding products (**5.3ah**). Notable, prenylated unit found in many natural products, pharmaceuticals and plays vital role in cell metabolism.[13] Eight members cyclic ketone and camphor reacted very efficiently with various naturally derived alcohols, delivered good isolated yields (**5ai-5al**).



[a]**Reaction conditions: 5.1**(1 mmol), **5.2´** (1-4 mmol), KOH (0.4-1.0 mmol), **Mn-24** (1-3 mol%), Toluene (2 mL), Temperature 130 °C, 15 h, [b]Isolated yields, [c]100 mL seal tube & 3 equiv. alcohol, [d]KOH: 1.0 equiv. & Mn-loading: 3 mol%; [e]Mn-loading: 5 mol%; [f]Mn-loading: 0.5 mol%, [f]KOH: 0.2 equiv.; [g]2.5 equiv. alcohol; [h]KOH: 1.7 equiv.

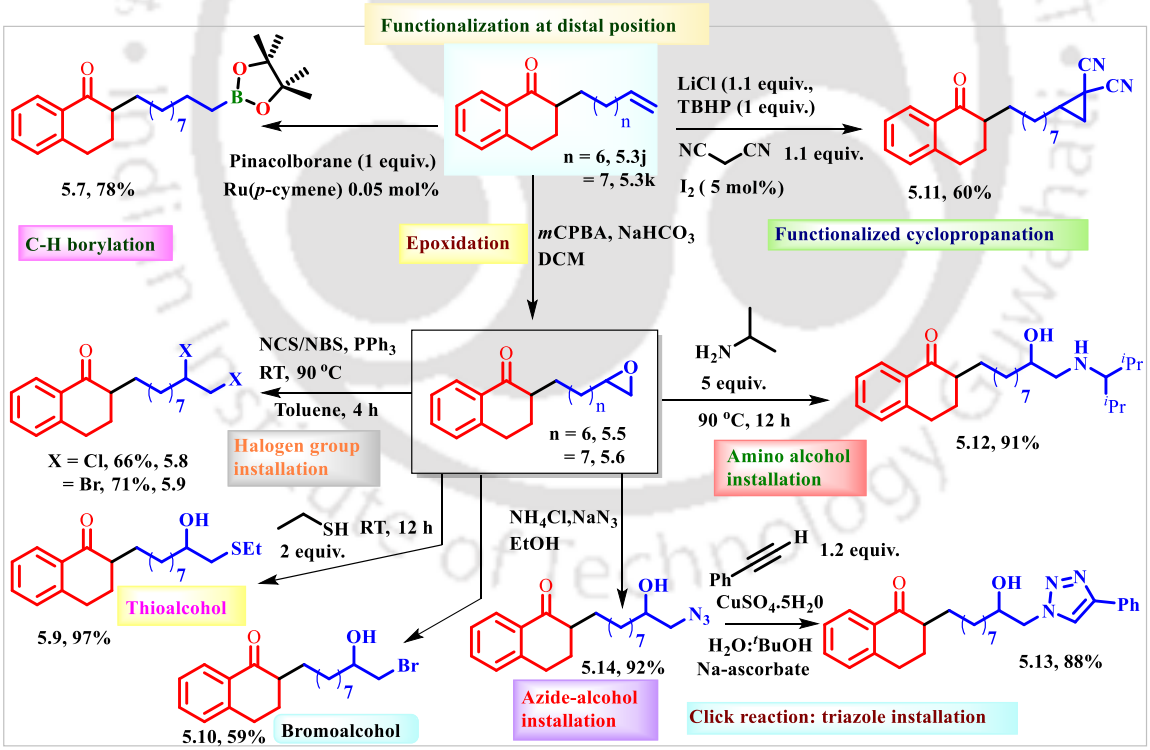
Next, the applicability of various saturated aliphatic cyclic and acyclic alcohols was tested to synthesize *α, α´*-disubstituted ketone derivatives. Notably, these *α, α´*-disubstituted ketones can easily be converted to synthetically and biologically important tetrasubstituted olefins and *α*-quaternary carbonyl derivatives[14] BH-alkylation of several open chain alkyl alcohols with branched ketones, such as 2-phenyl acetophenone and desoxyanisoin, was studied under modified reaction conditions. Gratifyingly, good yields of desired products (up to 80%) were isolated for all the cases (**5.4a-5.4e**). Next, the applicability of saturated cyclic alcohols with different bulky carbonyl

nucleophiles was examined. Cyclopropyl methanol has prone to open up the strain by forming acyclic chain molecules in presence of strong acids, bases or metal catalysts.ref Of note, the developed protocol effectively delivered corresponding *α*-functionalized product (**5.4f** & **5.4g**) in 76% yields without disturbing the cyclo propyl ring. Six-member cyclic methanol also gave good to excellent yields with bulky acyclic branched ketones under standard reaction conditions (**5.4h-5.4j**). Current catalytic system also effectively installed butyl to nonyl chain at *α*-position of tetralone derivatives in 75%-93% yields (**5.4l-5.4q**). Various biomass derived long chain fatty alcohols like capric, lauryl, cetyl and stearyl also suitable coupling to delivered desired *α*-functionalized tetralone derivatives up to 96% isolated yields (**5.4r-5.4t**). Valproic acid (used for prevent migraine and bipolar disorder) derived alcohol successfully reacted with *α*-tetralone, furnished desired product (**5.4w**) in 72% isolated yields. Cyclic alcohols like cyclohexayl methanol and sterically hindered adamantly methanol provide the targeted product in 71% isolated yields (**5.4x** & **5.4y**). The effect of the *α*-position methylene chain length on aryl ketone reactivity was investigated using aromatic and aliphatic alcohols. The reaction of 4-methoxybenzyl alcohol with a series of *α*-alkylated ketones (C_1-C_{18}) demonstrated a gradual decrease in yield of the desired *α, α′*-branched ketone products as the chain length increased, this can be attributed to the increasing steric hindrance at the *α*-position with longer alkyl chains. Similarly, employing cyclohexyl methanol with analogous branched ketones resulted in lower yields compared to the aromatic alcohol. This is likely due to the greater steric bulk of the cyclohexyl group's C(sp^3)-H compared to the C(sp^2)-H of the aryl group. The bulky C(sp^3)-H destabilizes the *β*-hydroxy ketone intermediate, potentially leading to the retro-aldol process. Interestingly, α-benzylated ketones provided excellent yields of the corresponding *α, α′*-disubstituted ketones when it reacted with aryl and cyclopropyl alcohols. However, using cetyl alcohol (C_{16}) afforded only a 13% yield of the dialkylated product, due to the competitive formation of carbonyl-reduction product and Guerbet condensation product as major byproducts. To demonstrate large scale applicability and environmental sustainability of developed catalytic approach, **5.3o**, **5.3z**, **5.3ab**, **5.4n**, **5.4p**, **5.4q**, **5.4r** and **5.4v** were synthesised in gram scale using lower catalyst, base loading keeping other conditions identical and evaluated green chemistry metrics which unveiled the impressive technical and environmental benefits of this current process. (discussed in experimental section 5.14)

5.3.3. Potential applications of distal alkene:

In synthetic organic chemistry alkenes and carbonyl moiety is considered one of most prevalent functionality and largely used in pharmaceutical, polymer, lubricants, detergents, fragrances and cosmetics industries.[15] This chemoselective alkylation with unsaturated alcohols not only delivered new distally olefinated ketones but also open up new opportunities to install different functional groups and moieties like heterocycles, carbocycle etc. To install different functional groups/moieties at distal position of newly prepared unsaturated carbonyl compounds, **5.3j** & **5.3k**

are used as a representative compounds. At first, ruthenium catalysed chemoselective hydroboration reaction **5.3k** was performed to afford carbonyl alkylboronic ester (**5.7**) which has broad applications in cross-coupling reactions. Next, I_2 catalysed dicyanocyclopropane formation **5.3k** was achieved using TBHP as an oxidant and LiCl as an additive in cyclohexane medium at 50 °C for 24 h. Epoxidation of terminal olefin of **5.3j** and **5.3k** furnished 92% (**5.3j**) and 90% (**5.3k**) yields respectively employing *m*CPBA as the oxidant. Next, the formed epoxide **5.6** was subjected to various fundamental organic transformation for structural modification. Dichlorination and dibromination of epoxide **5.6** was accomplished with excellent yields using NCS/Ph_3P or NBS/Ph_3P. Appel type reaction of **5.6** provided bromohydrin in 59% yields. Reaction between epoxide **5.6** and ethanthiol under basic medium at room temperature afforded secondary thiol alcohol, **5.10** in 97% yields. Epoxide **5.6** was also converted into terminal amino alcohol (**5.12**) with 91% yields. Notable, terminal amino alcohol could be used for further functionalization, specially transition metal catalysed N-substituted pyrrole could be installed at terminal position of ketone. Next, installed biologically important triazole unit at distal position of ketone via distal azidation and click reaction of epoxide **5.6**. Delightfully, in the both steps 92% and 88% yields were isolated.



Scheme 5.3. Synthetic applications of distally unsaturated branched ketones.

5.4. Mechanistic study:

5.4.1. Control experiments:

To understand the catalytic insight, several kinetic and control experiments were conducted. At first, three reactions-(i) dehydrogenation of butanol to butanal, (ii) condensation reaction between butanal and desoxyanisoin and (iii) hydrogenation of *α, β*-unsaturated ketone was performed to understand the functions of the catalyst in different stage of current protocol. Each reaction was performed in presence of catalyst **Mn-24** and absence of catalyst keeping other parameters identical to the standard reaction conditions. Results indicated that for each reaction absence of catalyst failed to deliver the desired product but presence of the catalyst successfully able to furnish the desired product which indicates that the catalyst plays significant role in each of the above three steps involved in this reaction. The deuterium scrambling experiment with deoxyanisoin and *α*-deuterated hexanol **5.2a-d2** under standard conditions resulted *α*-deuterated branched ketone in 34% yields (Figure 5.1, 3). The 81% deuterium incorporation at the *α*-position of the corresponding branched ketone product recommends the working of a BH cascade event in this protocol. The homogeneous nature of this catalytic cycle was examined by Hg-poisoning experiment. The addition of extra 2 equivalent metallic mercury drop in the standard reaction conditions which also successfully furnished identical yields of the desired branched product (**5.1a**) which clearly supported the non-radical reaction pathway of this protocol (Figure 5.1, 4). Selectively *α, β*-unsaturated ketone was obtained in 67% on reducing the hydrogen source alcohol and mol% of catalyst keeping other conditions constant.

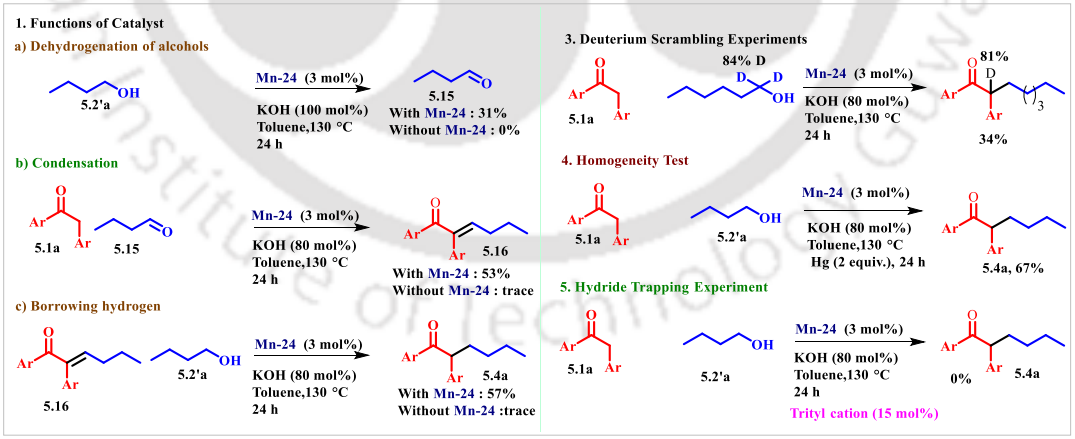


Figure 5.1. Control experiments for *α*-functionalization of branched ketones.

5.4.2. Kinetic study: Kinetic experiment for this *α, β*-unsaturated ketone synthesis also suggesting that the steady formation of butanal and gradual increment of *α, β*-unsaturated ketone during the course of the reaction under similar reaction conditions. The applicability of other alcohols and ketone were also test for various *α, β*-unsaturated ketone synthesis. Kinetic analysis

of the **Mn-24**-catalysed reaction for the synthesis of highly branched ketones with deoxyanisoin (**5.1a**) and hexanol (**5.2b´**) showed that, in contrast to both condensation and dehydrogenation of alcohols, the transfer hydrogenation of *α, β*-unsaturated branched ketones occurs very quickly.

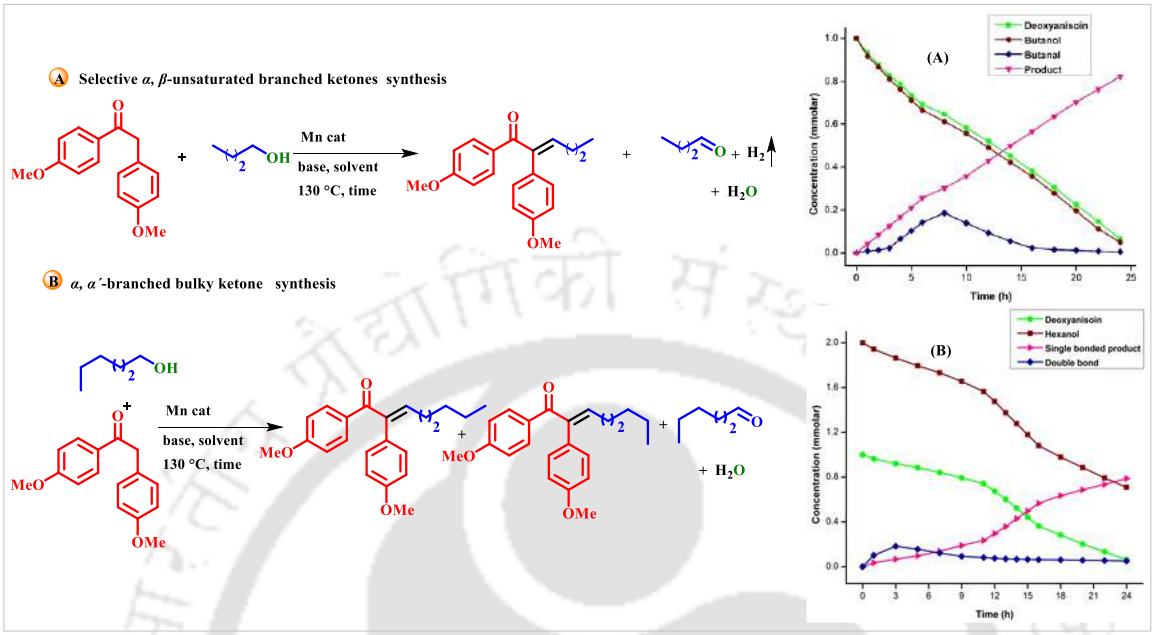


Figure 5.2. Kinetic profile of Mn-catalysed functionalization of bulky ketones with long chain alcohols. Graph of (A) reaction profile for selective alkenylation of bulky *α*-branched ketone. (B) alkylation of bulky *α*-branched ketone ketone.

5.4.3. Elucidation of catalytically active Mn-oxido complex:

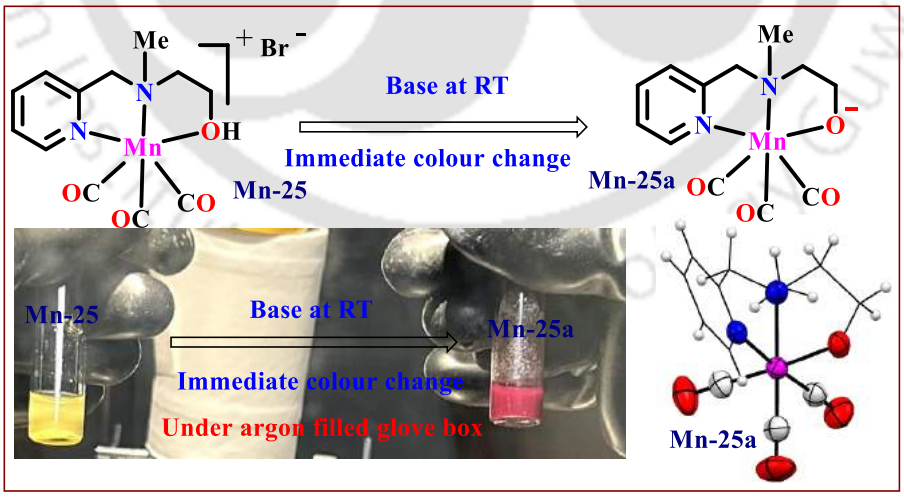


Figure 5.3. Treatment of base for elucidation of catalytic intermediated.

The immediate light-yellow solution converted into pink with the addition of base, KOH (9 mg, 0.4 mmol), in the THF solution of both Mn (**Mn-24**, 0.2 mmol, & **Mn-25**, 0.2 mmol) complexes. After stirring the mixture for 30 minutes at room temperature inside the glove box. The resulting mixture

was filtered through a celite pad. Then, the crystal has been grown by layering the filtrate THF part of both with pentane and keeping it at -10 °C inside the argon-filled glove box.

5.4.4. Role of catalyst for preventing retro-aldol process: A computational and experimental approach:

One major difficulty in BH-mediated alkylation of α-branched carbonyl compounds with long chain alcohol is the unstability of the formed β-hydroxy carbonyl compounds. Due to steric hindrance, the intermediate prefers to revert to its original reactants rather than eliminate water to form the desired α, β-unsaturated ketone.

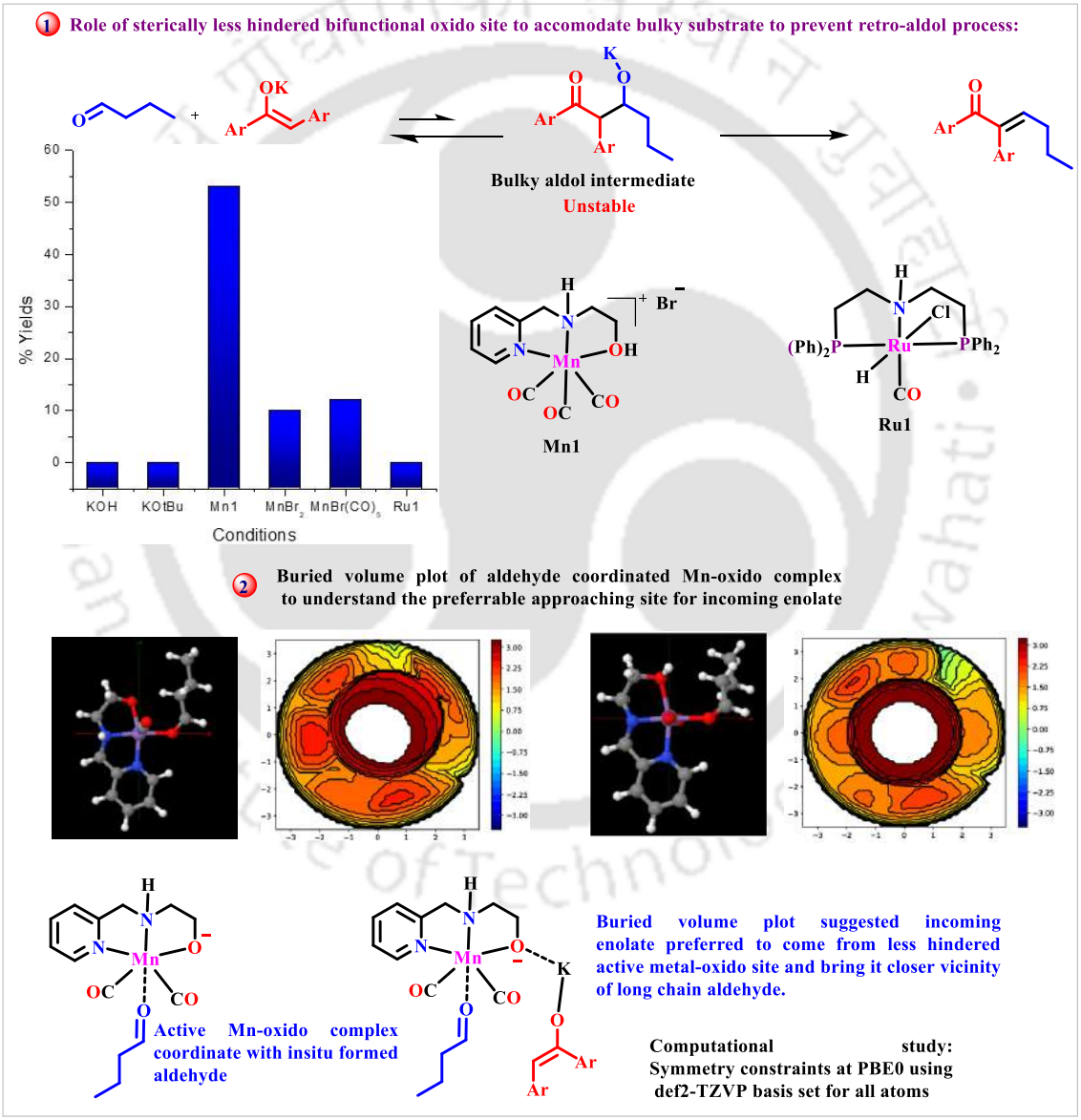


Figure 5.4. (1) Experimental study of retro-aldol process; (2) buried volume plot to understand the most favourable approaching site of catalyst to accommodate incoming substrate.

Therefore, a special type of catalyst is needed that can facilitate the reaction by coordinating both reactants, bringing them into close proximity and stabilizing the unstable intermediate. Thus, it would be crucial to have a greater understanding of the function of the less-hindered hydroxyl end in our Mn-catalysts for this process. The investigation of the aldol-condensation of butanal and desoxyanisoin demonstrates that $MnBr_2$ and $MnBr(CO)_5$ provided only 10–15% of the desired condensation product, while only base failed to yield any *α, β*-unsaturated ketone. This suggests metal may play a role in enhancing the electrophilicity of aldehyde through coordination. To our delight, when this reaction was performed in the presence of our rationally designed **Mn-24** catalyst, it successfully produced the desired *α, β*-unsaturated ketones in 53% isolated yield. The Ru-MACHO which is an excellent catalyst for BH transformations and extensively applied for BH-methylation was found completely inactive for coupling of *α*-branched carbonyl compounds and long chain aliphatic alcohol. This prompted us to examine the ability of Ru-MACHO in cross-aldol condensation reaction of butanal and desoxyanisoin. The catalyst completely failed to achieve the aldol-adduct. This underpins the role of catalyst in aldol step is extremely crucial for the success of the overall process. Our developed Mn-catalyst not only has a less sterically hindered environment to accommodate aldehyde, but it also contains an oxido arm that can use chelation to get the enolate closer to the aldehyde (Figure 5.4). The buried volume analysis also suggested that the incoming enolate also preferred to approach less hindered Mn-oxido end of **Mn-24** complex.

Detailed computational analysis also align with our experimental observation. Initially, our steric analysis of the aldehyde coordinated Mn suggested preferential approach of the incoming substrate towards the less hindered oxido or hydroxyl site. After chelation of both aldehyde and enolate with the catalyst, the entire adduct stabilizes by -28.1 kcal/mol. In contrast, the non-catalytic system leads to a potassium-coordinated adduct of both the aldehyde and the enolate, with a stabilization energy of only 13.4 kcal/mol. Subsequently, the nucleophilic enolate carbon attacks the electrophilic aldehyde carbon, resulting in the formation of a *β*-enolate ketone. In the presence of the Mn(I) catalyst, this pathway proceeds through a transition state (TS-1) with an energy barrier of 4.3 kcal/mol. The resulting intermediate is exergonic by 6 kcal/mol relative to TS-1 and 1.9 kcal/mol relative to the initial state (IM-1). Conversely, the non-catalytic pathway encounters a significantly higher energy barrier of 13.0 kcal/mol at its corresponding transition state (TS-1'). This intermediate (IM-2') is destabilized by 11.6 kcal/mol compared to IM-1'. Additionally, the energy barrier between TS-1' and IM-2' is only 1.4 kcal/mol, implying a highly unstable IM-2'. This suggests a reversible step in the absence of the Mn(I) catalyst, where IM-2' can revert to either the starting aldehyde and enolate or back to IM-1'. Conversely, precluding the reversibility in the presence of the Mn(I) catalyst by chelating the unstable *β*-enolate ketone.

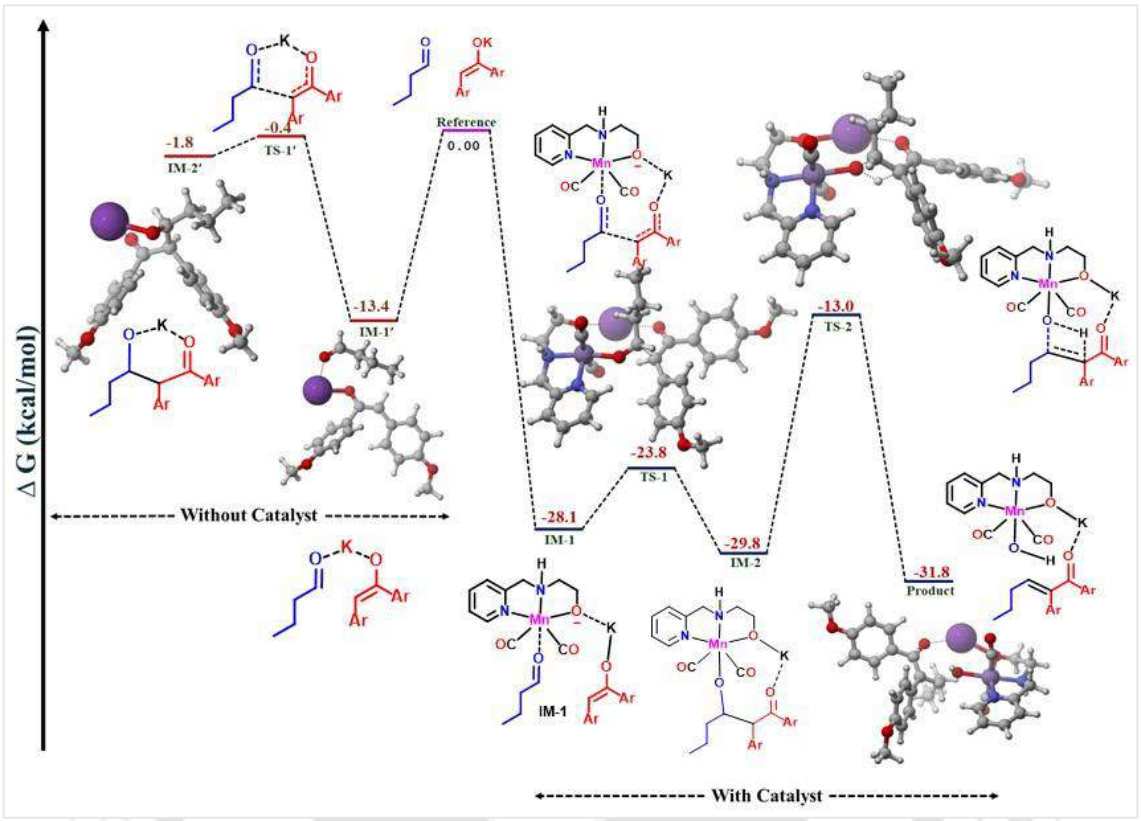


Figure 5.5. Computational analysis of catalytic and non-catalytic aldol reaction. [All calculations were performed using Param-Kamrupa, a supercomputer at IIT Guwahati, National Supercomputing System].

5.5. Catalytic cycle: Various experimental results and theoretical calculations suggested that the design of a less hindered hydroxyl site plays a key role in the success of this protocol. Two plausible catalytic cycles were drawn in figure 5.6. However, due to less steric hindrance at hydroxyl bifunctional site, it easily accommodates bulky alcohols and various bulky unstable intermediates like hinder *β*-hydroxyl aldol and highly branched *α, β*-unsaturated ketones more effectively. The computational analysis also suggested that the accommodations of such intermediates at less hindered hydroxyl site could be the energetically more favourable. Therefore, this transformation most likely to follow pathway-I to deliver the desired branched products.

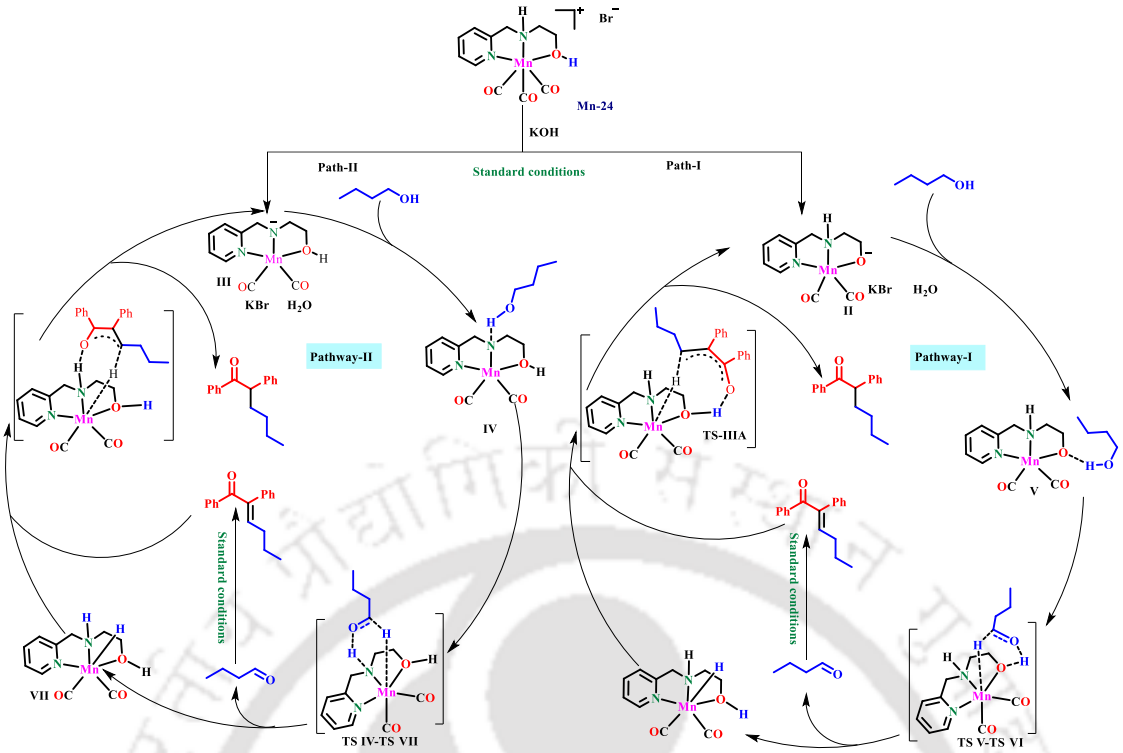
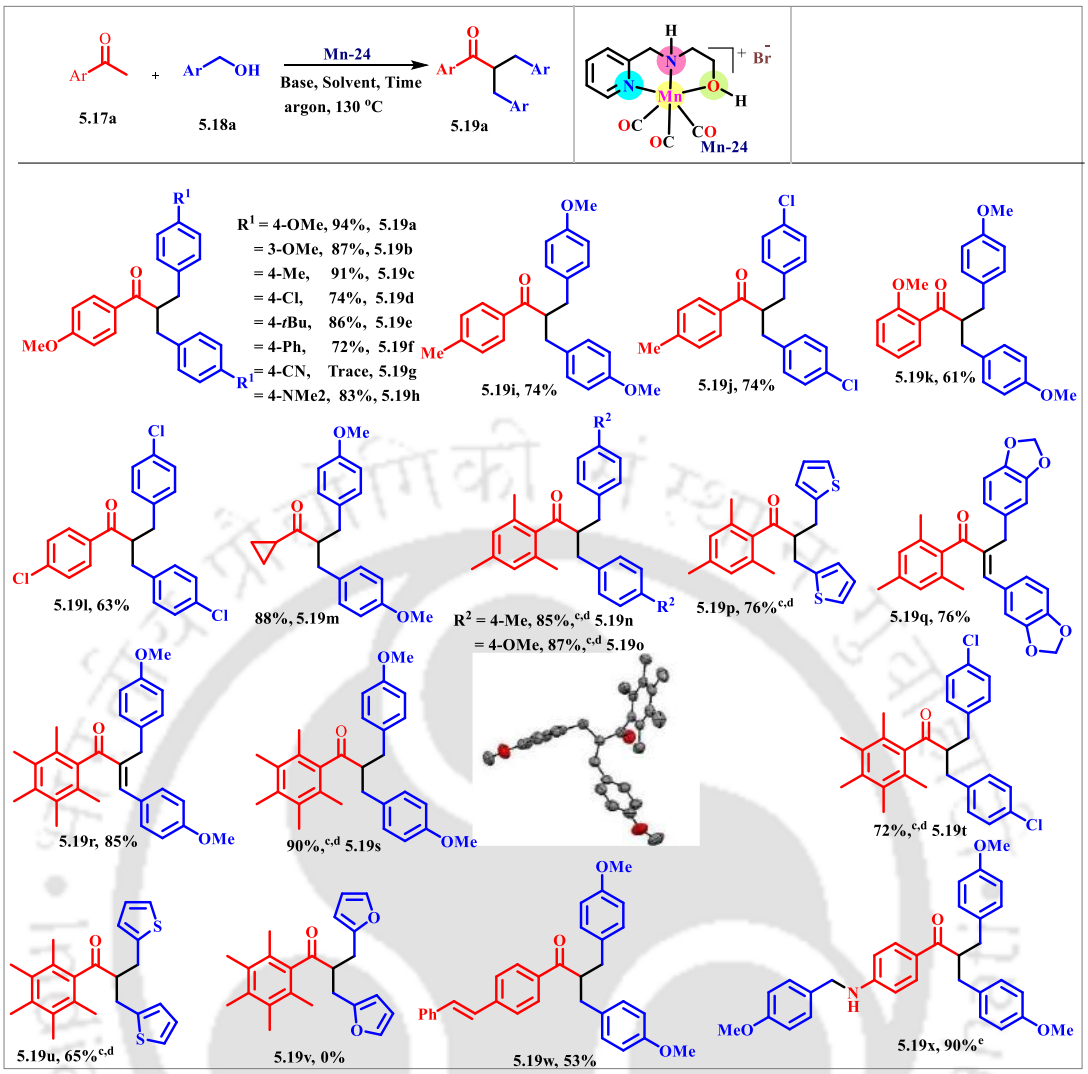


Figure 5.6. Catalytic cycles for *α*-functionalization of branched ketones.

5.6. One-pot *α, α´*-dialkylated branched ketone synthesis: The synthesis of *α, α´*-dialkylated branched ketone from *α*-branched ketones and alcohols was successfully established using developed Mn(I)catalyst. However, it would be more interesting if *α, α´*-dialkylated branched ketones could be synthesized directly from parent methyl ketones and alcohols. With the application of previously established reaction conditions (Table 5.1, entry 5), notably 4-methoxy acetophenone 4-methoxybenzyl alcohol efficiently reacted to deliver *α, α´*-dialkylated branched ketone in one pot by simply increasing the alcohol concentration to 2.2 equiv. and lowering the base loading (KOH, 0.25 equiv.). Then the scope and limitations of this methodology were explored. Pleasantly, different 4-substituted aromatic alcohols with electron-rich acetophenone delivered good to excellent yields of the desired double alkylated products (**5.19a**–**5.19k**) under developed reaction conditions; however, 4-cyanobenzyl alcohol was unable to furnish the desired product (**5.19g**). Highly strain cyclopropyl methyl ketone also reacted smoothly with 4-methoxybenzyl alcohol under catalytic protocol, furnishing 88% yields of the desired *α, α´*-branched product (**5.19m**). But in the case of penta substituted ketones, an excess amount of alcohol is required to achieve *α, α´*-disubstituted products (**5.19n**–**5.19u**). Hetero aromatic primary alcohols and halo substituted primary alcohols also gave good to excellent yields of *α, α´*-branched ketones with excess amounts of alcohol (**5.19t** & **5.19u**).



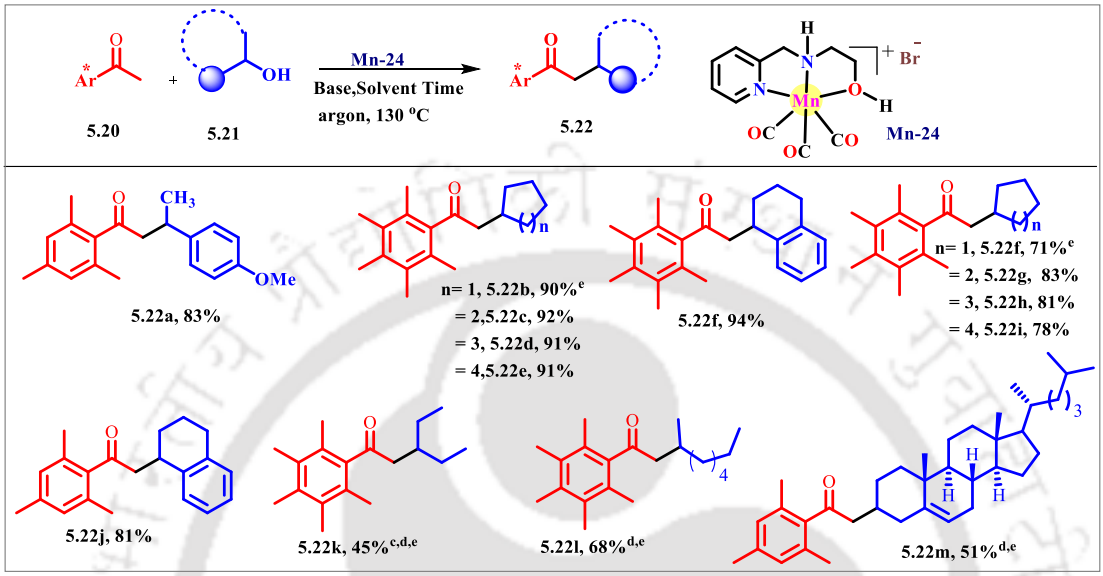
[a]**Conditions:** ketones (1 mmol), alcohols (2.2 mmol), KOH (0.25-0.4 equiv.), **Mn-24** (1 mol %), [c]Catalyst loading: 3 mol%, [d]KOH 0.5 mmol & alcohol: 6 equiv., [e]4 equiv. alcohol, under argon. [b]Isolated yield, Temperature: 130 °C.

The reaction of 4-amino acetophenone with 4-methoxy benzyl alcohol under the standard reaction delivered both C & N-alkylated products in 40% yield (**5.19x**) but the product yield increased up to 90% using 4 equiv. alcohol.

5.7. Activation of secondary alcohols for the synthesis of *β, β*-disubstituted ketones:

Next, the applicability of the **Mn-24** catalyst towards challenging secondary alcohol activation was investigated for functionalization of *α*-branched ketone (**5.1a**) applying the condition mentioned in table 5.1, entry 5. But under this reaction conditions, branched ketone (**5.1a**) and secondary alcohol [1-(4-methylphenyl) ethanol] were unreacted. Then, use of simple methyl ketone instead of *α*-branched ketones (**5.1a**) and [1-(4-methylphenyl) ethanol] also leads to the formation of mixture of undesired side products. Next, using 2, 4, 6-trimethyl acetophenone (to restrict self-aldol and transfer hydrogenation products) and tuning reaction reaction conditions (i.e., 1:2.2 ratio of ketones

and alcohols, KO^{t}Bu 1 equiv., 1 mol% of catalyst) under an argon atmosphere at 140 °C for 24 h, the *β, β*-branched ketone, **5.22a**, was isolated in 83% yields. Next, the applications of diverse cyclic secondary alcohols with different ring sizes were tested with pentamethyl substituted acetophenone. Pleasingly, under similar reaction conditions five to eight member's cyclic secondary alcohol furnished excellent yields (**5.22b**–**5.22e**).



[a]**Conditions:** ketones (1 mmol), alcohols (2.2 mmol), KO*t*Bu (1-2 equiv.), **Mn-24** (1 mol %), [c]alcohol: 4 equiv. [d]Catalyst loading: 3 mol%, [e]Alcohol: 2.5 equiv., Under argon. [b]Isolated yield, Temperature: 140 °C.

Reactions with 1-tetralol and penta methyl acetophenone also smoothly proceeds under the optimized conditions affording the desired product, **5.22f** in 94% yields. Further, cyclo pentanol, hexanol, heptanol, and octanol were also found to be suitable coupling partners with 2, 4, and 6-trimethyl substituted acetophenone, delivering 71%, 83%, 81%, and 78% isolated yields (**5.22f**–**5.22i**), respectively. Unsymmetrical alcohol 1-tetralol produced an 81% yield with 2, 4, and 6-trimethyl substituted acetophenone under similar conditions (**5.22j**). Acyclic secondary alcohols 2-octanol reacted with pentamethyl substituted acetophenone and gave 68% yields (**5.22k**). But short-chain pentan-3-ol underwent *β*-functionalization in the presence of a slight excess of alcohol. Notable, under catalytic conditions, naturally derived cholesterol also smoothly functionalized and furnished 51% yields (**5.22m**).

5.8. Conclusion: In summary, this chapter highlights the synthesis of new class of sterically less hindered bifunctional Mn(I) catalyst that successfully overcome retro-aldol process which is the crucial step in functionalization of bulky *α*-branched ketones with bulky alcohols. This integrated two-component approach offers a new platform to synthesize highly *α*-functionalized bulky ketones and simultaneous installation of various functional group, carbocycles and heterocycles at distal position of ketones. Density functional theory studies were performed to understand the role of less

hindered bifunctional active site in the success of this state-of-art. This rational designed Mn(I) catalyst could sweeping up several avenues in de(hydrogenative) chemistry gleams in the domain of organometallic catalysis and synthesized numerous novel distally functionalized ketones could be also useful in various area of research. The developed catalyst has potential to activate secondary alcohols to afford *β*-disubstituted ketone derivatives with excellent yields.

5.9. Experimental section:

5.9.1. General considerations: Unless otherwise mentioned, all chemicals were purchased from common commercial available 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, JACOMAX glove box filled with argon. DRX-400 Varian spectrometer and Bruker Advance III 400 MHz, 500MHzand 600 MHz spectrometers were used to record ^{1}H and ^{13}C NMR spectra using DMSO-d_6, $CDCl_3$, C_6D_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, dt = doublet of triplet, td = triplet of doublet and brs = broad singlet. ATIR data was collected on PerkinElmer IR spectrometer. Q-TOF ESI-MS instrument (Agilent: 6546 LC/Q-TOF) was used for recording mass spectra. PerkinElmer clarus-590 GC instrument using Elite Plot-Q is used for GC analysis. Single crystal X-RAY diffractometer (BRUKER D8QUEST) is used for single crystal data collection. SRL silica gel (100-200 mesh) was used for column chromatography.

5.9.2. General synthetic procedure of *α, α*-branch distally unsaturated and saturated ketones: In a 10 mL oven-dried round bottom flask/ 100 mL seal tube, *α*-branch ketone derivatives **5.1** (1.0 mmol), alkenyl alcohols/alkyl alcohols (0.5-3 mmol), KOH (0.2-0.8) were added. Then connected with high vacuum for 10 mins, then 1 mL dry toluene and **Mn-24** (1-3 mol %), was added under argon atmosphere. Then the reaction mixture was refluxed in preheated oil bath at 130 °C for 24 h. After completion of the reaction mixture was cooled to room temperature and ethyl acetate was added and filtered through celite pad. Filtrate mixture was evaporated in reduced pressure and purified by column chromatography using a gradient of hexane and ethyl acetate (eluent system) to afford the pure product **5.3/5.4**.

5.9.3. General synthetic procedure of one-pot *α, α*-branch ketones: In a 10 mL oven-dried round bottom flask, *α*-branch ketone derivatives **5.1´** (1.0 mmol), primary alcohols, **5.2´** (1.0-6 mmol), KOH (0.2-0.5 mmol) were added. Then connected with high vacuum for 10 mins, then 1 mL dry toluene and **Mn-24** (0.5-3 mol %)was added under argon atmosphere. The reaction mixture

was refluxed in an oil bath at 130 °C for 24 h. After completion of the reaction mixture was cooled to room temperature and ethyl acetate was added and filtered through celite pad. Filtrate mixture was evaporated in reduced pressure and purified by column chromatography using a gradient of hexane and ethyl acetate (eluent system) to afford the pure product **5.19**.

5.9.4. General synthetic procedure of *β, β*-disubstituted branch ketones: In a 100 mL oven-dried seal tube, highly substituted ketones, **5.1´´** (1 mmol) primary alcohols (2.5 mmol), KO^{t}Bu (1-2 mmol) were added. Then connected with high vacuum for 10 mins, then 1 mL dry toluene and **Mn-24** (1-3 mol%), was added under argon atmosphere. The reaction mixture was refluxed in an oil bath at 140°C for 24 h. After completion of the reaction mixture was cooled to room temperature and ethyl acetate was added and filtered through celite pad. Filtrate mixture was evaporated in reduced pressure and purified by column chromatography using a gradient of hexane and ethyl acetate (eluent system) to afford the pure product **5.22**.

5.10. Mechanistic investigation:

5.10.1. Dehydrogenation of alcohol: To an oven-dried 100 mL seal tube, **Mn-24** (3 mol%), 1-butanol (1.0 mmol), toluene (2 mL) were added under argon. The reaction mixture was kept for heating at 130 °C for 24 h. Then, the reaction mixture was submitted for crude NMR analysis (the reaction scheme is presented in **Figure 5.1.**).

5.10.2. Aldol condensation of ketone and aldehyde: Deoxyanisoin **5.1a** (1.0 mmol), KOH (45 mg, 0.8 mmol) and butanal **5.15** (3 mmol) were charged in 100 mL seal tube in toluene (2 mL) under argon. The flask was then placed in a preheated oil bath at 130 °C. After 24 h, the crude reaction mixture was diluted by ethyl acetate and filter through celite. The filtrate was concentrated under vacuum and resultant residue was purified by column chromatography using 100-200 mesh size silica with hexane/ethyl acetate as an eluent, 53% product (**5.16**) was obtained. No product (**5.16**) was formed in the absence of *t*BuOK and catalyst (**Mn-24**) (the reaction scheme is presented in **Figure 5.1.**).

5.10.3. Transfer hydrogenation of intermediate *α, β*-unsaturated ketone: To an oven dried 100 mL seal tube *α, β*-unsaturated ketone, **5.16** (0.5 mmol), butanol, **5.2´** (3 mmol), KOH (0.8 mmol) and **Mn-24** (3 mol%) were taken, then 2 mL toluene was added under argon atmosphere. The resulting mixture was then placed into the preheated oil bath at 140°C under an argon atmosphere and continued for 24 h. After completion, the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100–200 mesh) with hexane/ethyl acetate mixture (0–2%) as eluent, 57% of **5.4a** was obtained (the reaction scheme is presented in **Figure 5.1.**).

5.10.4. Deuterium scrambling experiments: To an oven dried 100 mL seal tube deoxyanisoin, **5.1a** (1 mmol), deuterated 1-hexanol, **5.4b–d2** (3.0 mmol), KOH (0.8 mmol) and **Mn-24** (3 mol%) were taken, then 2 mL toluene was added under argon atmosphere. The resulting mixture was then placed into the pre heated oil bath at 140 °C under an argon atmosphere and continued for 24 h. After completion, the reaction cooled to room temperature, after that ethyl acetate was added to it and filtered through celite. The filtrate was concentrated under vacuum, the residue was purified by column chromatography over silica gel (100–200 mesh) with hexane/ethyl-acetate mixture (0–2%) as eluent, 34% of '**5.4b-d2'** was obtained with 81% deuterium incorporation in *α*-position. The percentage of deuterium incorporation was analysed using ^{1}H NMR spectroscopy (the reaction scheme is presented in **Figure 5.1.**).

5.10.5. Hg-dropping experiment: In an oven dried 100 mL seal tube deoxyanisoin, **5.1a** (1 mmol, 150 mg), 1-butanol, **5.2´a** (3 mmol, 108 mg), KOH (0.8 mmol), and 2.0 equiv. metallic Hg were taken together and connected with high vacuum for 10 minutes. Then 2 mL dry toluene and **Mn-24** (3 mol%) are added to the mixture tube under argon. The reaction mixture is heated at 130 °C. After stirring for 24 h, the mixture is cooled down to room temperature. Then, reaction tube was taken out from hot oil bath and cooled to room temperature. Then purified the crude reaction mixture using 5% petroleum ether and ethyl acetate as an eluent (the reaction scheme is presented in **Figure 5.1.**).

5.10.6. Hydride trapping experiment: In an oven dried 100 mL seal tube deoxyanisoin, **5.1a** (1 mmol), 1-butanol, **5.2´b** (4 mmol), KOH (0.8 mmol) 2 mL dry toluene and **Mn-24** (2.5 mol%) are added sequentially inside the argon filled glove box. Then reaction mixture is stirred at room temperature. After stirring for 0.5 h, 10 mol% tritylium tetrafluoroborate is added to the previous reaction mixture. Then, the tube was sealed and placed in a preheated oil bath at 130 °C (oil bath temperature) for 24 h. After completion of the reaction, the tube was allowed to cool at room temperature. Then, analysed the ^{1}H nmr of crude reaction mixture which indicated that no product was formed (the reaction scheme is presented in **Figure 5.1.**).

5.11. Synthetic applications (All the reaction schemes are presented in **Figure 5.3.**):

5.11.1. Borylation at distal position of *α*-branch tetralone: The synthesis of **5.7** was carried out according to the literature procedure. To a screw cap 25 mL schlenk tube **5.3i** (0.25 mmol), $RuCl_2$(*p*-cymene) (1 mol%), and pinacolborane (0.30 mmol) were charged in the argon filled glove box.[11] The reaction mixture was allowed to stir at room temperature for 12 h. Upon completion, the resulted boronate ester product was separated by silica-gel column chromatography using ethyl acetate in hexane as an eluent to give colourless oil as a title compound (**5.7**). The compound was further analysed via ^{1}H, ^{13}C NMR and HRMS spectrometry.[15]

5.11.2. Experimental procedure of epoxidation of distal double bond: To a 10 mL RB equipped with a stir bar was added **5.3i & 5.3j** (3.0 mmol), $NaHCO_3$ (4.5 mmol) and DCM (7 mL). The mixture was cooled to 0 °C before *m*CPBA (5 mmol) was added. After being stirred at 0 °C for 2 h, the reaction was further stirred overnight. The mixture was then diluted with DCM (15 mL) and quenched with saturated Na_2SO_3 (5 mL). The mixture was further stirred for 10 min and the organic layer was washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure. The crude mixture was purified by silica flash chromatography to afford the desired product **5.5** & **5.6** as a yellow oil.[16]

5.11.3. Installation of cyclopropane ring at distal position: To a solution of alkene **5.3j** (0.2 mmol) in cyclohexane (3.0 mL) were added malononitrile (0.25 mmol), LiCl (0.3 mmol), I_2 (0.04 mmol) and 70% TBHP (0.25 mmol). The reaction was stirred at 50 °C for 24 h. After reaction completion, the mixture was washed with 5% aqueous $Na_2S_2O_3$ (5 mL), and the solution was extracted with dichloromethane. The organic phase was dried over anhydrous Na_2SO_4 and concentrated. Purification by preparative TLC (hexane ethyl acetate) afforded analytically pure dicyanocyclopropane **5.11**.[18]

5.11.4. Amino-alcohol synthesis: To a 10 ml RB, was equipped with a stir bar was added **5.3j** (0.2 mmol), and isopropyl amine (5 equiv.) in methanol was heated at 90 °C for overnight. After completion of the reaction, the methanol and excess of isopropyl amine was evaporated and the organic compound was extracted with DCM in the presence of brine. The compound **5.12** thus isolated in 91% was directly analysed through NMR.[19]

5.11.5. Synthesis of azido-alcohol: To a solution of **5.6**, (0.5 mmol) in a mixture of MeOH (2 mL) and H_2O (1 mL), NH_4Cl (0.6 mmol) and NaN_3 (2.5 mmol) were added. The resulting reaction mixture was heated at reflux overnight. The solution was cooled to room temperature, and the product was extracted with dichloromethane (3 × 10 mL) and washed with brine (2 × 15 mL). The combined organic layers were dried with Na_2SO_4 filtered, and concentrated under reduced pressure. The resulting crude product was purified by column chromatography using ethyl acetate/hexane as eluent to afford the target compound (**5.14**) as a colourless oil (92%).[20]

5.11.6. Installation of triazole moiety: Phenylacetylene (0.25 mmol) and azide compound, **5.14** (0.75) were suspended in a 1:1 water/*tert*-butyl alcohol mixture. Sodium ascorbate (0.02 mmol, freshly prepared in 1 mL water) was added, followed by $CuSO_4 \cdot 5H_2O$ (0.5 mmol) freshly prepared in 1 mL of water). The reaction mixture was refluxed (80 °C) for 12 h. After completion of the reaction, tert-butyl alcohol was evaporated ina rotary evaporator, and the reaction mixture was partitioned between ethyl acetate and water. The collected organic layer was washed with water,

aqueous ammonium chloride, and brine solution and dried over anhydrous Na_2SO_4. After evaporation, the product was purified by column chromatography.[21]

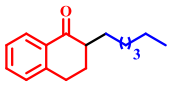
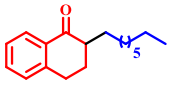
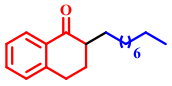
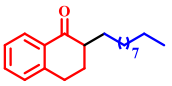
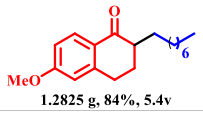
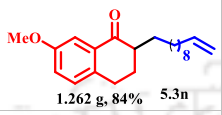
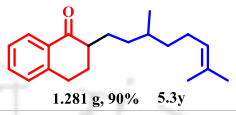
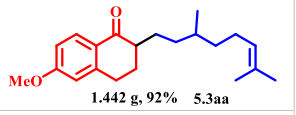
5.11.7. Installation of thioalcohol: In the methanolic saturated solution of NaOH (2 mmol NaOH in 4 mL MeOH) 1 mmol ethanthiol was added and stirred at room temperature for 1 h. After that 0.5 mmol epoxide **5.6** was added. The reaction mixture was stirred at room temperature for overnight. All volatiles are removed under reduced pressure and residue was extracted by CH_2Cl_2 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 (100-200 mess) column chromatography using 20-40 % ethyl acetate in hexane.[22]

5.11.8. Installation of dihalide at distal position: To a magnetically stirred solution of epoxide **5.6** (0.25 mmol) in toluene (3 mL) at room temperature were added Ph_3P (1.5 mmol) and NCS/NBS (1.5 mmol), and the mixture was heated at 90 °C for 10 h. The mixture was then poured into a separatory funnel and partitioned between satd $NaHCO_3$ and EtOAc. The organic phase was separated, dried over $MgSO_4$, filtered, and concentrated. The residue was purified by silica gel column chromatography to give dichloride **5.8 (66%)** and dibromide, **5.9** (71%) as a colourless oil.[23]

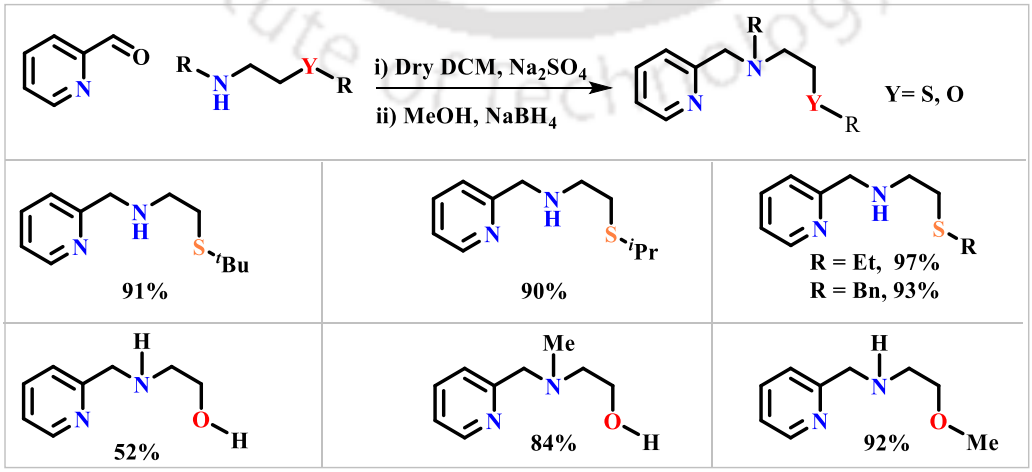
5.11.9. Synthesis of bromohydrin derivative: To a stirred solution of triphenylphosphine, PPh_3 (0.25 mmol) in dry CH_2Cl_2 (3 mL) was added bromine (0.50 mmol) under argon at 0 °C. The mixture was stirred for 15 min after which time a solution of **5.6** (0.40 mmol) in dry CH_2Cl_2 (2 mL) was added. The mixture was stirred for 15 min. and the reaction was quenched with water. The aqueous layer was extracted with CH_2Cl_2. The combined extracts were dried over $MgSO_4$ and concentrated under reduced pressure. The product was purified by silica gel flashchromatography yielding the bromohydrin, **5.10** (59%) as a colourless oil.[24]

5.12. Gram scale synthesis and green chemistry matric calculations:

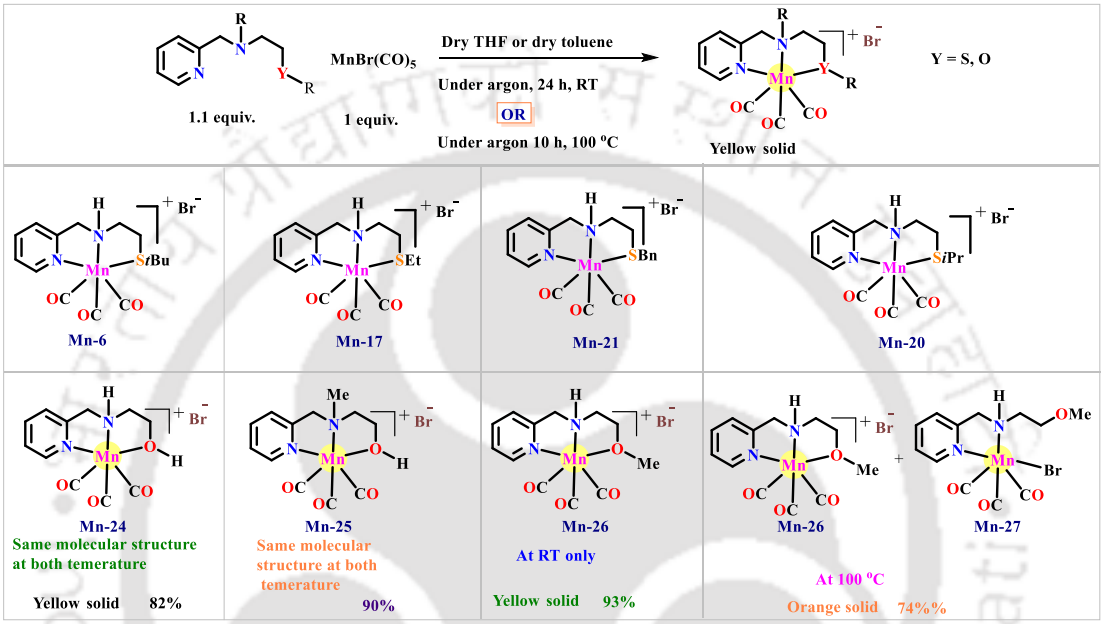
In a 50 mL oven-dried round bottom flask, α-branch ketone derivatives **5.1**(5.0 mmol), primary alcohols, **5.2** (5.0 mmol), KOH (0.20 mmol) were added. Then connected with high vacuum for 10 mins, then 4 mL dry toluene and **Mn-24** (0.5 mol %) was added under argon atmosphere. Then the reaction mixture was refluxed in preheated oil bath at 130 °C for 24 h. After completion of the reaction mixture was cooled to room temperature and ethyl acetate was added and filtered through celite pad. Filtrate mixture was evaporated in reduced pressure and purified by column chromatography using a gradient of hexane and ethyl acetate (eluent system) to afford the pure product **5.3**/**5.4**. Green chemistry matric of all the products are calculated using standard methods and all values are highlighted in above table.

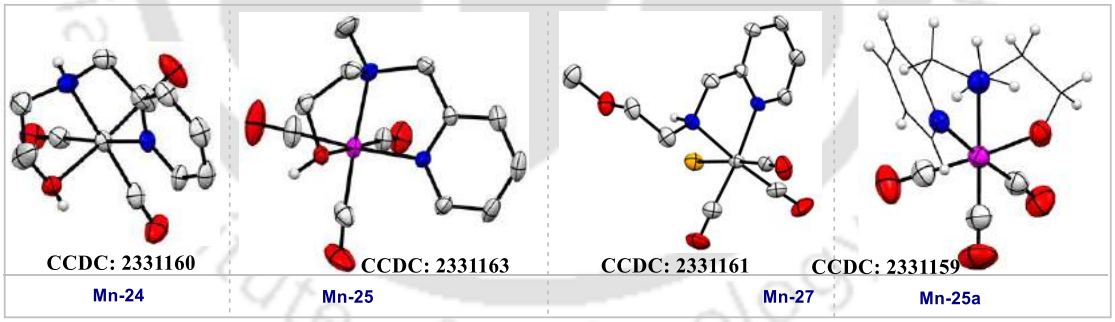
Compounds / Parameters	 0.979 g, 84% 5.4n	 1.176 g, 86% 5.4p	 1.226 g, 90% 5.4q	 1.332 g, 93% 5.4r
E-factor	1.23 kg waste/1kg waste	0.98 kg waste/1kg waste	0.95 kg waste/1kg waste	0.85 kg waste/1kg waste
Atom economy	93%	93.5%	94%	94.1%
Atom efficiency	78.1%	85.1%	84.6%	87.5%
Carbon efficiency	100%	100%	100%	100%
Reaction mass efficiency	79%	87%	84.4%	87.5%
Compounds / Parameters	 1.2825 g, 84%, 5.4v	 1.262 g, 84% 5.3n	 1.281 g, 90% 5.3y	 1.442 g, 92% 5.3aa
E-factor	0.86 kg waste/1kg waste	1.014 kg waste/1kg waste	0.92 kg waste/1kg waste	0.8 kg waste/1kg waste
Atom economy	94%	94.3%	94.1%	94.6%
Atom efficiency	78.1%	79.2%	84.7%	87%
Carbon efficiency	100%	100%	100%	100%
Reaction mass efficiency	84%	79.9%	85%	88%

5.13. Synthesis of Ligands: Pyridine-2-carboxaldehyde (5 mmol) and amino-ethanol/thiol derivatives (5 mmol) were dissolved in dry CH_2Cl_2 (15 mL) and then Na_2SO_4 (12.5 mmol) was added to it. The resulting suspension was stirred for 12 h at room temperature. Then, it was filtered and the filter residue was washed thoroughly with CH_2Cl_2 and the combined solvent was removed under reduced pressure. The residue obtained was directly used for the next step without further purification. The residue was dissolved in methanol (20 mL) and $NaBH_4$ (10 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 30 mL of water was added. After that, it was extracted by CH_2Cl_2 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 (100-200 mess) column chromatography using 20-40 % ethyl acetate in hexane.



5.14. Preparation of manganese complexes: All complexes were prepared according to previous reported literature methods.[29] Ligand NNS/NNO (1.1 mmol) was taken in 2 mL dry THF and was added drop wise to the orange-yellow suspension of $[MnBr(CO)_5]$ (1.0 mmol) in 3 mL degassed dry THF. Afterward, the suspension was refluxed for overnight under argon atmosphere. After the completion of the reaction, the reaction mixture was cooled down to the room temperature, then the solvent was evaporated to obtain the residue, which was further washed with hexane and diethyl ether, and dried under vacuum to a get yellow solid of Mn-complexes.



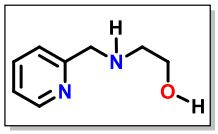


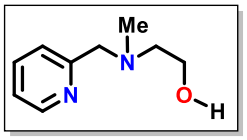
	Mn-24	**Mn-25**
Empirical formula	C_{11} H_{12} Mn N_2 O_4, Br	C_{12} H_{14} Mn N_2 O_4, Br
Formula weight	371.08	385.10
Temperature, T	296 K	296 K
Crystal system	monoclinic	triclinic
Space group	P 21/n	P -1

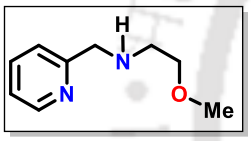
Unit cell dimensions	a=7.963(5)Å, α=90° b=21.994(12)Å, β=98.60(2) ° c= 8.314(5)Å, γ=90°	a=7.3733(5)Å, α=79.837(3)° b=8.8785(8)Å, β=75.722(2)° c=12.8155(14)Å, γ=71.616(4)°
Volume, V (Å3)	1439.8(15)	767.09(12)
Z	4	2
Density (calculated),	1.712	1.667
Absorption coefficient, μ (mm−1)	3.701	3.477
F(000)	736.0	384.0
Crystal size, mm3	0.39 0.35 0.31	0.22 0.15 0.10
Theta range for data collection	2.64to 26.50	1.649 to 24.992
Index ranges	-9 ≤ h ≤ 9, -26 ≤ k ≤ 26, -9 ≤ l ≤ 9	-8 ≤ h ≤ 8, -10 ≤ k ≤ 10, -15 ≤ l ≤ 15
Reflections collected	7574	3242
Independent reflections	2535	2544
Completeness to theta	0.999	0.941
Absorption correction	Multi-scan	Multi-scan
Refinement method	SHELXL-'2019/1'(Sheldrick,2018)'	SHELXL-'2019/1'(Sheldrick,2018)'
Data / restraints / parameters	2535/0/180	2544/0/ 186
Goodness-of-fit on F2	1.028	1.103
Final R indices [I>2sigma(I)]	R1 = 0.0675(2100),wR2= 0.1620(2535)	R1=0.0428(2124), wR2(reflections)= 0.1300(2544)
R indices (all data)	R_1= 0.0808, WR_2=0.1513	R_1= 0.0527, wR_2=0.1155
Extinction coefficient	3.701	3.477
Largest diff. peak and hole	0.973and -0.248e·Å-3	1.174 and -0.248e·Å-3

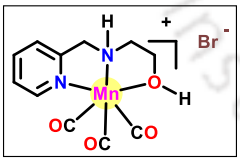
	Mn-25a	**Mn-27**
Empirical formula	C12 H13 Mn N2 O4	C_{11} H_{12} Mn N_2 O_4, Br
Formula weight	304.18	371.08
Temperature, T	297 K	298 K
Crystal system	'monoclinic'	monoclinic
Space group	C 1 2/c 1	P 21/n
Unit cell dimensions	a=13.0025(11),b=14.8905(12) c=14.8729(12), α=90, β=92.647(2),γ=90	a=8.6784(14), b=13.536(2) c=13.691(2) α=105.774(4) β=91.146(4) γ=90.908(4)
Volume, V ($Å^3$)	2876.5(4)	1439.8(15)
Z	8	4
Density (calculated), g cm^{-3}	1.405	1.712
Absorption coefficient, μ (mm^{-1})	0.928	3.701
F (000)	1248.0	736.0
Crystal size, mm^3	0.36 0.33 0.30	0.39 0.35 0.31
Theta range for data collection	2.081 to 25.065	2.64to 26.50
Index ranges	-15 ≤ h ≤ 15, -17 ≤ k ≤ 17, -17 ≤ l ≤ 17	-9 ≤ h ≤ 9, -26 ≤ k ≤ 26, -9 ≤ l ≤ 9
Reflections collected	9214	7574
Independent reflections	2541	2535
Completeness to theta	0.997	0.999
Absorption correction	multi-scan	multi-scan
Max. and min. transmission	'SHELXT 2018/2 (Sheldrick, 2018)	SHELXL-'2019/1'(Sheldrick,2018)'
Refinement method	2541/0/173	2535/0/180
Data / restraints / parameters	1.051	1.028
Goodness-of-fit on F^2	R1 = 0.0438(3784), wR2=0.1111(4559)	R1 = 0.0675(2100),wR2= 0.1620(2535)
Final R indices [I>2sigma(I)]	R1= 0.0577, WR2= 0.1011	R1= 0.0808, WR2=0.1513
R indices (all data)	1.311	3.701
Extinction coefficient	0.973 and -0.248e·Å-3	0.973and -0.248e·Å-3

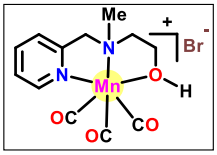
5.15. NMR data:

2-((pyridin-2-ylmethyl)amino)ethan-1-ol (5.23): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 20% to 50%) afforded the title compound in 52% yield (396 mg, 2.6 mmol) as yellow liquid. 
^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.54 (s, 1H), 7.65 (t, *J* = 7.6 Hz, 1H), 7.30 (d, *J* = 7.6 Hz, 1H), 7.20 – 7.11 (m, 2H), 3.97 (s, 3H), 3.95 (s, 3H), 3.74 – 3.60 (m, 3H), 2.87 – 2.77 (m, 3H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 159.0, 149.2, 136.7, 122.5, 122.23, 60.6, 54.2, 51.1.

2-(methyl (pyridin-2-ylmethyl) amino) ethan-1-ol (5.24): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 20% to 50%) afforded the title compound in 90% yield (747 mg, 4.53 mmol) as yellow liquid. 
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.48 (d, *J* = 4.6 Hz, 1H), 7.60 (t, *J* = 7.6 Hz, 1H), 7.27 (d, *J* = 7.8 Hz, 1H), 7.14 – 7.04 (m, 1H), 3.69 (s, 2H), 3.60 – 3.57 (m, 2H), 2.67 – 2.45 (m, 2H), 2.28 (s, 3H), 1.93 (brs, 1H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 158.9, 149.3, 136.7, 123.2, 122.5, 63.4, 59.0, 42.6.

2-methoxy-N-(pyridin-2-ylmethyl) ethan-1-amine (5.25): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 20% to 50%) afforded the title compound in 92% yield (764 mg, 4.6 mmol) as brown liquid. 
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.56 (d, *J* = 4.2 Hz, 1H), 7.64 (t, *J* = 7.6, Hz, 1H), 7.33 (d, *J* = 7.7 Hz, 1H), 7.11 – 7.07 (m, 1H), 3.88 (s, 2H), 3.60 – 3.46 (m, 2H), 3.29 (s, 3H), 2.79 – 2.77 (m, 2H), 2.55 (brs, 1H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 159.9, 149.4, 136.5, 122.3, 122.0, 72.2, 58.9, 55.3, 49.0.

NNO-Manganese (I) complex (Mn-24): Purification by washing using diethyl ether (10×4 mL) and hexane (10×2 mL afforded the title complex in 91% yield (304 mg, 0.82 mmol) as yellow crystalline solid. 
^{1}H NMR (500 MHz, DMSO-d_6) δ 8.88 (d, *J* = 5.2 Hz, 1H), 8.08 (t, *J* = 7.5 Hz, 1H), 7.64 (d, *J* = 7.8 Hz, 1H), 7.60 (t, *J* = 6.5 Hz, 1H), 7.46 (brs, 1H), 4.73 – 4.68 (m, 2H), 4.40 – 4.36 (m, 1H), 2.88 (m, 1H), 2.75 – 2.73 (m, 1H), 2.46 – 2.41 (m, 1H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 219.9, 216.7, 216.6, 160.2, 151.3, 138.2, 123.7, 120.2, 58.9, 57.79, 51.4.**IR (ATIR):** γ_{CO}2032, 1944 & 1925. **HRMS: (ESI):** Calc'd for. **$C_{18}H_{13}MnN_3O_3$ [M-Br]$^+$: 291.0178**; found = 291.0182. **Crystallization:** Methanolic saturated solution of **Mn-24**in 5 mL glass vial kept at room temperature.

NNO-Manganese (I) complex (Mn-25): Purification by washing using diethyl ether (10×4 mL) and hexane (10×2 mL afforded the title complex in 94% yield (361 mg, 0.94 mmol) as yellow crystalline solid. 
^{1}H NMR (500 MHz, Chloroform-d) δ 9.13 (s, 1H), 7.93 (s, 1H), 7.55 (s, 2H), 4.55 – 4.30 (m, 2H), 3.72 – 3.32 (m, 5H), 2.86 – 2.59 (m, 3H).**^{13}C NMR (150 MHz, $CDCl_3$) δ** 221.4, 218.2, 217.7,

159.2, 155.3, 140.2, 126.0, 123.0, 70.1, 63.3, 62.7, 55.3.IR (ATIR): γ_{CO}2032, 1944 & 1925. **HRMS: (ESI):** Calc'd for.**$C_{15}H_{22}BrMnN_2O_4$ [M-Br]$^+$: 305.0334**; found = **305.0330. Crystallization:** Methanolic saturated solution of **Mn-24** in 5 mL glass vial kept at room temperature.

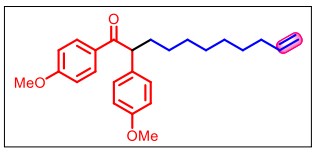
NNO-Manganese (I) complex (Mn-26): Purification by washing using diethyl ether (10×4 mL) and hexane (10×2 mL afforded the title complex in 91% yield (350 mg, 0.91 mmol) as yellow crystalline solid. **^{1}H NMR (500 MHz, Chloroform-d) δ** 8.99 (s, 1H), 7.78 (s, 1H), 7.37 – 7.34 (m, 2H), 4.52 – 4.50 (m, 2H), 4.08 – 3.96 (m, 4H), 3.79 (brs, 1H), 3.69 – 3.63 (m, 2H), 3.42 (s, 3H), 3.22 (s, 1H).**^{13}C NMR (150 MHz, CDCl3) δ** 222.5, 221.0, 158.8, 153.6, 138.1, 124.6, 121.1, 69.1, 58.7, 58.3, 55.4.IR (ATIR): γ_{CO}2032, 1944 & 1925. **HRMS: (ESI):** Calc'd for.**$C_{15}H_{22}BrMnN_2O_4$ [M-Br]$^+$: 305.0334**; found = **305.0332. Crystallization:** several combinations of solvents and techniques were applied to get the single-crystal of **Mn-26** but it formed poly crystals which are not suitable for analysis.

NNO-Manganese (I) complex (Mn-26+Mn-27): Purification by washing using diethyl ether (10×4 mL) and hexane (10×2 mL afforded the title complex in 74% yield (284 mg, 0.74 mmol) as orange crystalline solid.**^{1}H NMR (600 MHz, DMSO-d6) δ** 8.94 (s, 2H), 8.03–7.99 (m, 2H), 7.66 –7.53 (m, 4H), 6.00 (brs, 1H), 4.65–4.63 (m, 1H), 4.30–4.16 (m, 4H), 3.81–3.78 (m, 2H), 3.71–3.67 (m, 4H), 3.46–3.39 (m, 6H), 3.31–3.27 (m, 2H).**^{13}C NMR (150 MHz, DMSO-d6) δ** 222.9, 222.8, 222.4, 222.3, 221.9, 221.9, 162.3, 160.6, 153.5, 152.7, 139.2, 139.1, 125.3, 124.4, 122.3, 122.2, 70.3, 69.2, 58.7, 58.6, 57.8, 56.5, 55.7, 53.2, 40.2. IR (ATIR): γ_{CO}2032, 1944 & 1925. **HRMS: (ESI):** Calc'd for.**$C_{15}H_{22}BrMnN_2O_4$ [M-Br]$^+$: 305.0334**; found = **305.0330.**

Crystallization: Methanolic saturated solution of **Mn-27** in 5 mL glass vial kept at room temperature.

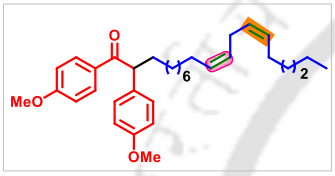
1,2-bis(4-methoxyphenyl)undec-10-en-1-one(5.3a): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 79% yield (312 mg, 0.79 mmol) as brown oil.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.95 (d, *J* = 8.7 Hz, 2H), 7.21 (d, *J* = 8.4 Hz, 2H), 6.85 (d, *J* = 8.6 Hz, 2H), 6.81 (d, *J* = 8.4 Hz, 2H), 5.83 – 5.75 (m, 1H), 4.98 (d, *J* = 17.1Hz, 1H), 4.91 (d, *J* = 10.1Hz, 1H), 4.43 (t, *J* = 7.2 Hz, 1H), 3.80 (s, 3H), 3.73 (s, 3H), 2.16 – 2.08 (m, 1H), 2.01 (q, *J* = 6.9 Hz, 2H), 1.80 – 1.73 (m, 1H), 1.35 – 1.30 (m, 2H), 1.28 – 1.24 (m, 10H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 199.0, 163.3, 158.5, 139.3, 132.4, 131.0, 130.1, 129.2, 114.3, 114.2, 113.7, 55.4, 55.2, 52.4, 34.1, 33.8, 29.7, 29.5, 29.1, 29.0, 27.8.**HRMS: (ESI):** Calc'd for. **$C_{26}H_{34}O_3$[M+H]$^+$: 395.2586; Found: 395.2587.**

1,2-bis(4-methoxyphenyl)undec-10-en-1-one (5.3b): Purification by column chromatography



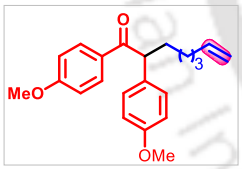
(SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 71% yield (270 mg, 0.71 mmol) as brown oil.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.87 (d, *J* = 8.8 Hz, 2H), 7.13 (d, *J* = 8.6 Hz, 2H), 6.78 (d, *J* = 8.8 Hz, 2H), 6.74 (d, *J* = 8.6 Hz, 2H), 5.75 – 5.67 (m, 1H), 4.90 (d, *J* = 17.1 Hz, 1H), 4.84 (d, *J* = 10.1 Hz, 1H), 4.36 (t, *J* = 7.2 Hz, 1H), 3.73 (s, 3H), 3.67 (s, 3H), 2.08 – 2.01 (m, 1H), 1.93 (q, *J* = 7.1 Hz, 2H), 1.73 – 1.66 (m, 1H), 1.32 – 1.26 (m, 3H), 1.23 – 1.13 (m, 7H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 199.0, 163.3, 158.6, 144.2, 139.3, 132.4, 131.0, 130.2, 129.2, 114.3, 113.7, 55.5, 55.3, 52.5, 34.1, 33.8, 29.7, 29.4, 29.1, 29.0, 27.8.**HRMS: (ESI):** Calc'd for. **$C_{25}H_{34}O_3$[M+H]$^+$: 382.2508; Found: 382.2460.**

The compound **5.3c** was purification by column chromatography (SiO_2, 100–200 mesh, eluent:



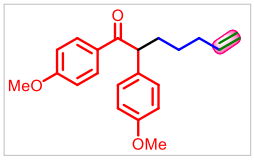
AcOEt/petroleum ether 1% to 5%) afforded the title compound in 53% yield (249 mg, 0.70 mmol) as Yellowish sticky liquid. **^{1}H NMR (600 MHz, $CDCl_3$) δ** 7.97 (d, *J* = 8.9 Hz, 1H), 7.23 (d, *J* = 8.8 Hz, 1H), 6.89 (d, *J* = 8.9 Hz, 1H), 6.84 (d, *J* = 8.7 Hz, 1H), 5.45 – 5.27 (m, 4H), 4.45 (t, *J* = 7.2 Hz, 1H), 3.84 (s, 3H), 3.77 (s, 3H), 2.79 (t, *J* = 6.9 Hz, 2H), 2.09 – 1.99 (m, 4H), 1.85 – 1.72 (m, 1H), 1.40 – 1.18 (m, 16H), 0.94 – 0.84 (m, 3H) **HRMS: (ESI):** Calc'd for. **$C_{35}H_{50}O_3$ [M+H]$^+$: 518.3760**; found = **518.3718.**

1,2-bis(4-methoxyphenyl)oct-7-en-1-one(5.3g): Purification by column chromatography (SiO_2,



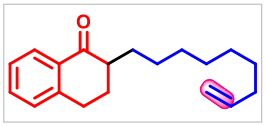
100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 62% yield (210 mg, 0.62 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.87 (d, *J* = 8.8 Hz, 2H), 7.13 (d, *J* = 8.6 Hz, 2H), 6.79 (d, *J* = 8.8 Hz, 2H), 6.74 (d, *J* = 8.6 Hz, 2H), 5.73 – 5.65 (m, 1H), 4.89 (d, *J* = 17.1 Hz, 1H), 4.83 (d, *J* = 10.1 Hz, 1H), 4.36 (t, *J* = 7.2 Hz, 1H), 3.75 (s, 3H), 3.68 (s, 3H), 2.10 – 2.03 (m, 1H), 1.94 (q, *J* = 7.1 Hz, 2H), 1.75 – 1.65 (m, 1H), 1.39 – 2.27 (m, 2H), 1.26 – 1.13 (m, 2H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 198.9, 163.3, 158.6, 139.0, 132.4, 131.0, 130.1, 129.2, 114.5, 114.4, 113.8, 55.5, 55.3, 52.4, 34.0, 33.7, 29.0, 27.3.**HRMS: (ESI):** Calc'd for.**$C_{22}H_{26}O_3$[M+H]$^+$: 339.1960**; found = **239.1976.**

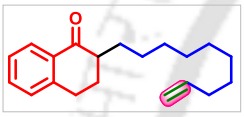
1,2-bis(4-methoxyphenyl)hept-6-en-1-one (5.3h): Purification by column chromatography (SiO_2,

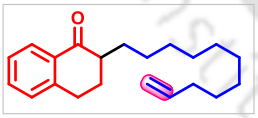


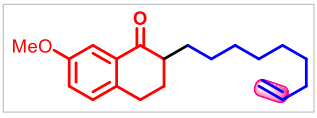
100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 60% yield (195 mg, 0.60 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.87 (d, *J* = 8.6 Hz, 2H), 7.13 (d, *J* = 8.4 Hz, 2H), 6.78 (d, *J* = 8.6 Hz, 2H), 6.74 (d, *J* = 8.4 Hz, 2H), 5.73 – 5.65 (m, 1H), 4.89 (d, *J* = 17.1 Hz, 1H), 4.84 (d, *J* = 10.1 Hz, 1H), 4.37 (t, *J* = 7.3 Hz, 1H), 3.74 (s, 3H), 3.67 (s, 3H), 2.10 – 2.01 (m, 1H), 2.01 – 1.96 (m, 2H), 1.76 – 1.66 (m, 1H), 1.36 – 1.18 (m, 2H). **^{13}C NMR**

(125 MHz, $CDCl_3$) δ 198.8, 163.3, 158.6, 138.7, 132.3, 131.0, 130.1, 129.2, 114.7, 114.4, 113.8, 55.5, 55.3, 52.4, 33.8, 33.6, 27.1.**HRMS: (ESI):** Calc'd for.**$C_{21}H_{24}O_3$[M+H]$^+$: 325.1804**; found = **325.1793.**

2-(non-8-en-1-yl)-3,4-dihydronaphthalen-1(2H)-one(5.3i): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 77% yield (208 mg, 0.77 mmol) as Yellowish liquid.  **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.02 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 1H), 7.29 (t, *J* = 7.5 Hz, 1H), 7.22 (d, *J* = 7.6 Hz, 1H), 5.85 – 5.77 (m, 1H), 4.98 (d, *J* = 17.1 Hz, 1H), 4.92 (d, *J* = 10.2 Hz, 1H), 3.03 – 2.93 (m, 2H), 2.49 – 2.44 (m, 1H), 2.26 – 2.20 (m, 1H), 2.04 (q, *J* = 7.0 Hz, 2H), 1.97 – 1.84 (m, 2H), 1.52 – 1.47 (m, 1H), 1.45 – 1.35 (m, 4H), 1.31 – 1.26 (m, 6H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 200.5, 144.0, 139.3, 133.1, 132.7, 128.7, 127.5, 126.6, 114.2, 47.6, 33.9, 29.8, 29.5, 29.5, 29.2, 29.0, 28.4, 28.3, 27.1. **HRMS: (ESI):** Calc'd for.**$C_{19}H_{26}O$[M+H]$^+$: 271.2062**; **found = 271.2066.**

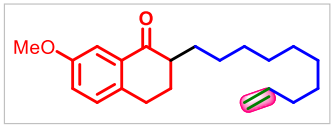
2-(dec-9-en-1-yl)-3,4-dihydronaphthalen-1(2H)-one (5.3j): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 81% yield (230 mg, 0.81 mmol) as Yellowish liquid.  **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.94 (d, *J* = 7.8 Hz, 1H), 7.36 (t, *J* = 7.4 Hz, 1H), 7.20 (t, *J* = 7.5 Hz, 1H), 7.14 (d, *J* = 7.6 Hz, 1H), 5.77 – 5.69 (m, 1H), 4.90 (d, *J* = 17.1 Hz, 1H), 4.84 (d, *J* = 10.1 Hz, 1H), 2.93 – 2.86 (m, 2H), 2.40 – 2.35 (m, 1H), 2.17 – 2.12 (m, 1H), 1.96 (q, *J* = 7.0 Hz, 2H), 1.89 – 1.77 (m, 2H), 1.44 – 1.35 (m, 2H), 1.32 – 1.27 (m, 3H), 1.24 – 1.20 (m, 8H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 200.5, 144.0, 139.3, 133.1, 132.7, 128.7, 127.5, 126.6, 114.2, 47.6, 33.9, 29.8, 29.6, 29.5, 29.5, 29.2, 29.0, 28.4, 28.3, 27.1.

2-(undec-10-en-1-yl)-3,4-dihydronaphthalen-1(2H)-one (5.3k): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 80% yield (239 mg, 0.80 mmol) as Yellowish liquid.  **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.02 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 1H), 7.28 (t, *J* = 7.5 Hz, 1H), 7.21 (d, *J* = 7.6 Hz, 1H), 5.85 – 5.77 (m, 1H), 4.98 (d, *J* = 17.1 Hz, 1H), 4.92(d, *J* = 10.1 Hz, 1H), 3.03 – 2.92 (m, 2H), 2.49 – 2.43 (m, 1H), 2.25 – 2.20 (m, 1H), 2.03 (q, *J* = 7.0 Hz, 2H), 1.97 – 1.84 (m, 2H), 1.52 – 1.43 (m, 2H), 1.42 – 1.34 (m, 4H), 1.33 – 1.26 (m, 9H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 200.5, 144.0, 139.3, 133.1, 132.6, 128.7, 127.5, 126.6, 114.2, 47.6, 33.9, 29.8, 29.6, 29.6, 29.5, 29.5, 29.2, 29.0, 28.4, 28.3, 27.1.**HRMS: (ESI):** Calc'd for.**$C_{21}H_{30}O$[M+H]$^+$: 299.2375**; found = **299.2373.**

7-methoxy-2-(non-8-en-1-yl)-3,4-dihydronaphthalen-1(2H)-one(5.3l): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 84% yield (252 mg, 0.84 mmol) as Yellowish liquid.  **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.51 – 7.50 (m, 1H), 7.13 (d, *J* = 8.4 Hz, 1H), 7.04 – 7.02 (m, 1H), 5.85 – 5.77 (m, 1H), 4.98 (d,

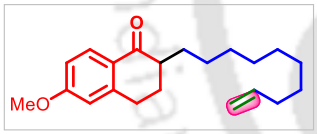
J = 17.1Hz, 1H), 4.92 (d, *J* = 10.2 Hz, 1H), 3.83 (s, 3H), 2.97 – 2.85 (m, 2H), 2.47 – 2.41 (m, 1H), 2.23 – 2.18 (m, 1H), 2.04 (q, *J* = 7.0 Hz, 2H), 1.95 – 1.83 (m, 2H), 1.53 – 1.46 (m, 1H), 1.45 – 1.36 (m, 3H), 1.32 – 1.22 (m, 7H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 200.5, 158.4, 139.3, 136.6, 133.4, 129.9, 121.5, 114.2, 109.5, 55.5, 47.4, 33.9, 29.8, 29.5, 29.5, 29.2, 29.0, 28.5, 27.5, 27.1. **HRMS: (ESI):** Calc'd for.**$C_{20}H_{28}O_2$ [M+H]$^+$: 301.2168**; found = **301.2157.**

2-(dec-9-en-1-yl)-7-methoxy-3,4-dihydronaphthalen-1(2H)-one (5.3m): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 89% yield (280 mg, 0.89 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.44 –7.43 (m, 1H), 7.06 (d, *J* = 8.4 Hz, 1H), 6.97– 6.95 (m, 1H), 5.78 – 5.70 (m, 1H), 4.94 – 4.84 (m, 2H), 3.76 (s, 3H), 2.90 – 2.78 (m, 2H), 2.40 –2.34 (m, 1H), 2.14 – 2.11 (m, 1H), 1.98 – 1.94 (m, 2H), 1.88 –1.75 (m, 2H), 1.45 – 1.36 (m, 1H), 1.31 – 1.22 (m, 12H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 200.6, 158.4, 139.3, 136.6, 133.4, 129.9, 121.5, 114.2, 109.5, 55.6, 47.4, 33.9, 29.8, 29.6, 29.5, 29.5, 29.2, 29.0, 28.5, 27.5, 27.1. **HRMS: (ESI):** Calc'd for.**$C_{21}H_{30}O_2$[M+H]$^+$: 315.2324**; found = **315.2313.**



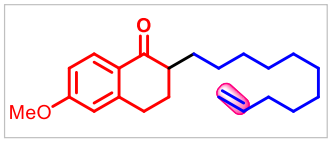
2-(dec-9-en-1-yl)-6-methoxy-3,4-dihydronaphthalen-1(2H)-one (5.3p): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 83% yield (261 mg, 0.83 mmol) as Yellowish liquid.

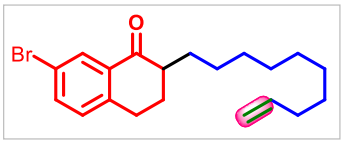
^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.99 (d, *J* = 8.7 Hz, 1H), 6.81 (d, *J* = 8.7 Hz, 1H), 6.67 (s, 1H), 5.85 – 5.76 (m, 1H), 4.98 (d, *J* = 17.1 Hz, 1H), 4.92 (d, *J* = 10.1 Hz, 1H), 3.84 (s, 3H), 2.98 – 2.88 (m, 2H), 2.44 – 2.38 (m, 1H), 2.23 – 2.17 (m, 1H), 2.03 (q, *J* = 6.9 Hz, 2H), 1.95 – 1.83 (m, 2H), 1.51 – 1.28 (m, 13H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 199.3, 163.4, 146.4, 139.3, 129.9, 126.3, 114.2, 113.1, 112.5, 55.4, 47.2, 33.8, 29.8, 29.6, 29.5, 29.2, 29.0, 28.7, 28.3, 27.1.



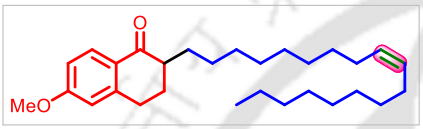
HRMS: (ESI): Calc'd for.**$C_{21}H_{30}O_2$[M+H]$^+$: 315.2324**; found = **315.2326.**

6-methoxy-2-(undec-10-en-1-yl)-3,4-dihydronaphthalen-1(2H)-one(5.3q): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 89% yield (292 mg, 0.89 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.00 (d, *J* = 8.7 Hz, 1H), 6.82 – 6.80 (m, 1H), 6.67 (s, 1H), 5.85 – 5.77 (m,1H), 4.98 (d, *J* = 17.1 Hz, 1H), 4.92(d, *J* = 10.1 Hz 1H), 3.84 (s, 3H), 2.99 – 2.88 (m, 2H), 2.44 – 2.38 (m, 1H), 2.23 – 2.17 (m, 1H), 2.03 (q, *J* = 7.1 Hz, 2H), 1.95 - 1.82 (m, 2H), 1.51 – 1.41 (m, 2H), 1.40 – 1.34 (m, 4H), 1.31 – 1.25 (m, 9H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 199.4, 163.4, 146.4, 139.3, 130.0, 126.3, 114.1, 113.1, 112.5, 55.4, 47.2, 33.9, 29.8, 29.6, 29.6, 29.6, 29.6, 29.2, 29.0, 28.7, 28.3, 27.2. **HRMS: (ESI): Calc'd for. $C_{22}H_{32}O_2$ [M+H]$^+$: 329.2481; found = 329.2499.**

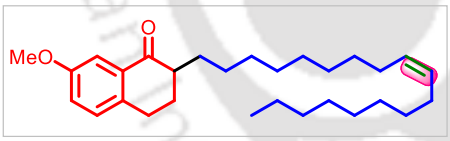


7-bromo-2-(dec-9-en-1-yl)-3,4-dihydronaphthalen-1(2H)-one(5.3r): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 74% yield (268mg, 0.74 mmol) as Yellowish liquid. 

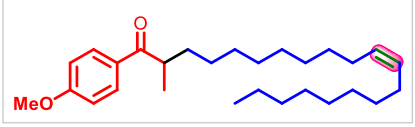
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.04 (s, 1H), 7.45 (d, *J* = 7.8 Hz, 1H), 7.02 (d, *J* = 8.1 Hz, 1H), 5.75 – 5.67 (m, 1H), 4.89 (d, *J* = 17.1, 1H), 4.83 (d, *J* = 10.1 Hz, 1H), 2.89 – 2.77 (m, 2H), 2.38 – 2.33 (m, 1H), 2.16 – 2.10 (m, 1H), 1.94 (q, *J* = 6.8 Hz, 2H), 1.85 – 1.74 (m, 2H), 1.40 – 1.33 (m, 1H), 1.27 – 1.16 (m, 12H), **^{13}C NMR (125 MHz, $CDCl_3$)** δ 199.2, 142.7, 139.3, 135.9, 134.2, 130.6, 130.4, 120.7, 114.2, 47.3, 33.9, 29.8, 29.6, 29.5, 29.4, 29.2, 29.0, 28.0, 27.9, 27.0. **HRMS: (ESI):** Calc'd for.**$C_{20}H_{27}BrO$ [M+H]$^+$: 363.1324**; found = **363.1320.**

(Z)-6-methoxy-2-(octadec-9-en-1-yl)-3,4-dihydronaphthalen-1(2H)-one (5.3t): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 62% yield (264 mg, 0.62 mmol) as Yellowish solid. 

^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.02 (d, *J* = 8.7 Hz, 1H), 6.83 (d, *J* = 8.7 Hz, 1H), 6.69 (s, 1H), 5.36 (t, *J* = 4.7 Hz, 2H), 3.87 (s, 3H), 3.01 – 2.91 (m, 2H), 2.46 – 2.41 (m, 1H), 2.25 – 2.20 (m, 1H), 2.03 (q, *J* = 6.5 Hz, 4H), 1.51 – 1.44 (m, 3H), 1.36 – 1.25 (m, 24H), 0.89 (t, *J* = 6.9 Hz, 3H).**^{13}C NMR (150 MHz, $CDCl_3$)** δ 199.5, 163.3, 146.5, 130.1, 130.0, 126.2, 113.1, 112.4, 55.5, 47.2, 32.0, 29.9, 29.9, 29.6, 29.6, 29.5, 29.4, 29.4, 29.4, 28.7, 28.2, 27.3, 27.2, 22.8, 14.2.**HRMS: (ESI):** Calc'd for.**$C_{29}H_{44}O_2$[M+H]$^+$: 425.3420**; found = **425.3404.**

(Z)-7-methoxy-2-(octadec-9-en-1-yl)-3,4-dihydronaphthalen-1(2H)-one (5.3s): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 63% yield (268 mg, 0.63 mmol) as Yellowish solid. 

^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.51 (d, *J* = 2.8 Hz, 1H), 7.14 (d, *J* = 8.4 Hz, 1H), 7.05 – 7.03 (m, 1H), 5.35 (t, *J* = 4.8 Hz, 2H), 3.83 (s, 3H), 2.97 – 2.89 (m, 2H), 2.47 – 2.42 (m, 1H), 2.25 – 2.19 (m, 1H), 2.01 (q, *J* = 6.8 Hz, 4H), 1.94 – 1.84 (m, 2H), 1.51 – 1.46 (m, 1H), 1.33 – 1.25 (m, 24H), 0.88 (t, *J* = 7.0 Hz, 3H).**^{13}C NMR (150 MHz, $CDCl_3$)** δ 200.7, 158.3, 136.7, 133.3, 130.0, 121.6, 109.3, 55.5, 47.4, 32.0, 29.9, 29.6, 29.6, 29.5, 29.4, 29.4, 29.4, 28.4, 27.5, 27.3, 27.1, 22.8, 14.2. **HRMS: (ESI):** Calc'd for.**$C_{29}H_{44}O_2$[M+H]$^+$: 425.3420**; found = **425.3404**.

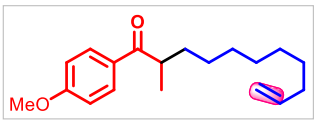
(Z)-1-(4-methoxyphenyl)-2-methylicos-11-en-1-one (5.3u): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 52% yield (216 mg, 0.52 mmol) as Yellowish liquid. 

^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.97 (d, *J* = 8.9 Hz, 2H), 6.96 (d, *J* = 8.9 Hz, 2H), 5.65 – 5.21 (m, 2H), 3.89 (s, 3H), 2.05 – 2.00 (M, 6H), 1.82 –

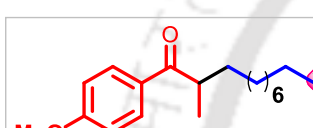
1.77 (m, 1H), 1.31 – 1.25 (m, 22H), 1.19 (d, *J* = 6.8 Hz, 3H), 0.91 – 0.88 (m, 5H).**^{13}C NMR (150 MHz, $CDCl_3$)** δ 203.4, 163.3, 130.6, 130.0, 129.9, 113.8, 55.5, 40.2, 34.0, 32.0, 29.9, 29.6, 29.6, 29.4, 27.6, 27.3, 22.8, 17.5, 14.2.

HRMS: (ESI): Calc'd for.**$C_{28}H_{46}O_2$[M+H]$^+$: 415.3576**; found = **415.3564.**

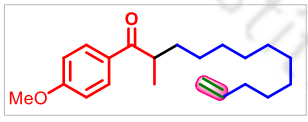
1-(4-methoxyphenyl)-2-methylundec-10-en-1-one (5.3v): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 57% yield (164 mg, 0.57 mmol) as Yellowish liquid.**^{1}H NMR (400 MHz, Chloroform-*d*)** δ 7.87 (d, *J* = 8.9 Hz, 2H), 6.86 (d, *J* = 8.9 Hz, 2H), 5.77 – 5.67 (m, 1H), 4.92 – 4.83 (m, 2H), 3.79 (s, 3H), 3.34 (q, *J* = 6.8 Hz, 1H), 1.94 (q, *J* = 7.0 Hz, 2H), 1.73 – 1.67 (m, 1H), 1.30 - 1.26 (m, 2H), 1.23 – 1.15 (m, 8H), 1.10 (d, *J* = 6.9 Hz, 3H).**^{13}C NMR (100 MHz, $CDCl_3$)** δ 203.2, 163.4, 139.2, 130.6, 129.9, 114.2, 113.8, 55.5, 40.2, 34.0, 33.8, 29.8, 29.4, 29.1, 29.0, 27.5, 17.5.**HRMS: (ESI):** Calc'd for.**$C_{19}H_{28}O_2$[M+H]$^+$: 289.2168**; found = **289.2168.**

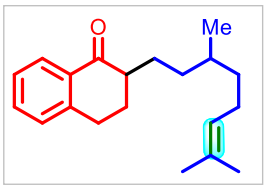


1-(4-methoxyphenyl)-2-methylundec-10-en-1-one (5.3w): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 60% yield (212 mg, 0.60 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.94 (d, *J* = 8.8 Hz, 2H), 6.94 (d, *J* = 8.8 Hz, 2H), 5.84 – 5.76 (m, 1H), 4.98 (d, *J* = 17.0 Hz, 1H), 4.90 (d, *J* = 10.1 Hz, 1H),3.86 (s, 3H), 3.41 (q, *J* = 6.8 Hz, 1H), 2.02 (q, *J* = 7.1 Hz, 2H), 1.80 – 1.75 (m, 1H), 1.37 – 1.31 (m, 2H), 1.30 – 1.25 (m, 11H), 1.17 (d, *J* = 6.8 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 203.2, 163.4, 139.3, 130.6, 129.9, 114.2, 113.8, 55.5, 40.3, 34.0, 33.9, 29.8, 29.5, 29.5, 29.2, 29.0, 27.5, 17.5.**HRMS: (ESI):** Calc'd for. **$C_{20}H_{30}O_2$[M+H]$^+$: 303.2324; Found: 303.2331.**

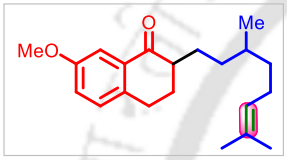


1-(4-methoxyphenyl)-2-methyltridec-12-en-1-one (5.3x): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 20%) afforded the title compound in 63% yield (199 mg, 0.63 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.87 (d, *J* = 8.8 Hz, 2H), 6.86 (d, *J* = 8.7 Hz, 2H), 5.77 – 5.69 (m, 1H), 4.91 (d, *J* = 17.1 Hz, 1H), 4.84 (d, *J* = 10.1 Hz, 1H), 3.79 (s, 3H), 3.37 – 3.30 (m, 1H), 1.95 (q, *J* = 6.9 Hz, 2H), 1.73 – 1.67 (m, 1H), 1.64 – 1.61 (m, 1H), 1.31 – 1.26 (m, 3H), 1.24 – 1.22 (m, 3H), 1.20 – 1.15 (m, 8H), 1.10 (d, *J* = 6.8 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 203.2, 163.4, 139.3, 130.6, 129.9, 114.2, 113.8, 55.5, 40.3, 34.0, 33.9, 29.8, 29.6, 29.5, 29.5, 29.2, 29.0, 27.5, 17.5.**HRMS: (ESI):** Calc'd for.**$C_{21}H_{32}O_2$[M+Na]$^+$: 339.2300**; found = **339.2255.**

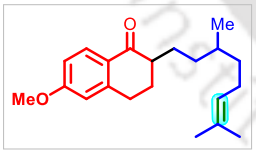


2-(3,7-dimethyloct-6-en-1-yl)-3,4-dihydronaphthalen-1(2H)-one (5.3y): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 90% yield (256 mg, 0.9 mmol) as Yellowish liquid. 

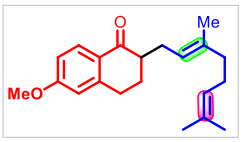
^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.85 (d, *J* = 7.7 Hz, 1H), 7.27 (t, *J* = 7.4 Hz, 1H), 7.12 (t, *J* = 7.2 Hz, 1H), 7.05 (d, *J* = 7.4 Hz, 1H), 4.94 – 4.90 (m, 1H), 2.85 – 2.77 (m, 2H), 2.30 – 2.23 (m, 1H), 2.08 – 2.05 (m, 1H), 1.86 – 1.69 (m, 4H), 1.50 (s, 3H), 1.42 (s, 3H), 1.35 – 1.16 (m, 4H), 1.09 – 0.98 (m, 2H), 0.78 – 0.68 (m, 3H).**^{13}C NMR (150 MHz, $CDCl_3$)**δ 200.6, 144.0, 133.1, 132.7, 131.2, 131.2, 128.7, 127.6, 126.6, 125.0, 125.0, 48.0, 47.8, 37.2, 36.9, 34.4, 34.2, 32.8, 32.7, 28.4, 28.4, 28.4, 28.2, 27.0, 26.9, 25.8, 25.7, 25.6, 19.7, 19.5, 17.7.**HRMS: (ESI):** Calc'd for.**$C_{20}H_{28}O[M+H]^+$: 285.2218**; found = **285.2214.**

2-(3,7-dimethyloct-6-en-1-yl)-7-methoxy-3,4-dihydronaphthalen-1(2H)-one (5.3z): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 20%) afforded the title compound in 84% yield (264 mg, 0.84 mmol) as Yellowish liquid. 

^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.52 – 7.51 (m, 1H), 7.14 (d, *J* = 8.4 Hz, 1H), 7.05 – 7.02 (m, 1H), 5.10 (t, *J* = 6.8 Hz, 1H), 3.83 (s, 3H), 2.97 – 2.85 (m, 2H), 2.44 – 2.39 (m, 1H), 2.24 – 2.18 (m, 1H), 2.05 – 1.93 (m, 2H), 1.89- 1.83 (m, 1H), 1.68 (s, 3H), 1.64 (t, *J* = 4.1 Hz, 1H), 1.60 (s, 3H), 1.56 – 1.32 (m, 4H), 1.27 – 1.10 (m, 2H), 0.91 – 0.90 (m, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)**δ 200.5, 158.4, 136.6, 133.4, 131.1, 129.9, 125.1, 121.5, 109.5, 55.6, 47.8, 47.7, 37.2, 36.9, 34.4, 34.2, 32.8, 32.7, 28.6, 28.4, 27.6, 27.5, 27.1, 26.9, 25.8, 25.7, 25.6, 19.7, 19.5, 17.7.**HRMS: (ESI):** Calc'd for.**$C_{21}H_{30}O_2[M+Na]^+$: 337.2143**; found = **337.2173.**

2-(3,7-dimethyloct-6-en-1-yl)-6-methoxy-3,4-dihydronaphthalen-1(2H)-one(5.3aa): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 90% yield (283 mg, 0.90 mmol) as Yellowish liquid. 

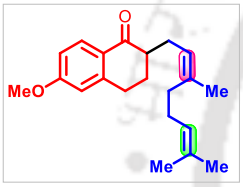
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.00 (d, *J* = 8.7 Hz, 1H), 6.81 (d, *J* = 8.7 Hz, 1H), 6.67 (s, 1H), 5.10 (t, *J* = 6.9 Hz, 1H), 3.84 (s, 3H), 2.99 – 2.89 (m, 2H), 2.41 – 2.36 (m, 1H), 2.25 – 2.16 (m, 1H), 2.04 – 1.94 (m, 2H), 1.91 – 1.83 (m, 1H), 1.68 (s, 3H), 1.60 (s, 3H), 1.54 – 1.32 (m, 5H), 1.27 – 1.12 (m, 2H), 0.90 (m, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 199.3, 163.4, 146.4, 131.1, 130.0, 126.3, 125.0, 113.1, 112.5, 55.4, 47.6, 47.5, 37.2, 36.9, 34.5, 34.3, 32.8, 32.7, 28.8, 28.7, 28.4, 28.2, 27.1, 27.0, 25.8, 25.7, 25.6, 19.7, 19.5, 17.7.**HRMS: (ESI):Calc'd for.$C_{21}H_{30}O_2[M+Na]^+$:337.2143; found = 337.2173.**

(E)-2-(3,7-dimethylocta-2,6-dien-1-yl)-6-methoxy-3,4-dihydronaphthalen-1(2H)-one (5.3ab): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 61% yield (190 mg, 0.61 mmol) as Yellowish liquid. 

^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.94 – 7.91 (m, 1H), 6.73 (d, *J* = 8.7 Hz, 1H), 6.60 (s, 1H), 5.10 (t, *J* = 7.1 Hz, 1H), 5.03 – 4.99 (m, 1H), 3.76 (s, 3H), 2.86 – 2.84 (m, 2H), 2.61 – 2.54 (m, 1H), 2.40 – 2.33 (m, 1H), 2.18 – 2.08 (m, 3H), 2.03 – 1.99 (m, 2H), 1.96 – 1.93 (m, 1H), 1.71 – 1.65 (m, 1H), 1.59 (s, 3H), 1.55 (s, 3H), 1.52 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 198.8, 163.4, 146.6, 137.0, 131.4, 129.9, 126.4, 124.4, 122.1, 113.1, 112.5, 55.4, 47.8, 39.9, 29.1, 28.1, 28.0, 26.7, 25.8, 25.7.**HRMS: (ESI):** Calc'd for.**$C_{21}H_{28}O_2$[M+Na]$^+$: 335.1987**; found = **335.1980.**

(Z)-2-(3,7-dimethylocta-2,6-dien-1-yl)-6-methoxy-3,4-dihydronaphthalen-1(2H)-one (5.3ac): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 55% yield (172 mg, 0.55 mmol) as Yellowish liquid.

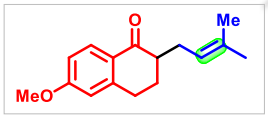
^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.93 (d, *J* = 8.7 Hz, 1H), 6.73 (d, *J* = 8.7 Hz, 1H), 6.59 (s, 1H), 5.10 (t, *J* = 7.2 Hz, 1H), 5.03 – 4.98 (m, 1H), 3.76 (s, 3H), 2.86 – 2.83 (m, 2H), 2.60 – 2.55 (m, 1H), 2.40 – 2.33 (m, 1H), 2.18 – 2.08 (m, 2H), 2.01 – 1.97 (m, 2H), 1.96 – 1.93 (m, 1H), 1.77 – 1.70 (m, 2H), 1.58 (s, 3H), 1.54 (s, 3H), 1.52 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 198.8, 163.4, 146.6, 137.0, 131.4, 129.9, 126.4, 124.4, 122.1, 113.1, 112.5, 55.4, 47.8, 39.9, 29.1, 28.1, 28.0, 26.7, 25.7, 23.5, 17.8, 16.2.



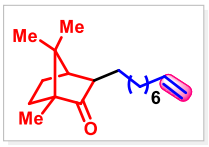
HRMS: (ESI): Calc'd for.**$C_{21}H_{28}O_2$[M+H]$^+$: 313.2168**; found = **313.2167.**

6-methoxy-2-(3-methylbut-2-en-1-yl)-3,4-dihydronaphthalen-1(2H)-one(5.3ae): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 2% to 5%) afforded the title compound in 64% yield (156 mg, 0.70 mmol) as Yellowish liquid.

^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.94 (d, *J* = 8.7 Hz, 1H), 6.74 (d, *J* = 8.3 Hz, 1H), 6.60 (s, 1H), 5.10 (t, *J* = 7.0 Hz, 1H), 3.77 (s, 3H), 2.90 – 2.80 (m, 2H), 2.60 – 2.53 (m, 1H), 2.40 – 2.34 (m, 1H), 2.18 – 2.09 (m, 2H), 1.81 – 1.72 (m, 1H), 1.64 (s, 3H), 1.56 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 197.7, 162.3, 145.5, 132.3, 128.8, 125.3, 121.0, 112.0, 111.4, 54.3, 46.7, 27.9, 27.1, 27.0, 24.8, 16.8.



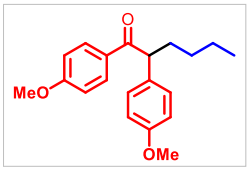
HRMS: (ESI): Calc'd for.**$C_{15}H_{18}O$[M+H]$^+$: 215.1436**; found = **215.1446.**

(1S,4S)-1,7,7-trimethyl-3-(non-8-en-1-yl)bicycle[2.2.1]heptan-2-one(5.3ah): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 51% yield (141 mg, 0.51 mmol) as Yellowish liquid. 

^{1}H NMR (500 MHz, Chloroform-*d*) δ 5.78 - 568 (m, 1H), 4.92 (d, *J* = 17.1 Hz, 1H), 4.85 (d, *J* = 10.1 Hz, 1H), 2.28 – 2.24 (m, 1H), 1. 97 – 1.95 (m, 2H), 1.70 – 1.67 (m, 2H), 1.57 – 1.51 (m, 2H), 1.46 – 1.41 (m, 1H), 1.33 – 1.26 (m, 2H), 1.26 – 1.17 (s, 10H), 0.92 (s, 3H), 0.81 (s, 3H), 0.78 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 206.5,

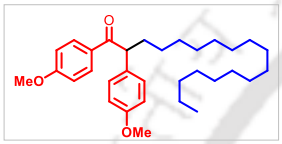
138.3, 113.2, 57.6, 48.8, 45.2, 44.9, 32.9, 30.2, 28.6, 28.5, 28.2, 28.0, 27.0, 26.2, 19.1, 18.6, 18.5, 8.7.**HRMS: (ESI):** Calc'd for.**$C_{19}H_{32}O$ [M+H]$^+$: 277.2531; Found: 277.2551.**

1,2-bis(4-methoxyphenyl)hexan-1-one(5.4a)[25] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 63% yield



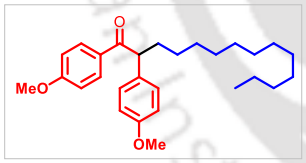
(197 mg, 0.63 mmol) as Yellowish liquid. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.95 (d, *J* = 8.9 Hz, 2H), 7.21 (d, *J* = 8.7 Hz, 2H), 6.86 (d, *J* = 8.9 Hz, 2H), 6.81 (d, *J* = 8.7 Hz, 2H), 4.43 (t, *J* = 7.3 Hz, 1H), 3.81 (s, 3H), 3.74 (s, 3H), 2.16 -2.09 (m, 1H), 1.81 – 1.74 (m, 1H), 1.35 – 1.18 (m, 4H), 0.85 (t, *J* = 7.0 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 199.0, 163.3, 158.6, 132.5, 131.0, 130.1, 129.3, 114.3, 113.8, 55.5, 55.3, 52.5, 33.9, 30.1, 22.9, 14.1.

1,2-bis(4-methoxyphenyl)octadecan-1-one (5.4d): Purification by column chromatography



(SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 73% yield (351 mg, 0.73 mmol) as white solid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.94 (d, *J* = 8.7 Hz, 2H), 7.20 (d, *J* = 8.5 Hz, 2H), 6.85 (d, *J* = 8.6 Hz, 2H), 6.80 (d, *J* = 8.4 Hz, 2H), 4.43 (t, *J* = 7.2 Hz, 1H), 3.79 (s, 3H), 3.73 (s, 3H), 2.15 – 2.09 (m, 1H), 1.80 – 1.74 (m, 1H), 1.27 – 1.20 (m, 28H), 0.87 (t, *J* = 6.45 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 199.0, 163.3, 158.6, 132.5, 131.0, 130.2, 129.3, 114.3, 113.8, 55.5, 55.3, 52.5, 34.2, 32.1, 29.8, 29.8, 29.8, 29.7, 29.6, 29.5, 27.9, 22.8, 14.2. **HRMS: (ESI):** Calc'd for. **$C_{32}H_{48}O_3$ [M+H]$^+$: 481.3682; Found: 481.3683.**

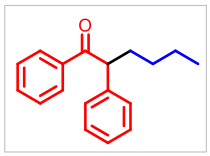
1,2-bis(4-methoxyphenyl)tetradecan-1-one (5.4c): Purification by column chromatography



(SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 71% yield (301 mg, 0.70 mmol) as white solid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.86 (d, *J* = 8.7 Hz, 2H), 7.12 (d, *J* = 8.5 Hz, 2H), 6.76 (d, *J* = 8.7 Hz, 2H), 6.72 (d, *J* = 8.4 Hz, 2H), 4.35 (t, *J* = 7.2 Hz, 1H), 3.70 (s, 3H), 3.64 (s, 3H), 2.07 – 2.00 (m, 1H), 1.73 – 1.64 (m, 1H), 1.22 – 1.11 (m, 20H), 0.79 (t, *J* = 6.65 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 199.0, 163.3, 158.6, 132.5, 131.0, 130.2, 129.2, 114.3, 113.8, 55.5, 55.3, 52.5, 34.2, 32.0, 29.8, 29.8, 29.7, 29.7, 29.6, 29.46, 27.8, 22.8, 14.2.

HRMS: (ESI): Calc'd for. **$C_{28}H_{42}O_3$: 426.3134; Found:426.3094.**

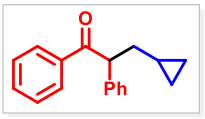
1,2-diphenylhexan-1-one (5.4d): Purification by column chromatography (SiO_2, 100–200 mesh,



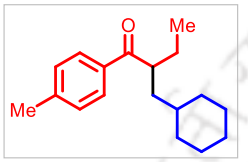
eluent: AcOEt/petroleum ether 1% to 2%) afforded the title compound in 76% yield (192 mg, 0.70 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.88 (d, *J* = 8.1 Hz, 2H), 7.39–7.37 (m, 1H), 7.29 (t, *J* = 7.7 Hz, 2H), 7.23–7.18 (m, 4H), 7.12–7.08 (m, 1H), 4.45 (t, *J* = 7.2 Hz, 1H), 2.14 –2.07 (m, 1H), 1.78–1.71 (m, 1H), 1.31–1.17 (m, 4H), 0.78 (t, *J* = 6.8 Hz, 3H). **^{13}C NMR (125**

MHz, $CDCl_3$) δ 200.3, 140.0, 137.2, 132.9, 129.0, 128.7, 128.6, 128.3, 127.0, 53.8, 33.9, 30.0, 22.8, 14.1. **HRMS: (ESI):** Calc'd for.**$C_{18}H_{20}O$ [M+H]$^+$: 253.1592**; found = **253.1597.**

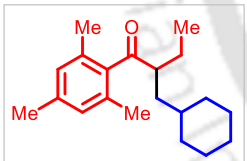
3-cyclopropyl-1,2-diphenylpropan-1-one (5.4f):[24] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 2%) afforded the title compound in 77% yield (194 mg, 0.77 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.99 (d, *J* = 8.3 Hz, 2H), 7.49 – 7.46 (m, 1H), 7.39 (t, *J* = 7.8 Hz, 2H), 7.33 (d, *J* = 7.7 Hz, 2H), 7.28 (t, *J* = 7.6 Hz, 2H), 7.19 (t, *J* = 7.2 Hz, 1H), 4.68 (t, *J* = 7.2 Hz, 1H), 2.09 – 2.03 (m, 1H), 1.78 – 1.73 (m, 1H), 0.67 – 0.59 (m, 1H), 0.43 – 0.38 (m, 1H), 0.37 0.32 (m, 1H), 0.07 – 0.06 (m, 1H), 0.05 – 0.01 (m, 1H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.3, 140.0, 137.1, 132.9, 128.9, 128.8, 128.6, 128.3, 127.0, 54.2, 39.3, 9.6, 4.8, 4.8.



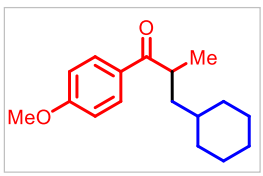
2-(cyclohexylmethyl)-1-(p-tolyl)butan-1-one (5.4h): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 52% yield (134 mg, 0.52 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.86 (d, *J* = 8.0 Hz, 2H), 7.26 – 7.24 (m, 2H), 3.46 -3.41 (m, 1H), 2.91 (t, *J* = 7.3 Hz, 1H), 2.41 (s, 3H), 1.78 – 1.63 (m, 7H), 1.55 – 1.48 (m, 1H), 1.34 –1.28 (m, 1H), 1.25 – 1.20 (m, 1H), 1.18 – 1.06 (m, 3H), 0.99 (t, *J* = 7.4 Hz, 1H), 0.86 (t, *J* = 7.4 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 204.4, 143.6, 135.4, 129.4, 128.4, 44.8, 39.7, 35.9, 33.8, 33.8, 26.7, 26.4, 26.1, 21.7, 18.1, 14.1, 12.2 **HRMS: (ESI):** Calc'd for. $C_{18}H_{26}O$ **[M+H]$^+$**: 259.2062, Found: 259.2070



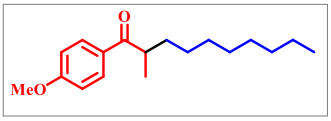
2-(cyclohexylmethyl)-1-mesitylbutan-1-one (5.4i): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 49% yield (140 mg, 0.49 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 6.82 – 6.79 (s, 2H), 3.45 (d, *J* = 6.4 Hz, 1H), 2.67 (t, *J* = 7.3 Hz, 2H), 2.27 (s, 3H), 2.18 (s, 6H), 2.07 (s, 1H), 1.76 – 1.69 (m, 5H), 1.67 – 1.65 (m, 1H), 1.59 – 1.58 (m, 1H), 1.51 – 1.43 (m, 1H), 1.27 – 1.07 (m, 3H), 1.02 – 0.97 (m, 3H), 0.92 – 0.87 (m, 1H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 210.9, 140.0, 138.3, 132.6, 128.6, 68.3, 46.9, 40.4, 32.1, 29.9, 26.8, 26.1, 25.6, 21.1, 19.2, 17.0, 14.0. **HRMS: (ESI):** Calc'd for. $C_{20}H_{30}O$ **[M+H]$^+$**: 287.2375; Found: 287.2381.



3-cyclohexyl-1-(4-methoxyphenyl)-2-methylpropan-1-one (5.4j): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 64% yield (165 mg, 0.64 mmol) as Yellowish liquid. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.95 (d, *J* = 8.6 Hz, 2H), 6.94 (d, *J* = 8.6 Hz, 2H), 3.87 (s, 3H), 3.57 – 3.50 (m, 1H), 1.78 – 1.76 (m, 1H), 1.73 – 1.63 (m, 5H), 1.31 – 1.23 (m, 3H), 1.21 – 1.18 (m, 1H), 1.16 (d, *J* = 6.7 Hz, 4H), 0.92 – 0.85 (m, 2H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 203.2, 163.4, 130.6, 129.8, 113.9, 55.5, 41.6, 37.5, 35.6, 34.0, 33.3, 26.7, 26.4, 26.3, 17.9. **HRMS: (ESI):** Calc'd for.**$C_{17}H_{24}O_2$[M+H]$^+$: 261.1855**; found = **261.1854.**

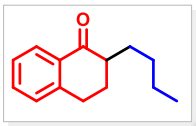


1-(4-methoxyphenyl)-2-methyldecan-1-one (5.4k):[26] Purification by column chromatography



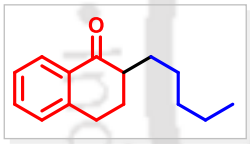
(SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 61% yield (150 mg, 0.61 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.96 – 7.94 (d, *J* = 7.4 Hz, 2H), 7.54 (t, *J* = 7.4 Hz, 1H), 7.46 (t, *J* = 7.8 Hz, 2H), 3.49 – 3.43 (m, 1H), 1.83 – 1.76 (m, 1H), 1.46 – 1.39 (m, 2H), 1.31 – 1.23 (m, 11H), 1.18 (d, *J* = 6.9 Hz, 3H), 0.86 (t, *J* = 6.85 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 204.7, 136.9, 132.9, 128.7, 128.6, 128.4, 127.7, 40.7, 33.7, 32.0, 29.9, 29.6, 29.4, 27.5, 22.8, 17.3, 14.2.

2-butyl-3,4-dihydronaphthalen-1(2H)-one (5.4l):[27] Purification by column chromatography



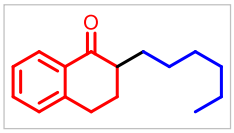
(SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 2%) afforded the title compound in 75% yield (152 mg, 0.75 mmol) as Yellowish liquid. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.02 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 1H), 7.29 (t, *J* = 7.5 Hz, 1H), 7.23 (d, *J* = 7.6 Hz, 1H), 3.01 – 2.95 (m, 2H), 2.49 – 2.44 (m, 1H), 2.26 – 2.21 (m, 1H), 1.97 – 1.86 (m, 2H), 1.63 (d, *J* = 6.3 Hz, 1H), 1.53 – 1.47 (m, 1H), 1.39 – 1.34 (m, 3H), 0.92 (t, *J* = 6.5 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.7, 144.1, 133.2, 132.7, 128.8, 127.6, 126.7, 47.6, 29.4, 29.2, 28.4, 28.3, 23.0, 14.2.

2-pentyl-3,4-dihydronaphthalen-1(2H)-one (5.4m):[28] Purification by column chromatography



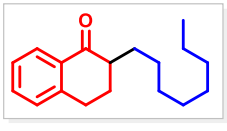
(SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 2%) afforded the title compound in 77% yield (166 mg, 0.77 mmol) as Yellowish liquid. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.02 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 1H), 7.29 (t, *J* = 7.6 Hz, 1H), 7.22 (d, *J* = 7.6 Hz, 1H), 3.02 – 2.93 (m, 2H), 2.49 – 2.44 (m, 1H), 2.25 – 2.21 (m, 1H), 1.96 – 1.85 (m, 2H), 1.64 – 1.52 (m, 1H), 1.49 – 1.45 (m, 1H), 1.42 – 1.40 (m, 1H), 1.36 – 1.30 (m, 4H), 0.91 – 0.86 (m, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.7, 144.1, 133.2, 132.7, 128.8, 127.6, 126.7, 47.6, 32.1, 29.5, 28.4, 28.3, 26.8, 22.7, 14.2.

2-hexyl-3,4-dihydronaphthalen-1(2H)-one (5.4n):[29] Purification by column chromatography



(SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 2%) afforded the title compound in 84% yield (193 mg, 0.70 mmol) as Yellowish liquid. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.02 (d, *J* = 7.8 Hz, 1H), 7.46 – 7.42 (m, 1H), 7.29 (t, *J* = 7.5 Hz, 1H), 7.22 (d, *J* = 7.6 Hz, 1H), 3.03 – 2.93 (m, 2H), 2.49 – 2.42 (m, 1H), 2.26 – 2.20 (m, 1H), 1.97 – 1.85 (m, 2H), 1.52 – 1.47 (m, 1H), 1.45 – 1.41 (m, 1H), 1.36 – 1.26 (m, 7H), 0.88 (t, *J* = 6.4 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.6, 144.1, 133.2, 132.7, 128.8, 127.6, 126.7, 47.6, 31.9, 29.6, 29.5, 28.4, 28.3, 27.1, 22.8, 14.2.

2-octyl-3,4-dihydronaphthalen-1(2H)-one (5.4p): Purification by column chromatography (SiO_2,

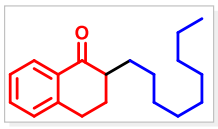


100–200 mesh, eluent: AcOEt/petroleum ether 1% to 2%) afforded the title compound in 90% yield (232 mg, 0.90 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.02 (d, *J* = 7.2 Hz, 1H), 7.47 – 7.43 (m, 1H),

7.29 (t, *J* = 7.5 Hz, 1H), 7.22 (d, *J* = 7.6 Hz, 1H), 3.04 – 2.93 (m, 2H), 2.49 – 2.44 (m, 1H), 2.26 – 2.20 (m, 1H), 1.97 – 1.85 (m, 2H), 1.52 – 1.39 (m, 3H), 1.33 – 1.26 (m, 10H), 0.87 (t, *J* = 6.7 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.7, 144.1, 133.2, 132.7, 128.8, 127.6, 126.7, 47.6, 32.0, 29.9, 29.7, 29.5, 29.45, 28.4, 28.3, 27.2, 22.8, 14.3.

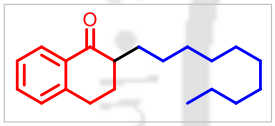
HRMS: (ESI): Calc'd for.**$C_{18}H_{26}O$ [M+H]$^+$: 259.2062**; found = **259.2063.**

2-nonyl-3,4-dihydronaphthalen-1(2H)-one (5.4q): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 2%) afforded the title compound in



89% yield (242 mg, 0.89 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.02 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 1H), 7.29 (t, *J* = 7.5 Hz, 1H), 7.23 (d, *J* = 7.6 Hz, 1H), 3.07 – 2.91 (m, 2H), 2.49 – 2.44 (m, 1H), 2.26 – 2.20 (m, 1H), 2.00 – 1.82 (m, 2H), 1.51 – 1.46 (m, 1H), 1.45 – 1.37 (m, 2H), 1.32 – 1.23 (m, 13H), 0.87 (t, *J* = 6.5 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.7, 144.1, 133.2, 132.7, 128.8, 127.6, 126.7, 47.6, 32.0, 29.9, 29.7, 29.7, 29.5, 29.5, 28.4, 28.3, 27.2, 22.8, 14.3. **HRMS: (ESI):** Calc'd for.**$C_{19}H_{28}O$ [M+H]$^+$: 273.2218**; found = **273.2223.**

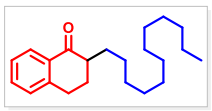
2-decyl-3,4-dihydronaphthalen-1(2H)-one (5.4r):[30] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in



89% yield (253 mg, 0.70 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.02 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 1H), 7.29 (t, *J* = 7.6 Hz, 1H), 7.22 (d, *J* = 7.7 Hz, 1H), 3.04 – 2.91 (m, 2H), 2.49 – 2.44 (m, 1H), 2.26 – 2.20 (m, 1H), 1.97 – 1.85 (m, 2H), 1.52 – 1.41 (m, 2H), 1.33 – 1.23 (m, 15H), 0.88 (t, *J*= 6.8 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.6, 144.1, 133.1, 132.7, 128.7, 127.6, 126.6, 47.6, 32.0, 29.9, 29.7, 29.7, 29.7, 29.5, 29.4, 28.4, 28.3, 27.1, 22.8, 14.2. **HRMS: (ESI):** Calc'd for.**$C_{20}H_{30}O$[M+H]$^+$:287.2375**; found = **287.2373.**

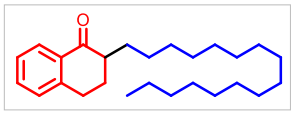
2-dodecyl-3,4-dihydronaphthalen-1(2H)-one (5.4s): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 94% yield (295 mg, 0.94 mmol) as Yellowish liquid.

^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.02 (d, *J* = 7.8 Hz, 1H), 7.45 – 7.42 (m, 1H), 7.28 (t, *J* =



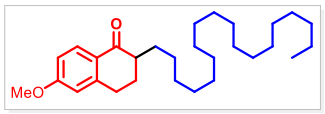
7.5 Hz, 1H), 7.22 (d, *J* = 7.6 Hz, 1H), 3.03 – 2.92 (m, 2H), 2.49 – 2.43 (m, 1H), 2.25 – 2.20 (m, 1H), 1.97 – 1.84 (m, 2H), 1.54 – 1.44 (m, 2H), 1.31 – 1.25 (m, 19H), 0.87 (t, *J* = 7.1 Hz, 3H). **HRMS: (ESI):** Calc'd for. **$C_{22}H_{34}O$ [M+H]$^+$: 315.2688**; found = **315.2689.**

2-hexadecyl-3,4-dihydronaphthalen-1(2H)-one (5.4t):[31] **Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded**

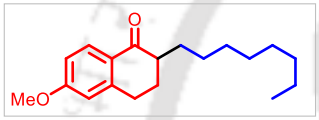


the title compound in 95% yield (352 mg, 0.70 mmol) as white solid.^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.02 (d, *J* = 8.0 Hz, 1H), 7.44 (td, *J* = 7.4, 1.5 Hz, 1H), 7.28 (t, *J* = 7.5 Hz, 1H), 7.22 (d, *J* = 7.6

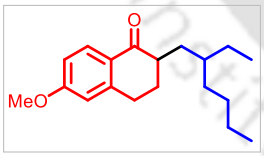
Hz, 1H), 3.02 – 2.93 (m, 2H), 2.48 – 2.44 (m, 1H), 2.25 – 2.20 (m, 1H), 1.96 – 1.85 (m, 2H), 1.51 – 1.45 (m, 1H), 1.43 – 1.39 (m, 1H), 1.33 – 1.23 (m, 27H), 0.87 (t, *J* = 6.8 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 200.6, 144.1, 133.2, 132.7, 128.8, 127.6, 126.7, 47.6, 32.1, 29.9, 29.8, 29.8, 29.8, 29.8, 29.8, 29.7, 29.5, 29.5, 28.4, 28.3, 27.2, 22.8, 14.3.

2-octadecyl-3,4-dihydronaphthalen-1(2H)-one (5.u): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 96% yield (411 mg, 0.96 mmol) as white solid. 

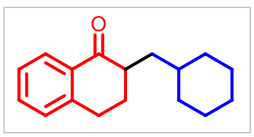
^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.02 (d, *J* = 8.7 Hz, 1H), 6.83 (d, *J* = 8.7 Hz, 1H), 6.70 (s, 1H), 3.87 (s, 3H), 3.03 – 2.89 (m, 2H), 2.46 – 2.41 (m, 1H), 2.25 – 2.20 (m, 1H), 1.96 – 1.85 (m, 2H), 1.52 – 1.47 (m, 1H), 1.45 – 1.41 (m, 1H), 1.34 – 1.25 (m, 29H), 0.90 (t, *J* = 6.8 Hz, 3H).**^{13}C NMR (150 MHz, $CDCl_3$) δ** 199.4, 163.4, 146.5, 130.0, 126.3, 113.1, 112.5, 55.5, 47.3, 32.1, 29.9, 29.8, 29.8, 29.8, 29.8, 29.7, 29.6, 29.5, 28.8, 28.3, 27.2, 22.8, 14.2.**HRMS: (ESI):** Calc'd for.**$C_{29}H_{48}O_2$ [M+H]$^+$: 429.3733**; **found: 429.3733.**

6-methoxy-2-octyl-3,4-dihydronaphthalen-1(2H)-one (5.4v):[32] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 83% yield (239 mg, 0.83 mmol) as Yellowish liquid. 

^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.99 (d, *J* = 8.7 Hz, 1H), 6.80 (dd, *J* = 8.7, 2.2 Hz, 1H), 6.70 – 6.65 (m, 1H), 3.84 (s, 3H), 2.98 – 2.88 (m, 2H), 2.44 – 2.38 (m, 1H), 2.23 – 2.17 (m, 1H), 1.95 – 1.82 (m, 2H), 1.74 – 1.64 (m, 1H), 1.50 – 1.39 (m,3H), 1.32 – 1.27 (m, 9H), 0.88 (t, *J* = 6.8 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 199.4, 163.4, 146.5, 130.0, 126.3, 113.1, 112.5, 55.5, 47.3, 32.0, 29.9, 29.6, 29.6, 29.4, 28.7, 28.3, 27.2, 22.7, 14.2.

2-(2-ethylhexyl)-6-methoxy-3,4-dihydronaphthalen-1(2H)-one (5.4w): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 72% yield (207 mg, 0.72 mmol) as white solid. 

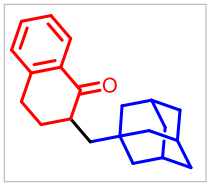
^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.51 – 7.50 (m, 1H), 7.13 (d, *J* = 8.4 Hz, 1H), 7.03 (dd, *J* = 8.4, 2.8 Hz, 1H), 3.82 (s, 3H), 2.97 – 2.85 (m, 2H), 2.54 – 2.48 (m, 1H), 2.23 – 2.18 (m, 1H), 1.93 – 1.88 (m, 1H), 1.86 – 1.78 (m, 1H), 1.46 – 1.25 (m, 10H), 0.90 – 0.85 (m, 6H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 201.0, 158.5, 136.6, 133.5, 130.0, 121.6, 109.6, 55.6, 45.2, 36.2, 33.5, 33.3, 29.1, 28.8, 27.4, 25.4, 23.2, 14.3, 10.4. **HRMS: (ESI):** Calc'd for. **$C_{19}H_{28}O_2$ [M+H]$^+$: 289.2168**; **found =289.2177.**

2-(cyclohexylmethyl)-3,4-dihydronaphthalen-1(2H)-one (5.x):[33] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 2%) afforded the title compound in 78% yield (189 mg, 0.78 mmol) as Yellowish liquid. 

^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.92 (d, *J* = 7.8 Hz, 1H), 7.34 (t, *J* = 7.2 Hz, 1H), 7.18 (t, *J* = 7.5 Hz, 1H), 7.12 (d, *J* = 7.6 Hz, 1H), 2.93 – 2.82 (m, 2H), 2.50 – 2.45 (m, 1H), 2.15 – 2.09 (m, 1H), 1.79 – 1.72 (m, 2H), 1.66 – 1.60 (m, 5H), 1.36 –

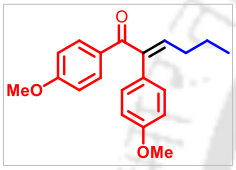
1.27 (m, 1H), 1.23 – 1.04 (m, 4H), 0.91 – 0.74 (m, 2H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 201.1, 143.9, 133.1, 132.7, 128.7, 127.5, 126.6, 44.7, 37.0, 34.9, 34.2, 32.7, 28.5, 28.2, 26.7, 26.5, 26.4.

2-(((3r,5r,7r)-adamantan-1-yl)methyl)-3,4-dihydronaphthalen-1(2H)-one (5.4y): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 1% to 5%) afforded the title compound in 70% yield (206 mg, 0.70 mmol) as Yellowish liquid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.00 (d, *J* = 7.8 Hz, 1H), 7.42 (t, *J* = 7.4 Hz, 1H), 7.27 (t, *J* = 7.3 Hz, 1H), 7.20 (d, *J* = 7.6 Hz, 1H), 3.06 – 2.92 (m, 3H), 2.54 – 2.51 (m, 1H), 2.20 – 2.15 (m, 1H), 2.11 – 2.07 (m, 1H), 1.96 – 1.95 (m, 2H), 1.71 – 1.68 (m, 4H), 1.65 – 1.60 (m, 4H), 1.53 (brs, 6H), 0.97 – 0.93 (m, 1H).

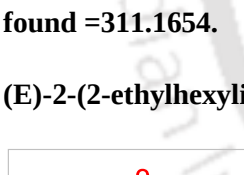


^{13}C NMR (125 MHz, $CDCl_3$) δ 201.1, 144.0, 132.9, 128.7, 127.7, 126.6, 43.5, 42.8, 42.7, 39.5, 39.1, 37.2, 37.1, 36.7, 32.9, 32.1, 28.8, 28.2, 28.1. **HRMS: (ESI):** Calc'd for. **$C_{21}H_{26}O$ $[M+H]^+$: 295.2062**; **found =295.2061.**

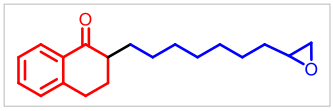
(E)-1,2-bis(4-methoxyphenyl)hex-2-en-1-one (5.16): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 10%) afforded the title compound in 60% yield (186 mg, 0.60 mmol) as yellow liquid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.94 (d, *J* = 8.8 Hz, 2H), 7.26 – 7.25 (m, 2H), 6.88 (d, *J* = 8.8 Hz, 2H), 6.80 (d, *J* = 8.8 Hz, 2H), 6.11 (t, *J* = 7.7 Hz, 1H), 3.83 (s, 3H), 3.76 (s, 3H), 2.04 (q, *J* = 7.5 Hz, 2H), 1.48 – 1.40 (m, 2H), 0.87 (t, *J* = 7.4 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 197.7, 163.9, 159.3, 140.6, 132.2, 130.3, 130.1, 129.8, 127.2, 114.2, 114.0, 55.6, 55.4, 32.0, 22.9, 13.9. **HRMS: (ESI):** Calc'd for. **$C_{20}H_{22}O_3$ $[M+H]^+$: 311.1647**; **found =311.1654.**



(E)-2-(2-ethylhexylidene)-7-methoxy-3,4-dihydronaphthalen-1(2H)-one (5.16a): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 10%) afforded the title compound in 65% yield (186 mg, 0.70 mmol) as gummy liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.60 (s, 1H), 7.15 (d, *J* = 8.3 Hz, 1H), 7.05 – 7.03 (m, 1H), 6.66 (d, *J* = 10.7 Hz, 1H), 3.85 (s, 3H), 2.98 (t, *J* = 6.4 Hz, 2H), 2.77 (t, *J* = 6.4 Hz, 2H), 2.39 – 2.32 (m, 1H), 1.58 – 1.49 (m, 2H), 1.40 – 1.33 (m, 2H), 1.31 – 1.22 (m, 4H), 0.93 – 0.75 (m, 6H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 187.5, 158.7, 145.1, 136.5, 135.1, 134.6, 129.5, 121.3, 110.5, 55.6, 40.3, 34.9, 29.9, 28.6, 28.3, 26.5, 22.9, 14.1, 12.1. **HRMS: (ESI):** Calc'd for. **$C_{19}H_{26}O_2$ $[M+H]^+$: 287.2011**; found = **287.2014.**



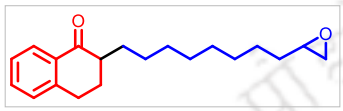
2-(7-(oxiran-2-yl)heptyl)-3,4-dihydronaphthalen-1(2H)-one (5.5): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 92% yield (263 mg, 0.92 mmol) as colourless liquid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.02 (d, *J* = 7.8 Hz, 1H), 7.45 (t, *J* = 7.4 Hz, 1H), 7.29 (t, *J* = 7.6 Hz, 1H), 7.22 (d, *J* =



7.7 Hz, 1H), 3.01 – 2.95 (m, 2H), 2.91 – 2.88 (m, 1H), 2.74 – 2.72 (m, 1H), 2.49 – 2.43 (m, 2H), 2.25 – 2.24 (m, 1H), 1.96 – 1.85 (m, 2H), 1.54 – 1.50 (m, 3H), 1.49 – 1.41 (m, 4H), 1.36 – 1.32 (m, 6H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.5, 144.1, 133.2, 132.7, 128.8, 127.6, 126.7, 52.5, 47.6, 47.2, 32.6, 29.8, 29.5, 29.5, 29.5, 28.4, 28.4, 27.1, 26.1. **HRMS: (ESI):** Calc'd for.**$C_{19}H_{26}O_2$[M+H]$^+$:287.2011**; found = **287.1997.**

2-(8-(oxiran-2-yl)octyl)-3,4-dihydronaphthalen-1(2H)-one (5.6): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 90% yield (270 mg, 0.90 mmol) as colourless liquid.

^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.02 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 1H), 7.29 (t, *J* = 7.7 Hz, 1H), 7.22 (d, *J* = 7.6 Hz, 1H), 3.00 – 2.96 (m, 2H), 2.91 – 2.88 (m, 1H), 2.75 – 2.73 (m, 1H), 2.46 – 2.44 (m, 2H), 2.26 – 2.20 (m, 1H), 1.94 – 1.88 (m, 2H), 1.53 – 1.50 (m, 3H), 1.44 – 1.41 (m, 2H), 1.33 – 1.29 (m, 8H), 1.25- 1.22 (m, 2H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.6, 139.1, 128.2, 123.8, 122.6, 121.7, 114.4, 47.5, 42.6, 42.3, 27.6, 26.3, 24.9, 24.6, 24.6, 24.5, 23.5, 23.4, 22.2, 21.1. **HRMS: (ESI):** Calc'd for.**$C_{20}H_{28}O_2$ [M+H]$^+$: 301.2168**; found = **301.2166.**



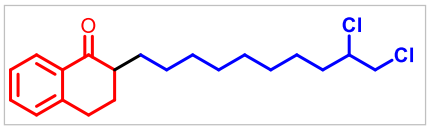
2-(10-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)decyl)-3,4-dihydronaphthalen-1(2H)-one (5.7): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 20%) afforded the title compound in 78% yield (322 mg, 0.78 mmol) as white solid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.02 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.3 Hz, 1H), 7.29 (t, *J* = 7.5 Hz, 1H), 7.22 (d, *J* = 7.6 Hz, 1H), 3.63 (t, *J* = 6.6 Hz, 2H), 3.00 – 2.96 (m, 2H), 2.49 – 2.43 (m, 1H), 2.25 – 2.20 (m, 1H), 1.95 – 1.86 (m, 2H), 1.61 – 1.53 (m, 4H), 1.50 - 1.48 (m, 1H), 1.45 – 1.04 (m, 24H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.6, 144.1, 133.2, 132.8, 128.8, 127.6, 126.7, 63.2, 47.7, 33.0, 29.9, 29.7, 29.6, 29.6, 29.5, 28.5, 28.4, 27.2, 25.9, 25.0.

HRMS: (ESI): Calc'd for.**$C_{26}H_{41}BO_3$ [M+H]$^+$: 413.3227**; found = **413.3243.**

2-(8-(1-oxo-1,2,3,4-tetrahydronaphthalen-2-yl)octyl)cyclopropane-1,1-dicarbonitrile (5.11): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 61% yield (212 mg, 0.61 mmol) as white solid.

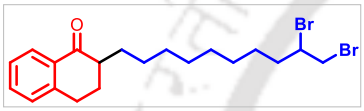
^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.01 (d, *J* = 7.7 Hz, 1H), 7.45 (t, *J* = 7.4 Hz, 1H), 7.29 (t, *J* = 7.5 Hz, 1H), 7.23 (d, *J* = 7.6 Hz, 1H), 3.02 – 2.97 (m, 2H), 2.49-2.45 (m, 1H), 2.25 – 2.22 (m, 1H), 2.01 – 1.98 (m, 1H), 1.94 – 1.87 (m, 3H), 1.73 – 1.68 (m, 2H), 1.64 – 1.62 (m, 1H), 1.61 – 1.59 (m, 1H), 1.57 – 1.55 (m, 1H), 1.53 – 1.50 (m, 2H), 1.48 – 1.47 (m, 1H), 1.35 – 1.31 (m, 7H), 0.93 – 0.86 (m, 1H).**^{13}C NMR (150 MHz, $CDCl_3$) δ** 200.8, 144.1, 133.2, 132.6, 128.8, 127.5, 126.6, 115.8, 109.0, 36.7, 31.5, 30.2, 29.7, 29.5, 29.4, 29.3, 29.1, 28.4, 28.3, 28.1, 27.1, 26.0, 8.7. **HRMS: (ESI):** Calc'd for.**$C_{23}H_{28}N_2O$[M+H]$^+$: 349.2280**; found = **349.2273.**

2-(9,10-dichlorodecyl)-3,4-dihydronaphthalen-1(2H)-one (5.8): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 10%) afforded the title compound in 66% yield (234 mg, 0.66 mmol) as yellow liquid.



^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.02 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.3 Hz, 1H), 7.29 (t, *J* = 7.5 Hz, 1H), 7.22 (d, *J* = 7.6 Hz, 1H), 4.05 – 4.00 (m, 1H), 3.76 – 3.73 (m, 1H), 3.66 – 3.62 (m, 1H), 3.01 – 2.95 (m, 2H), 2.49 – 2.43 (m, 1H), 2.25 – 2.20 (m, 1H), 2.01 – 1.86 (m, 3H), 1.74 – 1.67 (m, 1H), 1.62 – 1.59 (m, 1H), 1.57 – 1.45 (m, 2H), 1.45 – 1.39 (m, 2H), 1.34 – 1.30 (m, 8H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.6, 144.1, 133.2, 132.7, 128.8, 127.6, 126.6, 61.4, 48.4, 47.6, 35.2, 29.8, 29.6, 29.5, 29.5, 29.1, 28.5, 28.4, 27.1, 25.9. **HRMS: (ESI):** Calc'd for.**$C_{20}H_{28}Cl_2O[M+H]^+$: 355.1595**; found = **355.1588.**

2-(9,10-dibromodecyl)-3,4-dihydronaphthalen-1(2H)-one (5.9): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 10%) afforded the title compound in 71% yield (314 mg, 0.71 mmol) as brown solid.



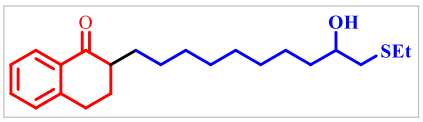
^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.04 (d, *J* = 7.8 Hz, 1H), 7.47 (t, *J* = 7.5 Hz, 1H), 7.31 (t, *J* = 7.5 Hz, 1H), 7.25 (d, *J* = 7.6 Hz, 1H), 3.81 – 3.78 (m, 1H), 3.57 – 3.55 (m, 1H), 3.42 – 3.39 (m, 1H), 3.04 – 2.99 (m, 2H), 2.51 – 2.46 (m, 1H), 2.26 – 2.23 (m, 2H), 1.97 – 1.88 (m, 3H), 1.58 – 1.55 (m, 2H), 1.51 – 1.41 (m, 4H), 1.34 – 1.32 (m, 7H).**^{13}C NMR (150 MHz, $CDCl_3$) δ** 200.7, 144.1, 133.2, 132.6, 128.8, 127.6, 126.7, 71.2, 47.6, 40.8, 35.2, 29.8, 29.5, 29.5, 29.5, 28.4, 28.3, 27.1, 27.1, 25.7. **HRMS: (ESI):** Calc'd for.**$C_{20}H_{28}Br_2O$ [M+H]$^+$: 445.0565**; found = **445.0487.**

2-(10-bromo-9-hydroxydecyl)-3,4-dihydronaphthalen-1(2H)-one (5.10): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 20%) afforded the title compound in 59% yield (224 mg, 0.59 mmol) as pale white solid.

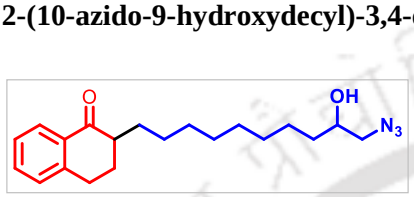
^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.02 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 1H), 7.29 (t, *J* = 7.6 Hz, 1H), 7.23 (d, *J* = 7.6 Hz, 1H), 4.18 – 4.15 (m, 1H), 3.85 – 3.83 (m, 1H), 3.64 – 3.61 (m, 1H), 3.01 – 2.95 (m, 2H), 2.50 – 2.44 (m, 1H), 2.25 – 2.22 (m, 1H), 2.14 – 2.10 (m, 1H), 1.95 – 1.88 (m, 2H), 1.81 – 1.75 (m, 1H), 1.58 – 1.53 (m, 1H), 1.51 – 1.47 (m, 1H), 1.44 – 1.40 (m, 2H), 1.37 – 1.30 (m, 8H), 1.26 – 1.23 (m, 2H).**^{13}C NMR (150 MHz, CDCl3) δ** 200.6, 144.1, 133.2, 132.7, 128.8, 127.6, 126.7, 53.3, 47.6, 36.5, 36.2, 29.8, 29.5, 29.5, 28.9, 28.4, 28.3, 27.1, 26.9. **HRMS: (ESI): Calc'd for.**$C_{20}H_{29}BrO_2[M+H]^+$: 381.1424, **found:** 381.1399.

2-(10-(ethylthio)-9-hydroxydecyl)-3,4-dihydronaphthalen-1(2H)-one (5.9): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 10% to 20%) afforded the title compound in 97% yield (361 mg, 0.97 mmol) as colourless liquid.

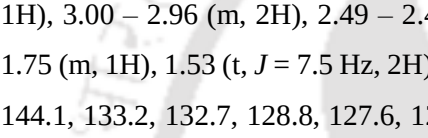
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.02 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.5 Hz, 1H), 7.28 (t, *J* = 7.6 Hz, 1H), 7.22 (d, *J* = 7.6 Hz, 1H), 3.67 – 3.61 (m, 1H), 3.03 – 2.93 (m, 2H), 2.77 – 2.73 (m, 1H), 2.57 – 2.53 (m, 2H), 2.47 – 2.42 (m, 2H), 2.24 – 2.21 (m, 1H), 1.95 – 1.85 (m, 2H), 1.79 – 1.62 (m, 1H), 1.54–1.42 (m, 5H), 1.39 – 1.29 (m, 10H), 1.26 (t, *J* = 7.3 Hz, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.6, 144.1, 133.1, 132.7, 128.7, 127.6, 126.6, 69.3, 47.6, 40.0, 36.4, 29.8, 29.7, 29.6, 29.6, 29.5, 28.4, 28.3, 27.1, 26.2, 25.8, 15.0. **HRMS: (ESI):** Calc'd for.**$C_{22}H_{35}O_2S$ [M+H]$^+$: 363.2358**; found = **363.2338.**



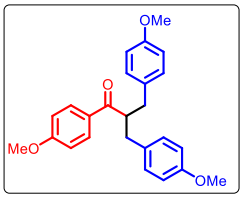
2-(10-azido-9-hydroxydecyl)-3,4-dihydronaphthalen-1(2H)-one (5.14): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 30%) afforded the title compound in 92% yield (316 mg, 0.92 mmol) as white solid. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.02 (d, *J* = 7.7 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 1H), 7.29 (t, *J* = 7.5 Hz, 1H), 7.22 (d, *J* = 7.5 Hz, 1H), 3.75 – 3.66 (m, 1H), 3.59 – 3.53 (m, 1H), 3.49 – 3.43 (m, 1H), 3.00 – 2.96 (m, 2H), 2.49 – 2.44 (m, 1H), 2.25 – 2.21 (m, 1H), 1.96 – 1.88 (m, 2H), 1.82 – 1.75 (m, 1H), 1.53 (t, *J* = 7.5 Hz, 2H), 1.42 – 1.28 (m, 13H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.6, 144.1, 133.2, 132.7, 128.8, 127.6, 126.7, 65.4, 64.6, 47.7, 30.7, 29.8, 29.6, 29.5, 29.5, 28.5, 27.1, 26.1. **HRMS: (ESI):** Calc'd for.**$C_{20}H_{29}N_3O_2$[M+H]$^+$: 344.2338**; found = **344.2350.**



2-(9-hydroxy-10-(4-phenyl-1H-1,2,3-triazol-1-yl)decyl)-3,4-dihydronaphthalen-1(2H)-one (5.13): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/petroleum ether 10% to 30%) afforded the title compound in 88% yield (392 mg, 0.88 mmol) as white solid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.01 (d, *J* = 7.8 Hz, 1H), 7.84 (s, 1H), 7.73 (d, *J* = 7.6 Hz, 2H), 7.43 (t, *J* = 7.4 Hz, 1H), 7.37 (t, *J* = 7.5 Hz, 2H), 7.29 (t, *J* = 7.5 Hz, 2H), 7.22 (d, *J* = 7.6 Hz, 1H), 4.50 – 4.47 (m, 1H), 4.26 – 4.22 (m, 1H), 4.15 – 4.09 (m, 1H), 3.01 – 2.95 (m, 2H), 2.48 – 2.43 (m, 1H), 2.24 – 2.19 (m, 1H), 1.99 – 1.84 (m, 3H), 1.58 – 1.47 (m, 5H), 1.42 – 1.39 (m, 2H), 1.33 – 1.29 (m, 8H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 200.7, 147.5, 144.1, 133.2, 132.7, 130.6, 128.9, 128.8, 128.2, 127.5, 126.7, 125.7, 121.2, 70.6, 56.3, 47.6, 34.6, 29.8, 29.5, 29.4, 28.4, 28.3, 27.1, 27.1, 25.5. **HRMS: (ESI):** Calc'd for. **$C_{28}H_{35}N_3O_2$ [M+H]$^+$: 446.2808**; **found =446.2823.**

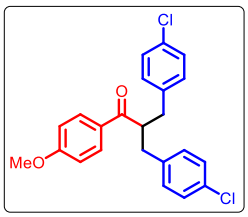


2-(4-methoxybenzyl)-1,3-bis(4-methoxyphenyl)propan-1-one (5.19a) : Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 94% yield as yellow gel. ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.73 (d, *J* = 8.9 Hz, 2H), 7.04 (d, *J* = 8.5 Hz, 4H), 6.80 (d, *J* = 8.9 Hz, 2H), 6.74 (d, *J* = 8.6 Hz, 4H), 3.89 – 3.85 (m, 1H), 3.80 (s, 3H), 3.73 (s, 6H), 3.03 (dd, *J* = 10 Hz, 2H), 2.72 (dd, *J* =



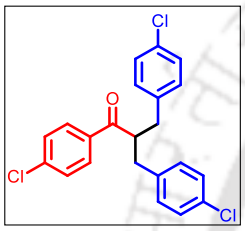
5 Hz, 2H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 202.1, 163.3, 158.1, 131.9, 130.6, 130.5, 130.0, 113.9, 55.5, 55.3, 50.6, 37.5.

2-(4-chlorobenzyl)-3-(4-chlorophenyl)-1-(4-methoxyphenyl)propan-1-one (5.19d):

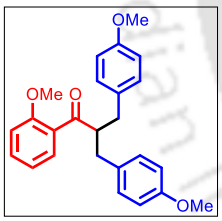


Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 74% yield as white solid.^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.70 (dd, *J* = 8.8, 1.8 Hz, 2H), 7.16 (d, *J* = 8.3 Hz, 4H), 7.04 (d, *J* = 8.3 Hz, 4H), 6.81 (d, *J* = 8.8 Hz, 2H), 3.90 – 3.85 (m, 1H), 3.80 (s, 2H), 3.06 (dd, *J* = 13.7, 8.1 Hz, 2H), 2.73 (dd, *J* = 13.7, 6.1 Hz, 2H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 201.0, 163.6, 138.0, 132.2, 130.5, 130.4, 130.1, 128.6, 113.9, 55.5, 49.7, 37.8.

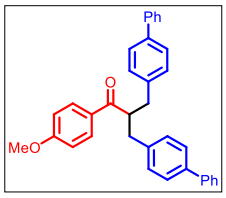
2-(4-chlorobenzyl)-1,3-bis(4-chlorophenyl)propan-1-one (5.19k): Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 63% yield as white solid. ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.53 (d, *J* = 10 Hz, 2H), 7.24 (d, *J* = 10 Hz, 2H), 7.10 (d, *J* = 5 Hz, 4H), 6.96 (d, *J* = 10 Hz, 4H), 3.81 – 3.78 (m, 1H), 2.98 (dd, *J* = 10 Hz, 2H), 2.68 (dd, *J* = 10 Hz, 2H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 201.7, 139.8, 137.5, 135.5, 132.4, 130.4, 129.5, 129.0, 128.7, 50.4, 37.8.



2-(4-methoxybenzyl)-1-(2-methoxyphenyl)-3-(4-methoxyphenyl)propan-1-one (5.19j): Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 20%) afforded the title compound in 61% yield as yellow gel.^{1}H NMR (500 MHz, $CDCl_3$) δ 7.72 (s, 1H), 7.54 (t, *J* = 7.1 Hz, 2H), 7.18 – 7.15 (m, 1H), 7.02 (d, *J* = 8.3 Hz, 4H), 6.75 – 6.74 (m, 4H), 3.85 – 3.80 (m, 1H), 3.73 (s, 6H), 3.03 – 2.98 (m, 2H), 2.79 – 2.74 (m, 2H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 197.8, 153.3, 134.5, 130.6, 126.4, 126.3, 125.1, 121.7, 117.9, 109.0, 50.3, 46.6, 32.8.



3-([1,1'-biphenyl]-4-yl)-2-([1,1'-biphenyl]-4-ylmethyl)-1-(4-methoxyphenyl)propan-1-one (5.19f): Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 72% yield as white .^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.55 (d, *J* = 7.4 Hz, 5H), 7.46 (d, *J* = 8.0 Hz, 4H), 7.41 (t, *J* = 7.6 Hz, 5H), 7.31 (t, *J* = 7.3 Hz, 2H), 7.18 (d, *J* = 8.0 Hz, 4H), 6.77 (s, 2H), 3.59 – 3.50 (m, 1H), 3.22 (dd, *J* = 13.5, 6.7 Hz, 2H), 2.65 (dd, *J* = 13.5, 7.2 Hz, 2H), 2.25 (s, 3H), 1.99 (s, 6H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 210.7, 141.1, 139.2, 139.0, 139.0, 138.0, 134.3, 129.9, 129.1, 128.9, 127.3, 127.1, 127.1, 57.8, 35.8, 31.7, 21.2, 19.8, 14.3.



1-cyclopropyl-2-(4-methoxybenzyl)-3-(4-methoxyphenyl)propan-1-one (5.19m): Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 88% yield as yellow gel. ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.08 (d, *J* = 8.6 Hz, 4H), 6.83 (d, *J* = 8.7 Hz, 4H), 3.80 (s, 6H), 3.23 – 3.18 (m, 1H), 2.93 (dd, *J* = 10, 2H), 2.71 (dd, 6.0 Hz, 2H), 1.69 – 1.65 (m, 1H), 0.84 – 0.82 (m, 2H), 0.68 – 0.65 (m, 2H).**^{13}C NMR (150 MHz, CDCl$_3$)** δ 213.7, 158.1, 131.8, 130.1, 113.9, 57.3, 55.3, 37.1, 21.7, 11.1.

2-(4-chlorobenzyl)-3-(4-chlorophenyl)-1-(2,3,4,5,6-pentamethylphenyl)propan-1-one (5.19t): Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 72% yield as white. ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.11 (d, *J* = 8.3 Hz, 4H), 6.92 (d, *J* = 8.3 Hz, 4H), 3.19 – 3.16 (m, 1H), 3.04 (dd, *J* = 5 Hz, 2H), 2.42 (dd, *J* = 5Hz, 2H), 2.13 (s, 3H), 2.05 (s, 6H), 1.76 (s, 6H). **^{13}C NMR (125 MHz, CDCl$_3$)** δ 211.3, 138.9, 138.4, 136.1, 133.3, 132.2, 130.8, 128.7, 128.6, 58.4, 35.1, 17.8, 16.9, 16.1.

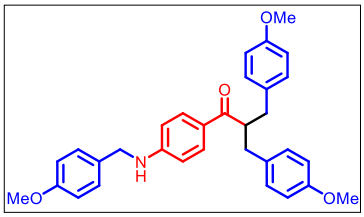
1-(2,3,4,5,6-pentamethylphenyl)-3-(thiophen-2-yl)-2-(thiophen-2-ylmethyl)propan-1-one (5.19u): Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 65% yield as white solid. ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.05–7.04 (m, 2H), 6.82 – 6.80 (m, 2H), 6.72 – 6.71 (m, 2H), 3.30 (q, *J* = 5 Hz, 1H), 3.24 (dd, *J* =15, 5 Hz, 2H), 2.88 (dd, *J* = 15, 5 Hz, 2H), 2.14 (s, 3H), 2.07 (s, 6H), 1.85 (s, 6H). **^{13}C NMR (150 MHz, CDCl$_3$)** δ 211.1, 142.1, 138.7, 133.3, 128.8, 126.8, 126.4, 124.1, 58.7, 29.6, 17.6, 16.9, 16.1.

2-(4-methoxybenzyl)-3-(4-methoxyphenyl)-1-(p-tolyl)propan-1-one (5.19i): Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 74% yield as white solid ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.76 (d, *J* = 7.9 Hz, 2H), 7.25 (d, *J* = 7.9 Hz, 2H), 7.15 (d, *J* = 8.2 Hz, 4H), 6.86 (d, *J* = 8.3 Hz, 4H), 4.03 – 4.01 (m, 1H), 3.84 (s, 6H), 3.15 (dd, *J* = 15, 5 Hz, 2H), 2.83 (dd, *J* = 15, 5 Hz, 2H), 2.45 (s, 3H). **^{13}C NMR (125 MHz, CDCl$_3$)** δ 203.2, 158.1, 143.6, 135.1, 131.9, 130.1, 129.3, 128.4, 55.3, 50.8, 37.4, 21.7.

2-(4-chlorobenzyl)-3-(4-chlorophenyl)-1-(p-tolyl)propan-1-one (5.19l): Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 15%) afforded the title compound in 74% yield as white solid ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.55 (d, *J* = 8.1 Hz, 2H), 7.09 (t, *J* = 8.8 Hz, 6H), 6.97 (d, *J* = 8.3 Hz, 4H), 3.84 – 3.81 (m,

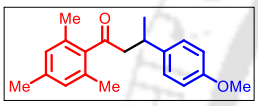
1H), 3.00 (dd, *J* = 15, 10 Hz, 2H), 2.65 (dd, *J* =15, 10 Hz, 2H), 2.28 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 202.3, 144.2, 137.9, 134.7, 132.3, 130.5, 129.5, 128.7, 128.4, 50.1, 37.7, 21.7.

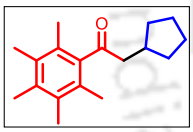
2-(4-methoxybenzyl)-1-(4-((4-methoxybenzyl)amino)phenyl)-3-(4-methoxyphenyl)propan-1-one: Purification by column chromatography (SiO2, 100–200 mesh, eluent: AcOEt/petroleum ether 5% to 30%) afforded the title compound in 691% yield as white solid ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.67 (d, *J* = 8.7 Hz, 2H), 7.22 (d, *J* = 8.5 Hz, 2H), 7.03 (d, *J* = 8.5 Hz, 4H), 6.87 (d, *J* = 8.6 Hz, 2H), 6.73 (d, *J* = 8.5 Hz, 4H), 6.48 (d, *J* = 8.7 Hz, 2H), 4.44 -4.43 (m, 1H), 4.26 (d, *J* = 4.3 Hz, 2H), 3.83 – 3.81 (m, 1H), 3.79 (s, 3H), 3.72 (s, 6H), 3.04 – 3.00 (m, 2H), 2.69 (d, *J* = 6.3 Hz, 1H), 2.66 (d, *J* = 6.3 Hz, 1H).**^{13}C NMR (126 MHz, $CDCl_3$)** δ 201.1, 159.2, 158.0, 151.9, 132.3, 130.8, 130.3, 130.1, 128.9, 127.0, 114.3, 113.9, 111.7, 55.4, 55.3, 50.0, 47.2, 37.5.



1-mesityl-3-(4-methoxyphenyl)butan-1-one(5.22a): Yellow liquid, yields: 83%

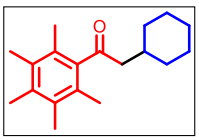
^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.06 (d, *J* = 8.0 Hz, 2H), 6.73 (d, *J* = 8.0 Hz, 2H), 6.68 (s, 1H), 3.67 (s, 3H), 3.41 – 3.37 (m, 1H), 2.93 – 2.80 (m, 2H), 2.15 (s, 3H), 1.96 (s, 6H), 1.24 (d, *J* = 7.0 Hz, 2H). **^{13}C NMR (126 MHz, $CDCl_3$)** δ 209.2, 158.1, 139.6, 138.7, 138.3, 132.7, 128.6, 128.0, 113.9, 55.3, 53.4, 33.8, 22.6, 21.1, 19.0.



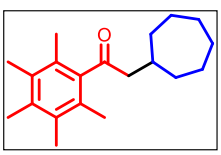


2-cyclopentyl-1-(2,3,4,5,6-pentamethylphenyl)ethan-1-one (5.22b): Yellow liquid, yields: 90%· ^{1}H NMR (500 MHz, Chloroform-*d*) δ 2.71 (d, *J* = 6.8 Hz, 2H), 2.43 – 2.37 (m, 1H), 2.22 (s, 3H), 2.17 (s, 6H), 2.10 (s, 6H), 1.98 – 1.90 (m, 3H), 1.62 – 1.58 (m, 3H), 1.18 – 1.14 (m, 2H). **^{13}C NMR (126 MHz, $CDCl_3$)** δ 211.8, 141.0, 135.3, 133.1, 127.4, 53.9, 52.0, 40.4, 32.9, 25.1, 17.2, 16.0.

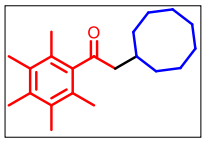
2-cyclohexyl-1-(2,3,4,5,6-pentamethylphenyl)ethan-1-one (5.22c): Yellow liquid, yields: 92%^{1}H NMR (500 MHz, Chloroform-*d*) δ 2.56 (d, *J* = 6.4 Hz, 2H), 2.22 (s, 3H), 2.17 (s, 6H), 2.09 (s, 6H), 2.06 – 2.02 (m, 1H), 1.86 – 1.84 (m, 2H), 1.71 – 1.65 (m, 3H), 1.38 – 1.31 (m, 2H), 1.21 – 1.15 (m, 1H), 1.02 – 0.94 (m, 2H). **^{13}C NMR (151 MHz, $CDCl_3$)** δ 211.3, 141.0, 135.4, 133.2, 127.4, 53.3, 33.5, 32.5, 26.5, 26.3, 17.1, 16.8, 16.1.



2-cycloheptyl-1-(2,3,4,5,6-pentamethylphenyl)ethan-1-one (5.22d): Yellow liquid , Yields: 91%, ^{1}H NMR (500 MHz, Chloroform-*d*) δ 2.62 (d, *J* = 6.5 Hz, 2H), 2.22 (s, 3H), 2.17 (s, 6H), 2.09 (s, 6H), 1.86 – 1.80 (m, 2H), 1.67 – 1.58 (m, 5H), 1.53 – 1.47 (m, 4H), 1.30 – 1.22 (m, 2H). **^{13}C NMR (126 MHz, $CDCl_3$)** δ 211.3, 140.9, 135.3, 133.1, 127.4, 54.1, 35.1, 34.2, 28.4, 26.5, 17.1, 16.7, 16.0.

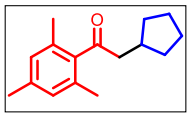


2-cyclooctyl-1-(2,3,4,5,6-pentamethylphenyl)ethan-1-one (5.22e): Yields: 91%



^{1}H NMR (500 MHz, Chloroform-*d*) δ 2.61 (d, *J* = 6.4 Hz, 2H), 2.31 – 2.26 (m, 1H), 2.22 (s, 3H), 2.17 (s, 6H), 2.11 (s, 6H), 1.76 – 1.71 (m, 2H), 1.69 – 1.61 (m, 4H), 1.57 – 1.48 (m, 5H), 1.39 – 1.32 (m, 2H). **^{13}C NMR (126 MHz, $CDCl_3$)** δ 211.3, 141.0, 135.3, 133.2, 127.5, 54.2, 32.6, 32.3, 27.3, 26.3, 25.4, 17.2, 16.8, 16.1.

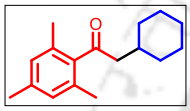
2-cyclopentyl-1-mesitylethan-1-one(5.22f): Yields: Yield: 71%



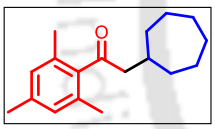
^{1}H NMR (500 MHz, Chloroform-*d*) δ 6.81 (s, 2H), 2.73 (d, *J* = 6.9 Hz, 1H), 2.41 – 2.35 (m, 1H), 2.26 (s, 3H), 2.19 (s, 6H), 1.95 – 1.89 (m, 2H), 1.64 – 1.55 (m, 4H), 1.18 – 1.11 (m, 2H). **^{13}C NMR (126 MHz, $CDCl_3$)** δ 210.7, 140.0, 138.3, 132.6, 128.6, 51.3, 35.0, 32.9, 25.1, 21.1, 19.3.

2-cyclohexyl-1-mesitylethan-1-one (5.22g): Yields: Yields: 83%

^{1}H NMR (500 MHz, Chloroform-*d*) δ 6.73 (s, 2H), 2.50 (d, *J* = 6.5 Hz, 2H), 2.18 (s, 3H), 2.11 (s, 6H), 1.99 – 1.91 (m, 1H), 1.75 – 1.73 (d, *J* = 12.0 Hz, 1H), 1.63 – 1.57 (m, 3H), 1.34 – 1.21 (m, 2H), 1.15 – 1.05 (m, 1H), 0.94 – 0.86 (m, 2H).**^{13}C NMR (126 MHz, $CDCl_3$)** δ 210.1, 140.1, 138.2, 132.6, 128.6, 52.6, 33.5, 32.9, 26.4, 26.3, 21.1, 19.2.

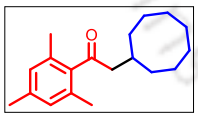


2-cycloheptyl-1-mesitylethan-1-one (5.22h): Yields: 81%



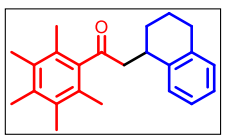
^{1}H NMR (500 MHz, Chloroform-*d*) δ 6.81 (s, 2H), 2.64 (d, *J* = 6.6 Hz, 2H), 2.26 (s, 3H), 2.18 (s, 6H), 1.82 – 1.77 (m, 2H), 1.53 – 1.48 (m, 4H), 1.29 – 1.22 (m, 4H), 1.29 – 1.22 (m, 2H). **^{13}C NMR (126 MHz, $CDCl_3$)** δ 210.3, 140.1, 138.3, 132.7, 128.7, 53.4, 35.1, 34.5, 28.4, 26.5, 21.1, 19.2.

2-cyclooctyl-1-mesitylethan-1-one (5.22i): Yields: 78%

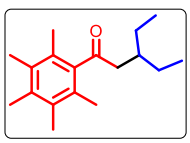


^{1}H NMR (500 MHz, Chloroform-*d*) δ 6.81 (s, 2H), 2.63 – 2.61 (m, 2H), 2.26 (s, 3H), 2.19 (s, 6H), 1.74 – 1.64 (m, 5H), 1.61 – 1.58 (m, 3H), 1.55 – 1.49 (m, 5H), 1.38 – 1.32 (m, 2H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 210.3, 140.1, 138.3, 132.7, 128.7, 53.5, 32.7, 32.6, 27.3, 26.3, 25.4, 21.1, 19.3.

1-(2,3,4,5,6-pentamethylphenyl)-2-(1,2,3,4-tetrahydronaphthalen-1-yl)ethan-1-one (5.22f): Yields: 94%, ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.16 (d, *J* = 7.0 Hz, 1H), 7.11 – 7.04 (m, 3H), 3.67 – 3.62 (m, 1H), 3.01 (d, *J* = 6.4 Hz, 2H), 2.80 – 2.73 (m, 2H), 2.21 (s, 3H), 2.17 (s, 6H), 2.11 (s, 6H), 2.09 – 2.05 (m, 1H), 1.85 – 1.78 (m, 3H). **^{13}C NMR (126 MHz, $CDCl_3$)** δ 210.6, 140.7, 140.3, 137.3, 135.5, 133.2, 129.3, 128.5, 127.4, 126.0, 125.9, 53.6, 32.3, 29.7, 28.7, 19.8, 17.1, 16.8, 16.



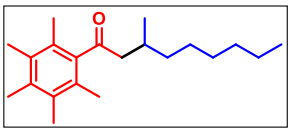
3-ethyl-1-(2,3,4,5,6-pentamethylphenyl)pentan-1-one (5.22k): Yields: 45%



^{1}H NMR (600 MHz, Chloroform-*d*) δ 2.63 – 2.59 (m, 2H), 2.22 (m, 3H), 2.17 (m, 6H), 2.10 (m, 6H), 1.47 – 1.37 (m, 4H), 0.91 – 0.86 (m, 6H). **^{13}C NMR (151**

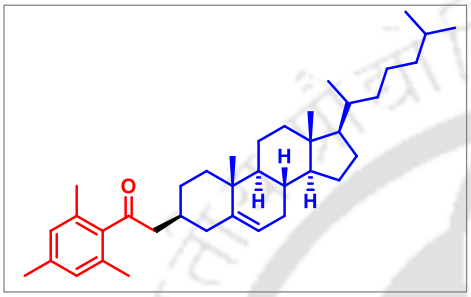
MHz, $CDCl_3$) δ 211.7, 141.1, 135.3, 133.2, 127.4, 49.7, 35.2, 25.7, 17.1, 16.8, 16.1, 10.9.

3-methyl-1-(2,3,4,5,6-pentamethylphenyl)nonan-1-one (5.22l): Yields: 68%



^{1}H NMR (500 MHz, Chloroform-*d*) δ 2.69 – 2.64 (m, 2H), 2.53 – 2.47 (m, 2H), 2.22 (m, 3H), 2.17 (s, 6H), 2.10 (s, 6H), 1.42 – 1.39 (m, 1H), 1.34 – 1.22 (m, 9H), 1.22 – 1.19 (m, 1H), 1.06 – 1.01 (m, 3H), 0.90 – 0.84 (m, 3H). **^{13}C NMR (150 MHz, $CDCl_3$)** δ 211.5, 141.0, 135.4, 133.2, 127.4, 53.1, 37.0, 32.0, 29.6, 28.0, 27.0, 22.8, 20.2, 17.2, 16.8, 16.1, 14.2.

2-((3S,8S,9S,10R,13R,14S,17R)-10,13-dimethyl-17-((R)-6-methylheptan-2-yl)



2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H-cyclopenta[a]phenanthren-3-yl)-1-mesitylethan-1-one (5.22m): Yields: 51% ^{1}H NMR (500 MHz, Chloroform-*d*) δ 6.82 (s, 1H), 5.16 (s, 1H), 2.70 (s, 1H), 2.64-2.63 (m Hz, 2H), 2.29 – 2.24 (m, 3H), 2.20 – 2.16 (m, 7H), 1.99 – 1.93 (m, 2H), 1.90 – 1.78 (m, 2H), 1.73 – 1.68 (m, 2H), 1.39 – 1.31 (m, 6H), 1.15 – 1.12 (m, 7H), 1.02- 1.00 (m, 5H), 0.91 – 0.90 (m, 4H), 0.87 – 0.86 (m, 9H), 0.80 – 0.74 (m, 1H), 0.69 (s, 3H).**^{13}C NMR (150 MHz, $CDCl_3$) δ** 210.2, 146.1, 139.9, 138.3, 132.7, 128.7, 123.0, 56.4, 56.3, 54.7, 51.9, 42.7, 40.1, 39.7, 37.8, 37.3, 36.3, 36.2, 35.9, 33.4, 32.8, 32.0, 28.4, 28.2, 26.7, 24.4, 24.0, 23.0, 22.7, 21.5, 21.2, 19.6, 19.3, 12.1.

5.16. References:

[1] a) F. Huang, Z. Liu, Z. Yu, *Angew. Chem. Int. Ed*. **2016**, *55*, 862 – 875; *Angew. Chem*. **2016**, *128*, 872 – 885; b) S. Thiyagarajan, C. Gunanathan, *J. Am. Chem. Soc*. **2019**, *141*, 3822 – 3827; c) F. Sun, J. Huang, Z. Wei, C. Tang, W. Liu, *Angew. Chem. Int. Ed*. **2023**, *62*, e202303433.

[2] a) L. K. M. Chan, D. L. Poole, D. Shen, M. P. Healy, T. J. Donohoe, *Angew. Chem. Int. Ed.* **2014**, *53*, 761 – 765; *Angew. Chem.* **2014**, *126*, 780 – 784; b) D. Shen, D. L. Poole, C. C. Shotton, A. F. Kornahrens, M. P. Healy, T. J. Donohoe, *Angew. Chem. Int. Ed.* **2015**, *54*, 1642 – 1645; *Angew. Chem.* **2015**, *127*, 1662 – 1665 c) K. Ganguli, A. Mandal, M. Pradhan, A. K. Deval, S. Kundu, *ACS Catal*. **2023**, *13*, 7637−7649.

[3] a) J. R. Frost, C. B. Cheong, W. M. Akhtar, D. F. Caputo, N. G. Stevenson, T. J. Donohoe, *J. Am. Chem. Soc*. **2015**, *137*, 15664 – 15667;

[4] C. Schlepphorst, B. Maji, F. Glorius, *ACS Catal*. **2016**, *6*, 4184– 4188.

[5] K. Ganguli, A. Mandal, S. Kundu; *ACS Catal*. **2022**, *12*, 12444−12457.

[6] K. Das, S. Waiba, A. Jana, B. Maji, *Chem. Soc. Rev*. **2022**, *51*, 4386–4464.

[7] a) B. Zhao, Z. Han, K. Ding, *Angew. Chem. Int. Ed.* **2013**, *52*, 4744 – 4788; *Angew. Chem.***2013**, *125*, 4844 – 4889; b) A. Mondal, R. Sharma, D. Pal, D. Srimani, *Eur. J. Org. Chem*. **2021**, *2021*, 3690–3720; c) K. Das, S. Waiba, A. Jana, B. Maji, *Chem. Soc. Rev*. **2022,***51*, 4386–4464.

[8] a) Z. J. Dubey, W. Shen, J. A. Little, M. J. Krische, *J. Am. Chem. Soc*. **2023**, *145*, 8576–8582; b) V. W. Bhoyare, A. G. Tathe, V. Gandon, N. T. Patil, *Angew. Chem. Int. Ed*. **2023**, *62*, e2023127; c) S. Ghosh, S. Patel, I. Chatterjee, *Chem. Commun*. **2021**, *57*, 11110–1113.

[9] L. Caputi, E. Aprea, *Recent Pat. Food, Nutr. Agric*. **2011**, *3*, 9.

[10] Freedonia Industry Research. Report: US Flavors & Fragrances Market. Available at: http://www.reportlinker.com/p0100133/US- Flavors-Fragrances-Market.html (Accessed on: September 8, 2010).

[11] C.-Y. Zhao, D.-W. Ji, H. Zheng, G.-C. He, H. Liu, Y.-C. Hu, Q.-A. Chen, *ACS Catal*. **2021**, *11*, 6825.

[12] a) C.-Y. Zhao, Y.-Y. Liu, X.-X. Zhang, G.-C. He, H. Liu, D.-W. Ji, Y.-C. Hu, Q.-A. Chen, *Angew. Chem. Int. Ed*. **2022**, *61*, e202207202; *Angew. Chem*. **2022**, *134*, e202207202; b) P. Chakraborty, S. Pradhan, J. R. Premkumar, B. Sundararaju, *J. Catal*. **2023**, *421*, 309-318.

[13] a) A. Ludwiczuk, K. Skalicka-WoŽniak, M. I. Georgiev, S. Badal, R. Delgoda, Terpenoids, Elsevier, Oxford, U.K. **2017**, pp. 233–266; b) N. E. Menyiy, N. E. Omari, A. Balahbib, T. Benali, F. E. Guaouguaou, S. Charfi and A. Bouyahya, S. C. Mandal, A. K. Nayak, A. K. Dhara, Elsevier, Oxford, U.K. **2022**, pp. 313–361.

[14] B. X. Li, D. N. Le, K. A. Mack, A. McClory, N.-K. Lim, T. Cravillion, S. Savage, C. Han D B Collum, H. Zhang, F. Gosselin, *J. Am. Chem. Soc*. **2017**, *139*, 10777–10783.

[15] W. Keim, *Angew. Chem. Int. Ed*. **2013**, *52*, 12492 – 12496; *Angew. Chem*. **2013**, *125*, 12722 – 12726.

[16] S. Kisan, V. Krishnakumar, C. Gunanathan, *ACS Catal*. **2017**, *7*, 5950 – 5954.

[17] X. Wang, Y. Li, X. Wu, *ACS Catal*. **2022**, *12*, 3710–3718.

[18] A. Yoshimura, T. N. Jones, M. S. Yusubov, V. V. Zhdankin, *Adv. Synth. Catal*. **2014**, *356*, 3336 –3340.

[19] B. Olofsson, P. Somfai, *J. Org. Chem*. **2002**, *67*, 8574-8583.

[20] R. Munirathinam, D. Joe, J. Huskens, W. Verboom, *J. Flow Chem*. **2012**, *2*, 129–134.

[21] S. S. Bag, H. Gogoi, *J. Org. Chem*. **2018**, *83*, 7606−7621.

[22] K. Das, A. Mondal, D. Srimani, *J. Org. Chem*. **2018**, *83*, 9553−9560.

[23] D. Dı´az, T. Martı´n, V. S. Martı´n, *J. Org. Chem*. **2001**, *66*, 7231-7233.

[24] B. X. Li, D. N. Le, K. A. Mack, A. McClory, N-K. Lim, T. Cravillion, S. Savage, C. Han, D. B. Collum, H. Zhang, F. Gosselin, *J. Am. Chem. Soc*. **2017**, *139*, 10777−10783.

[25] G. Dey, S. Saifi, M. Sk, A. S. K. Sinha, D. Banerjee, A. Aijaz, *Dalton Trans*. **2022**, *51*, 17973–17977.

[26] V. Lubczyk, H. Bachmann, R. Gust, *J. Med. Chem*. **2003**, *46*, 1484-1491.

[27] K. Li, J. Chen, C. Yang, K. Zhang, C. Pan, B. Fan, *Org. Lett*. **2020**, *22*, 4261−4265.

[28] M. Yokota, D. Fujita, J. Ichikawa, *Org. Lett*. **2007**, *9*, 4639–4642.

[29] H. Mizutani, R. Kawanishi, K. Shibatomi, *Chem. Commun*. **2021**, *57*, 6676–6679.

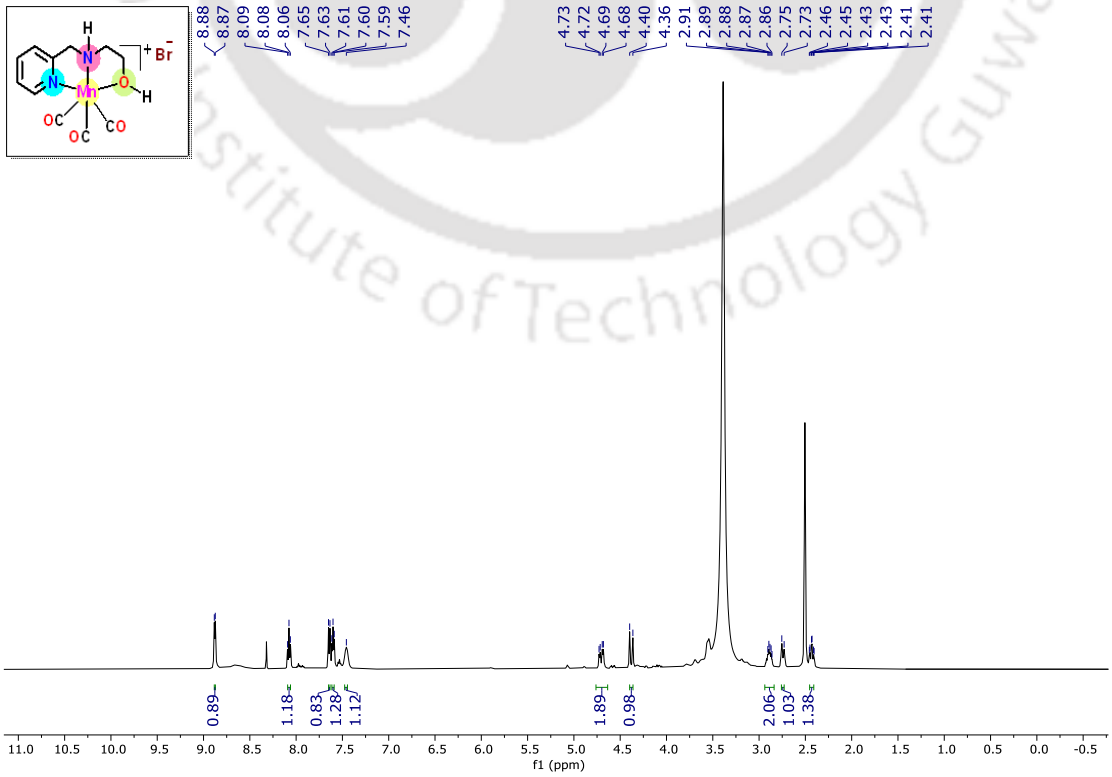
[30] T. Hatakeyama, S. Ito, H. Yamane, M. Nakamuraa, E. Nakamura, *Tetrahedron* **2007**, *63*, 8440–8448.

[31] S. Charvet, M. Médebielle, J. C. Vantourout, *J. Org. Chem*. **2022**, *87*, 5690−5702.

[32] S. S. Gawali, B. K. Pandia, S. Pal, C. Gunanathan, *ACS Omega*. **2019**, *4*, 10741−10754.

[33] A. K Bains, A. Biswas, D. Adhikari, *Adv. Synth. Catal*. **2022**, *364*, 47–52.

5.17. Selected ^{1}H and ^{13}C copies.



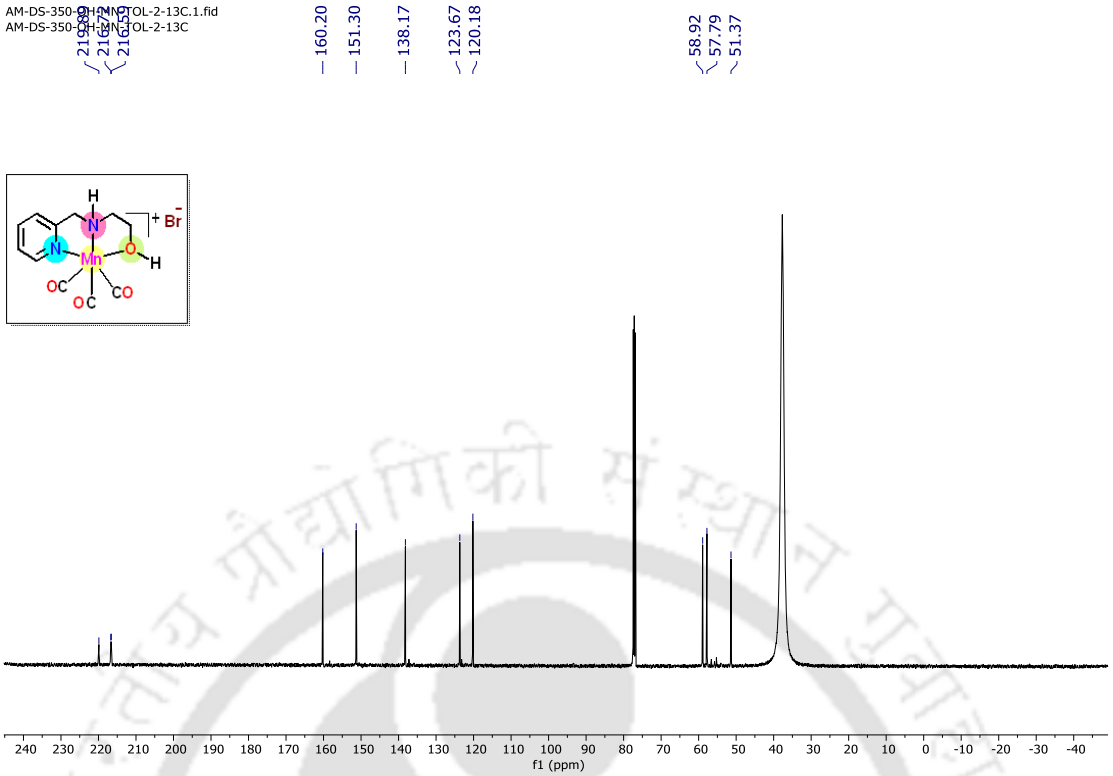
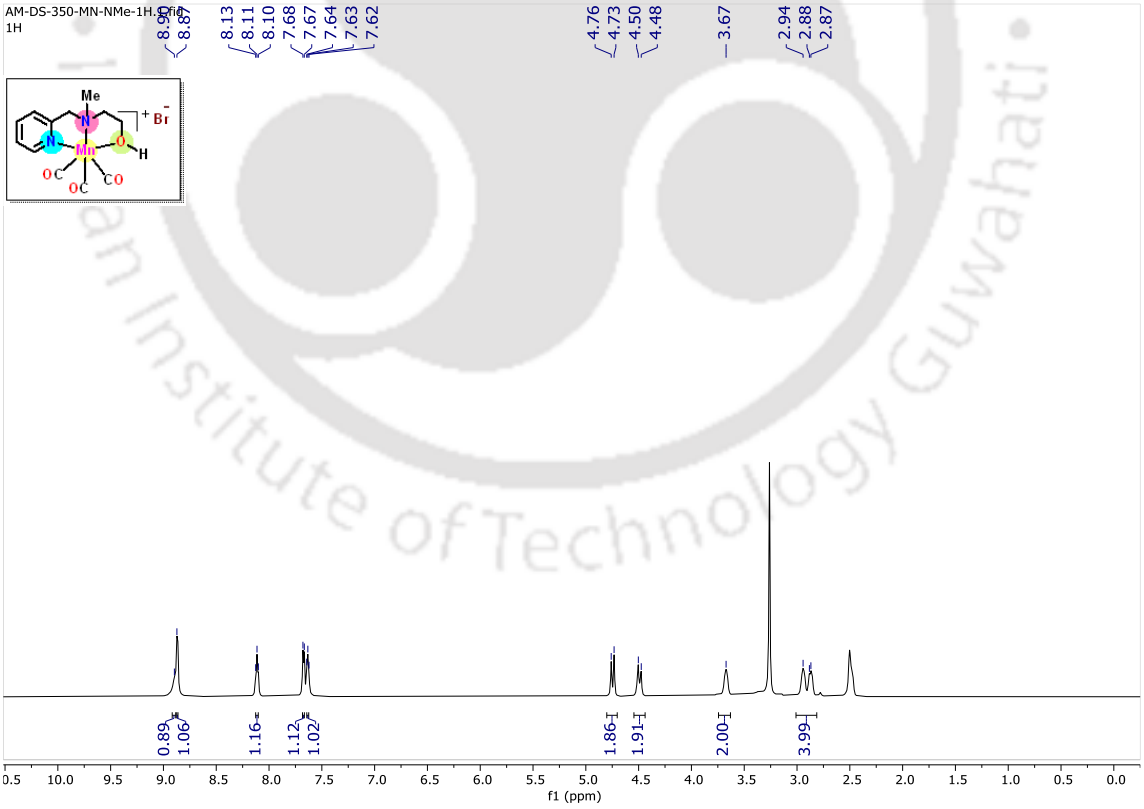


Figure 5.7. ^{1}H (600 MHz)&$^{13}C\{^{1}H\}$ (150 MHz) NMR Spectrum of **Mn-24** in $CDCl_3$.



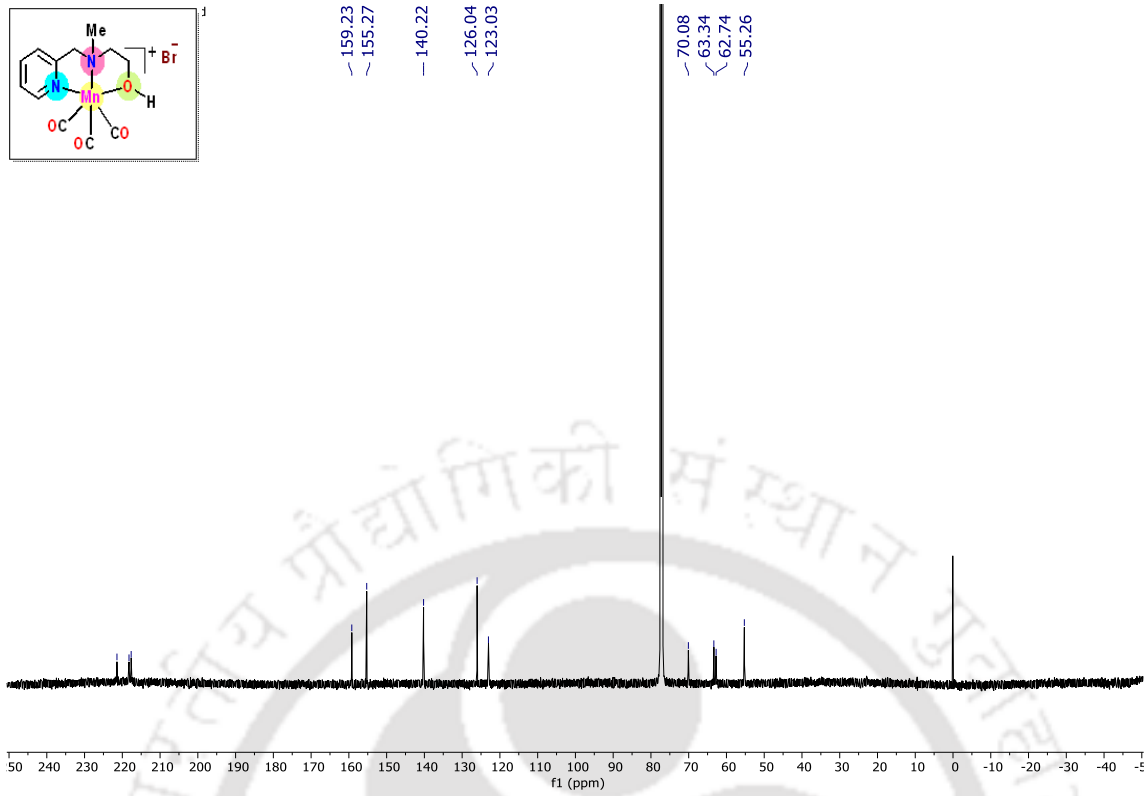
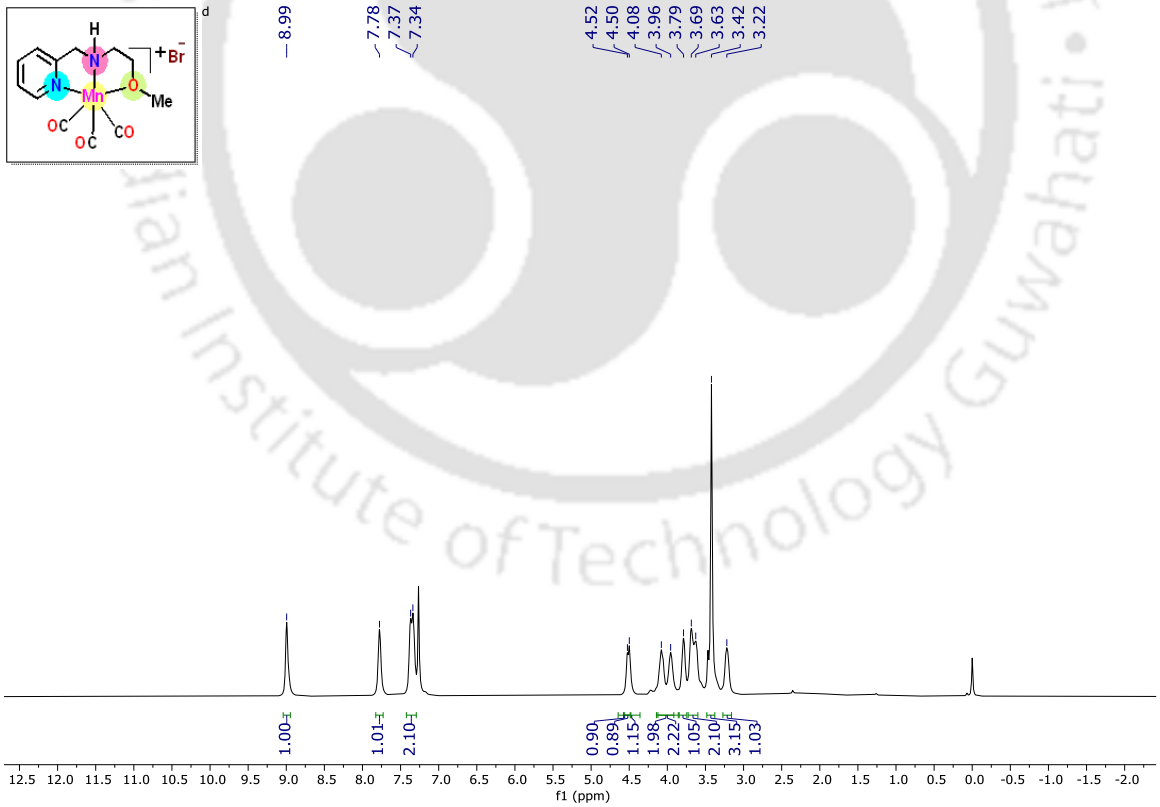


Figure 5.8. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(Mn-25)** in $CDCl_3$.



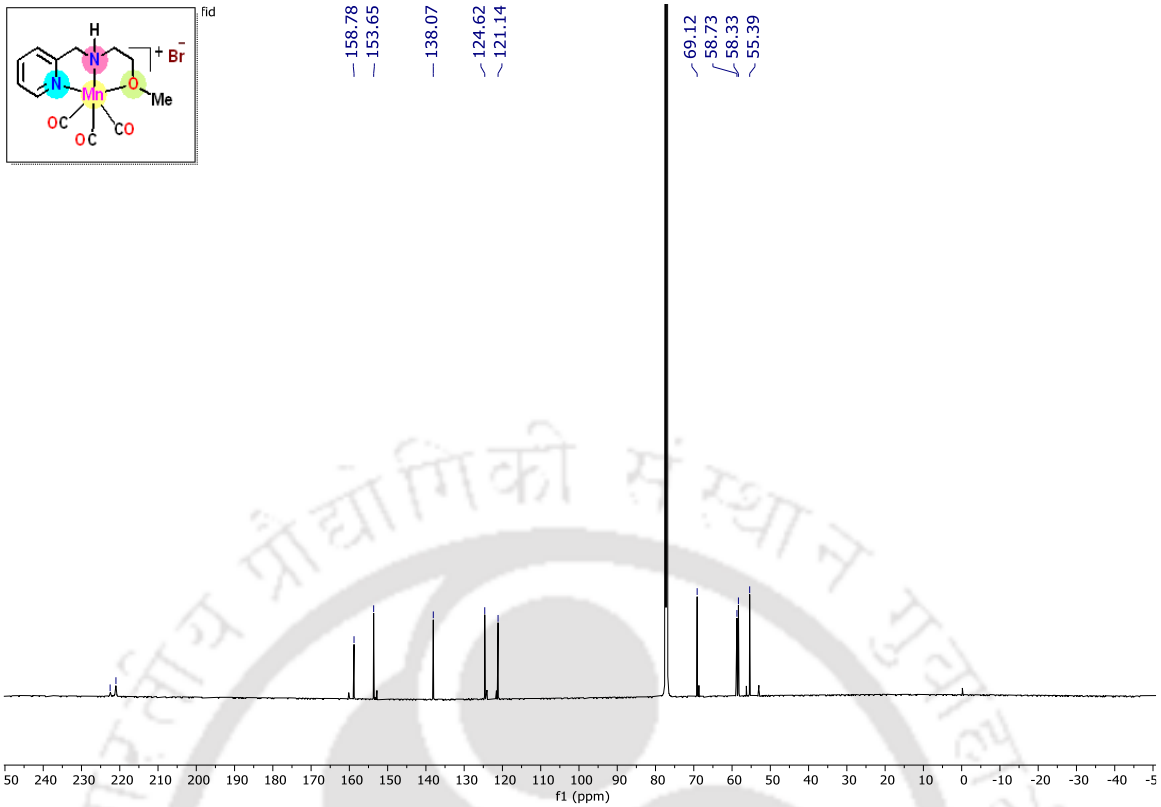
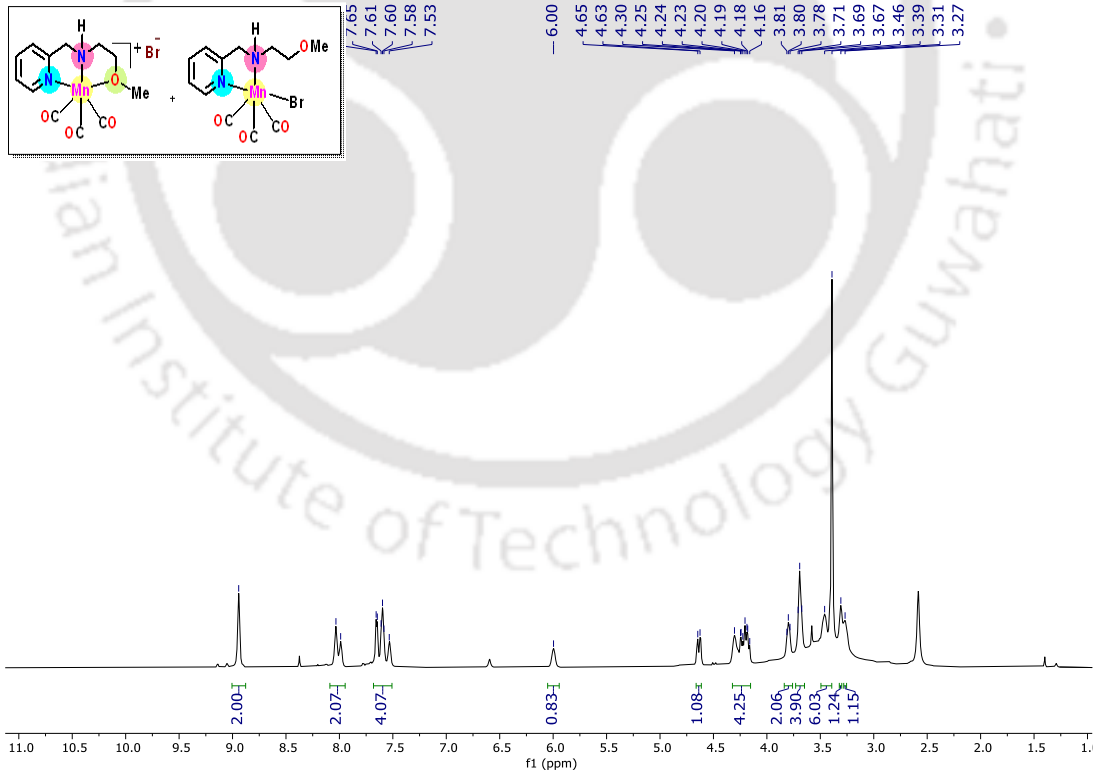


Figure 5.9. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(Mn-26)** in $CDCl_3$.



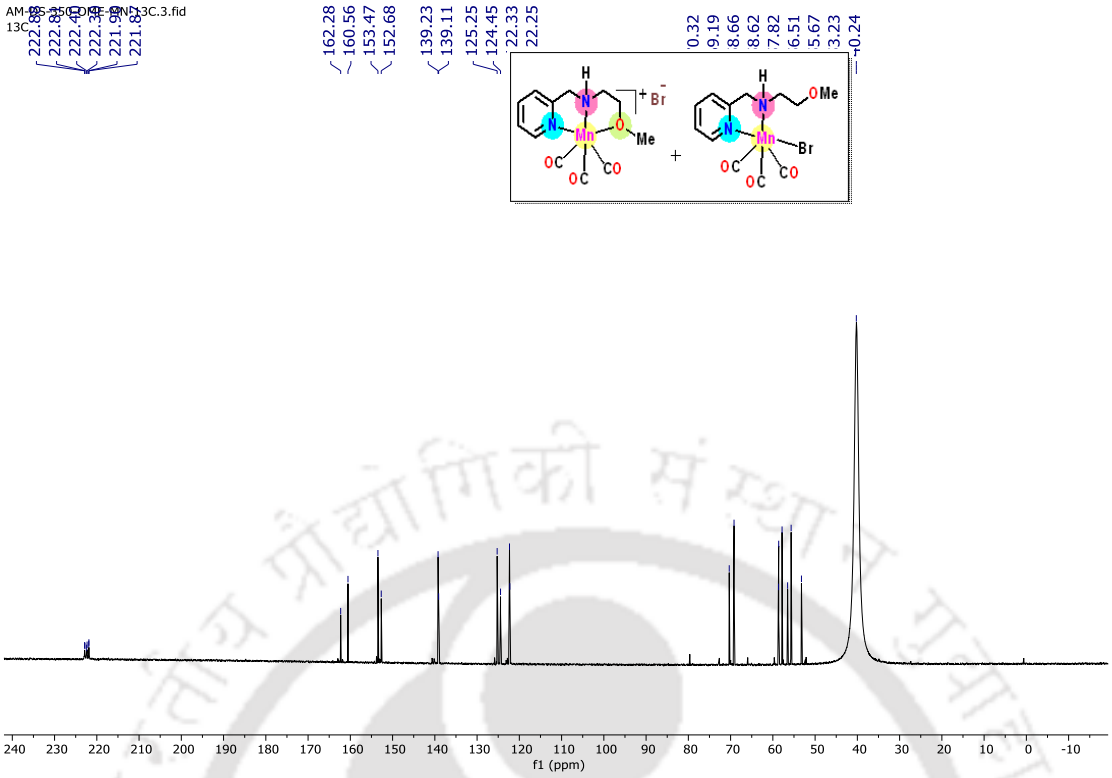


Figure 5.10. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(Mn-26+Mn-27)** in $CDCl_3$.

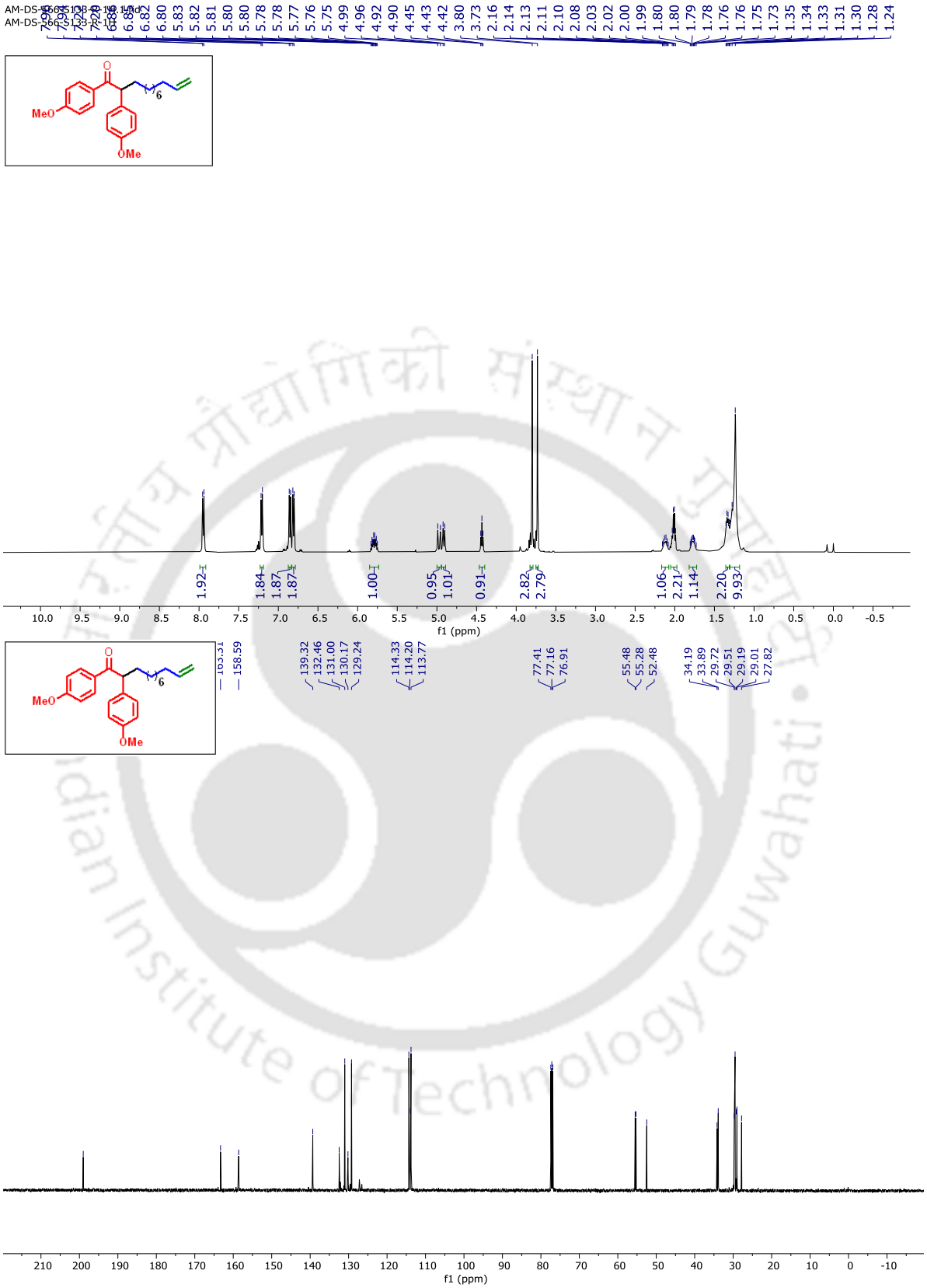


Figure 5.11. ^{1}H (500 MHz) and$^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.3a)** in $CDCl_3$.

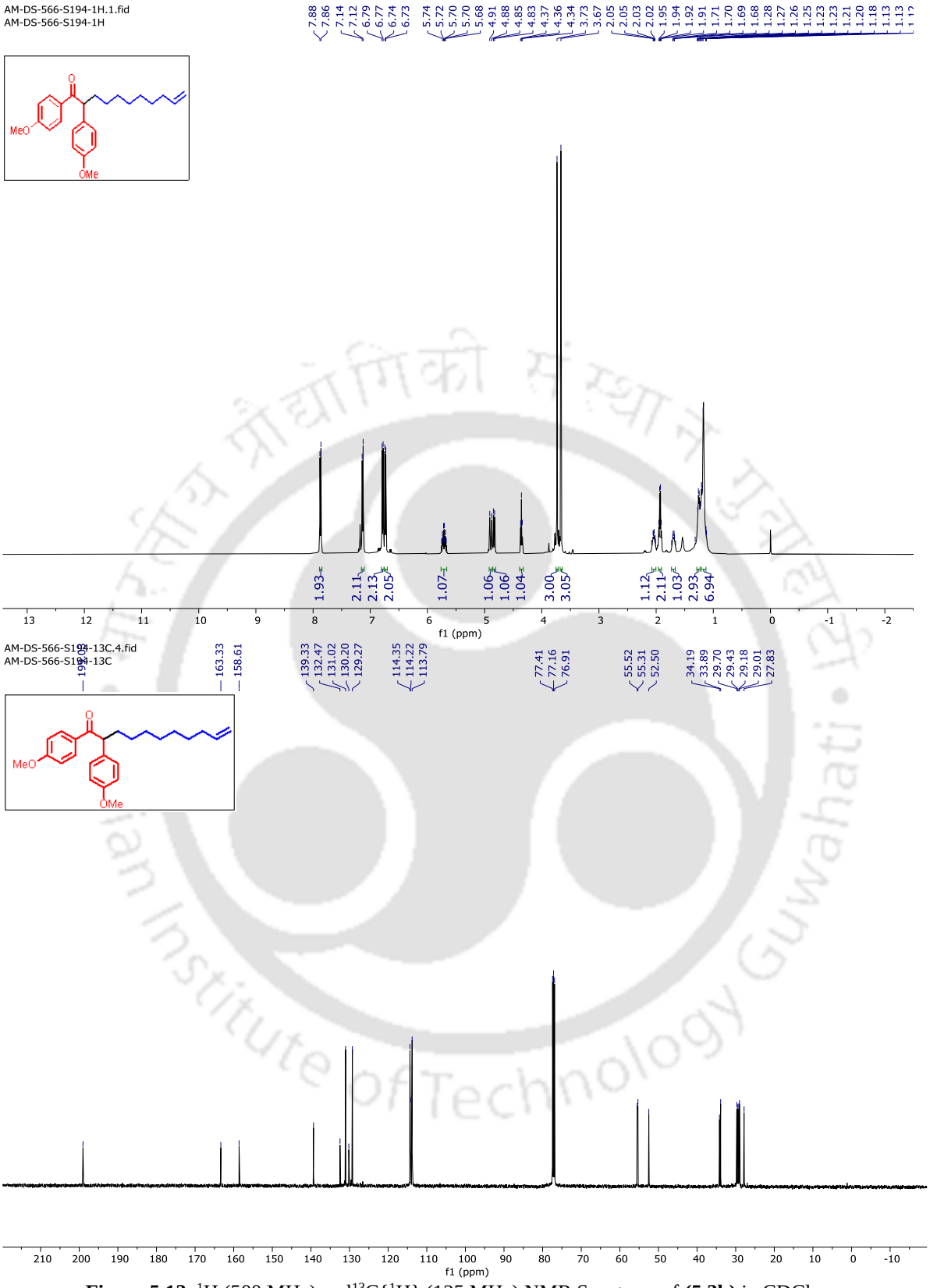


Figure 5.12. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.3b)** in $CDCl_3$.

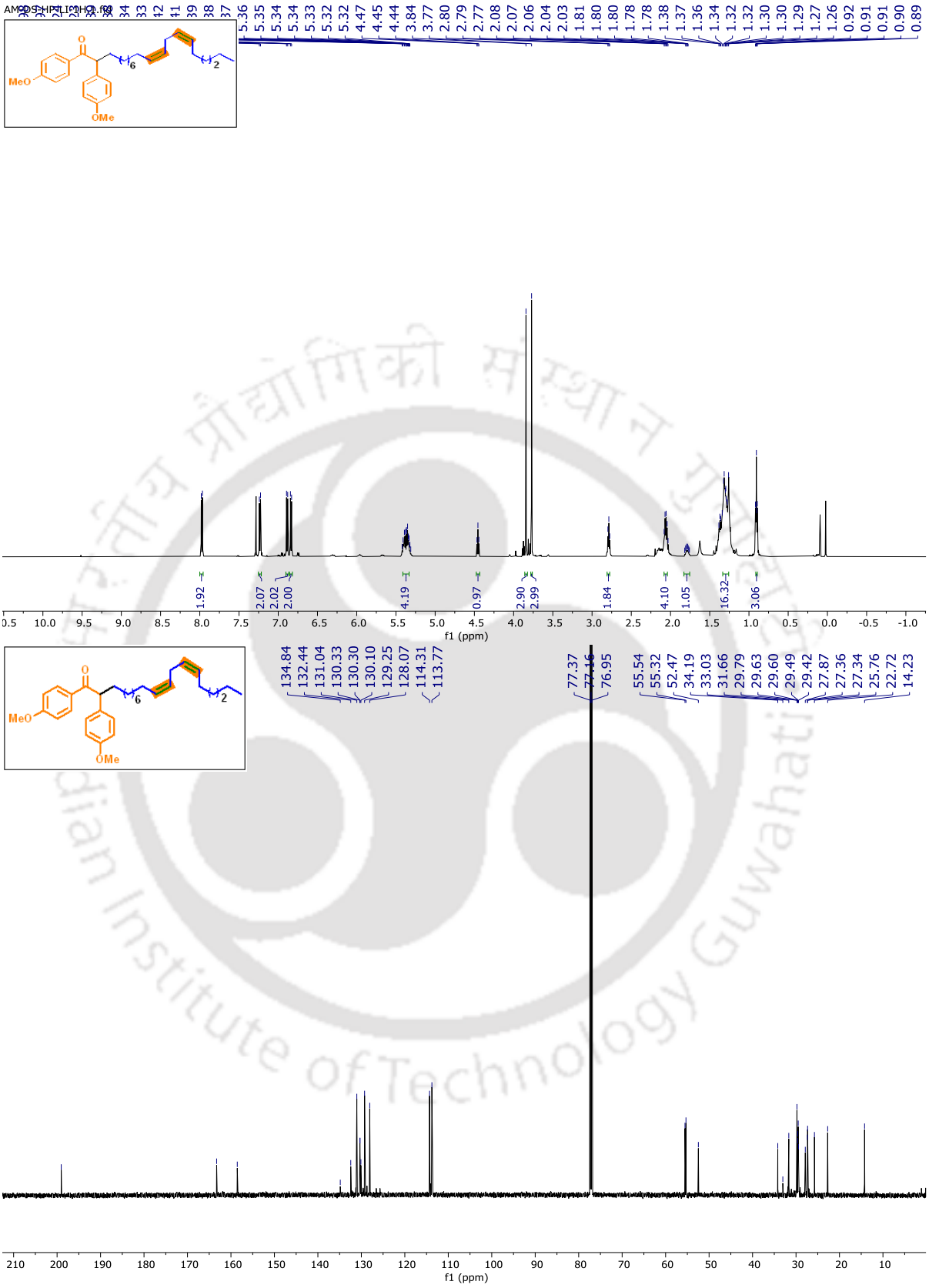


Figure 5.13. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.5c)** in $CDCl_3$.

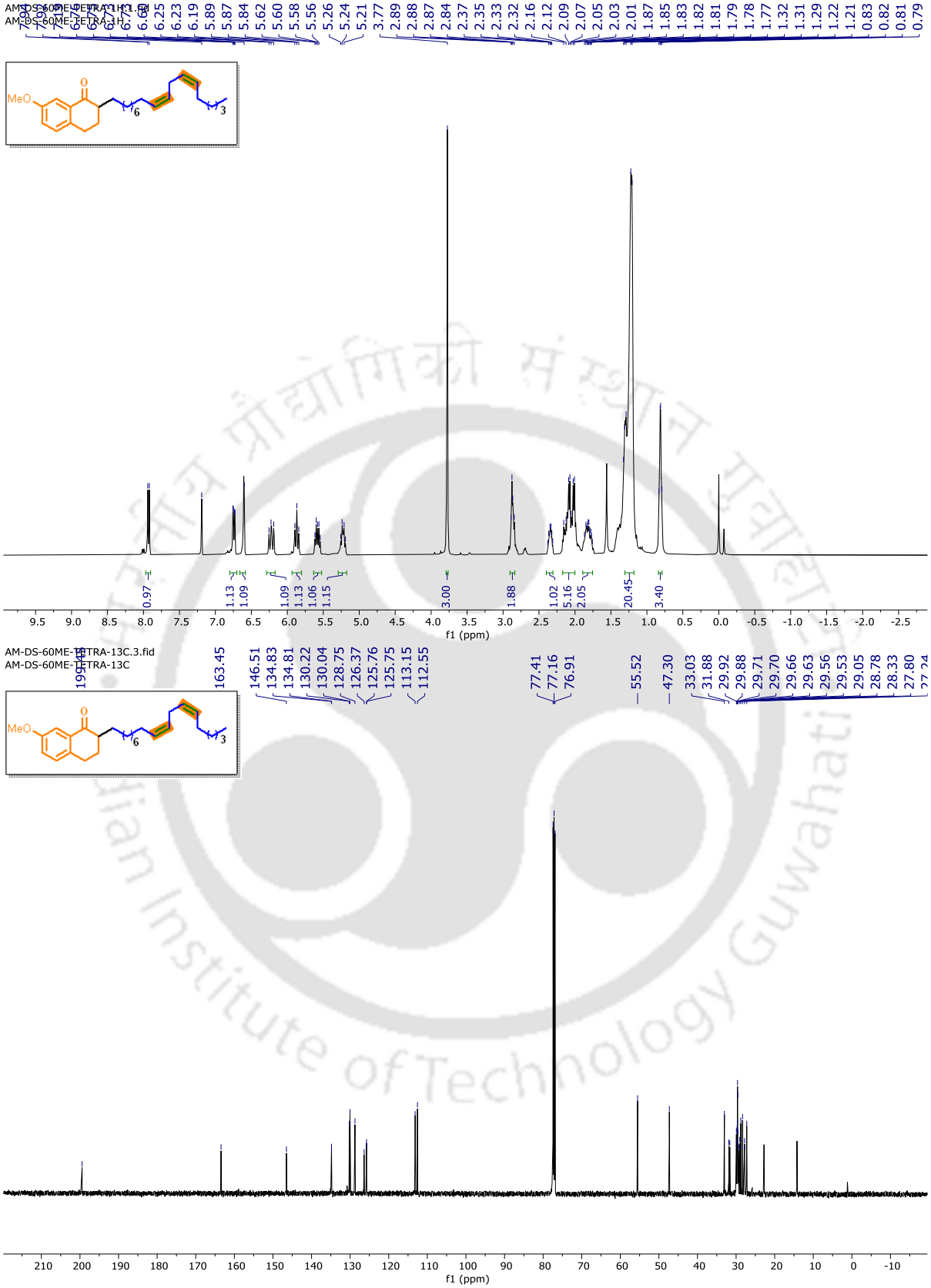


Figure 5.14. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.3f)** in $CDCl_3$.

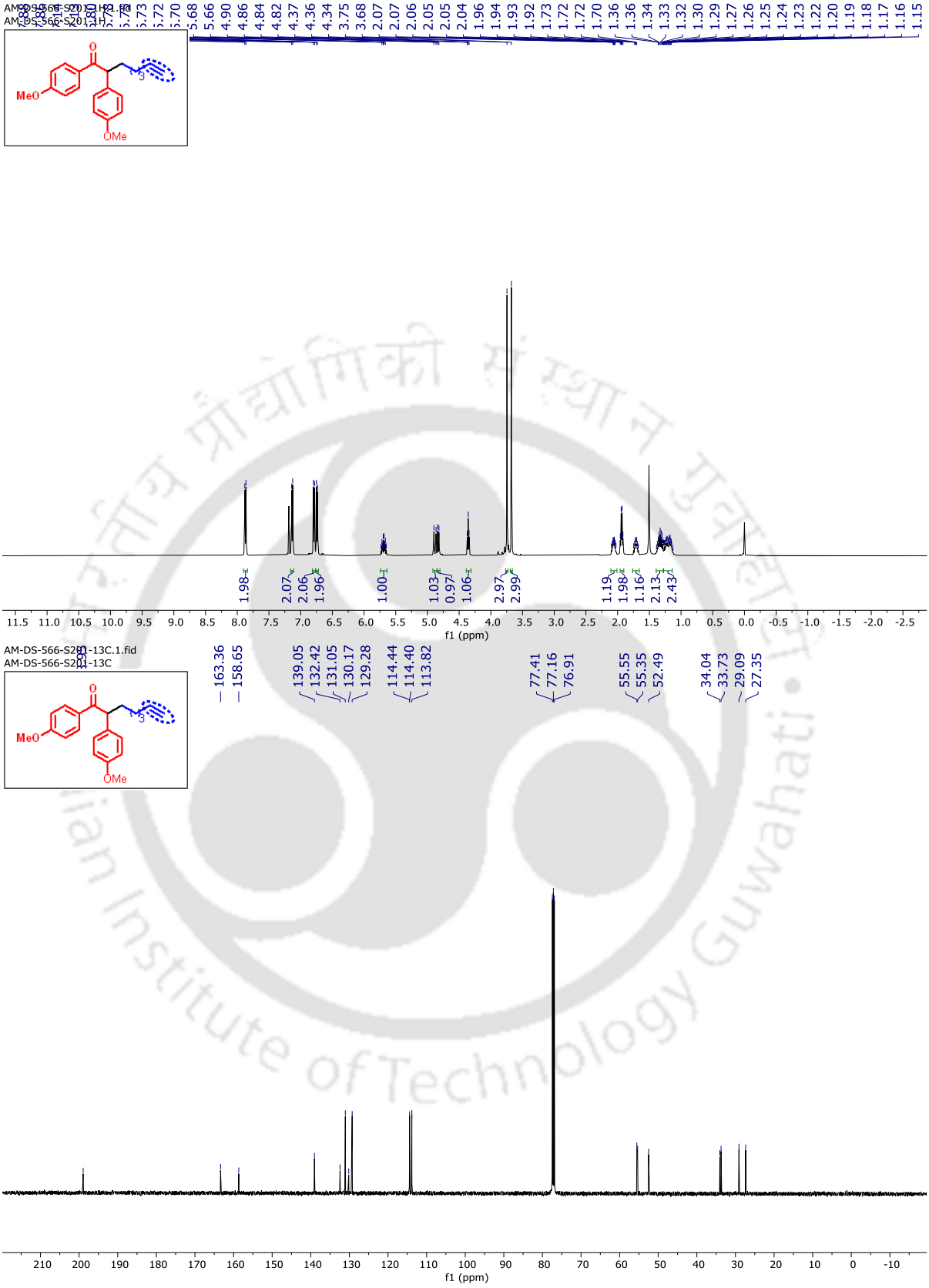


Figure 5.15. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.3g)** in $CDCl_3$.

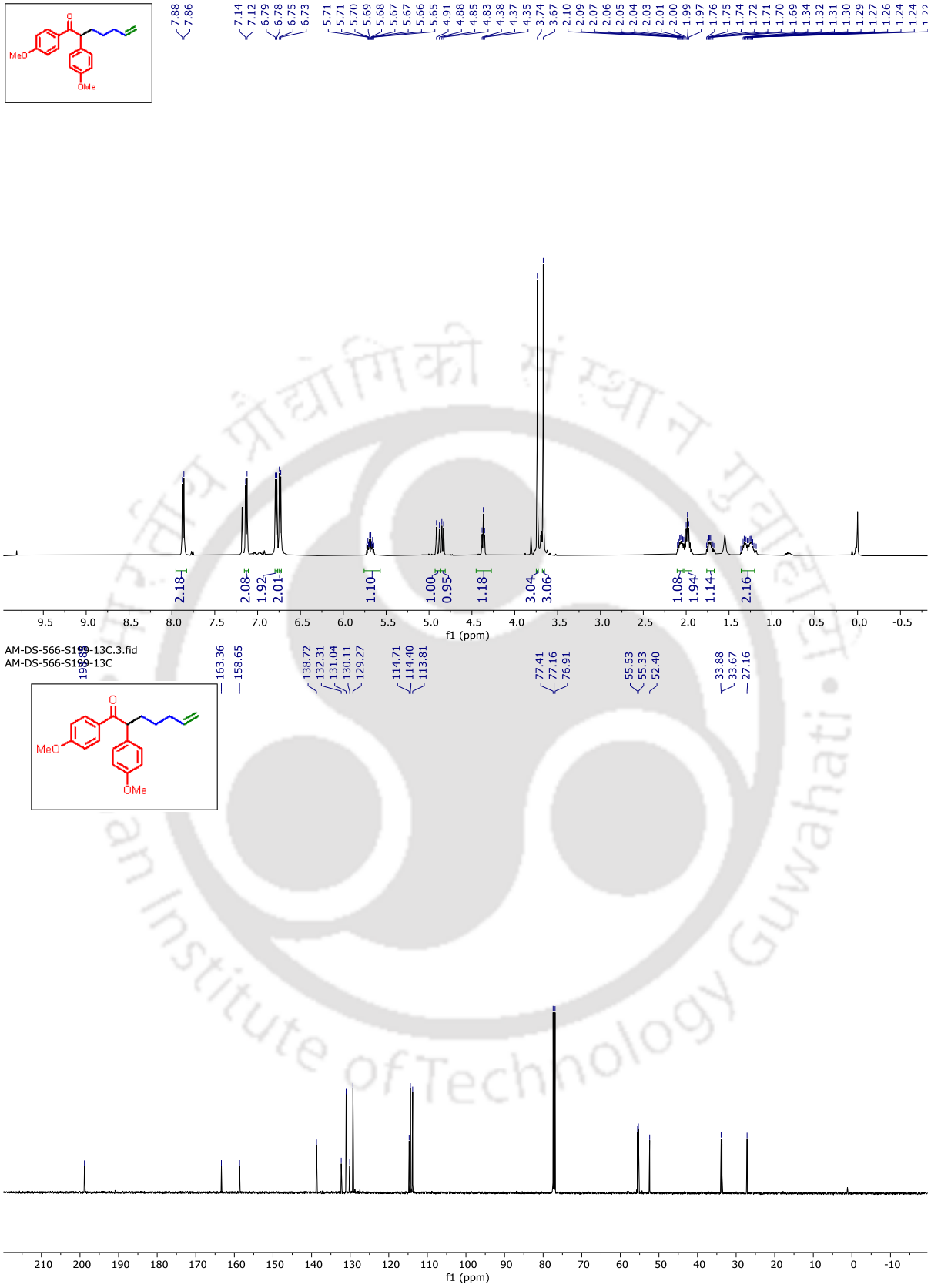


Figure 5.16. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.3h)** in $CDCl_3$.

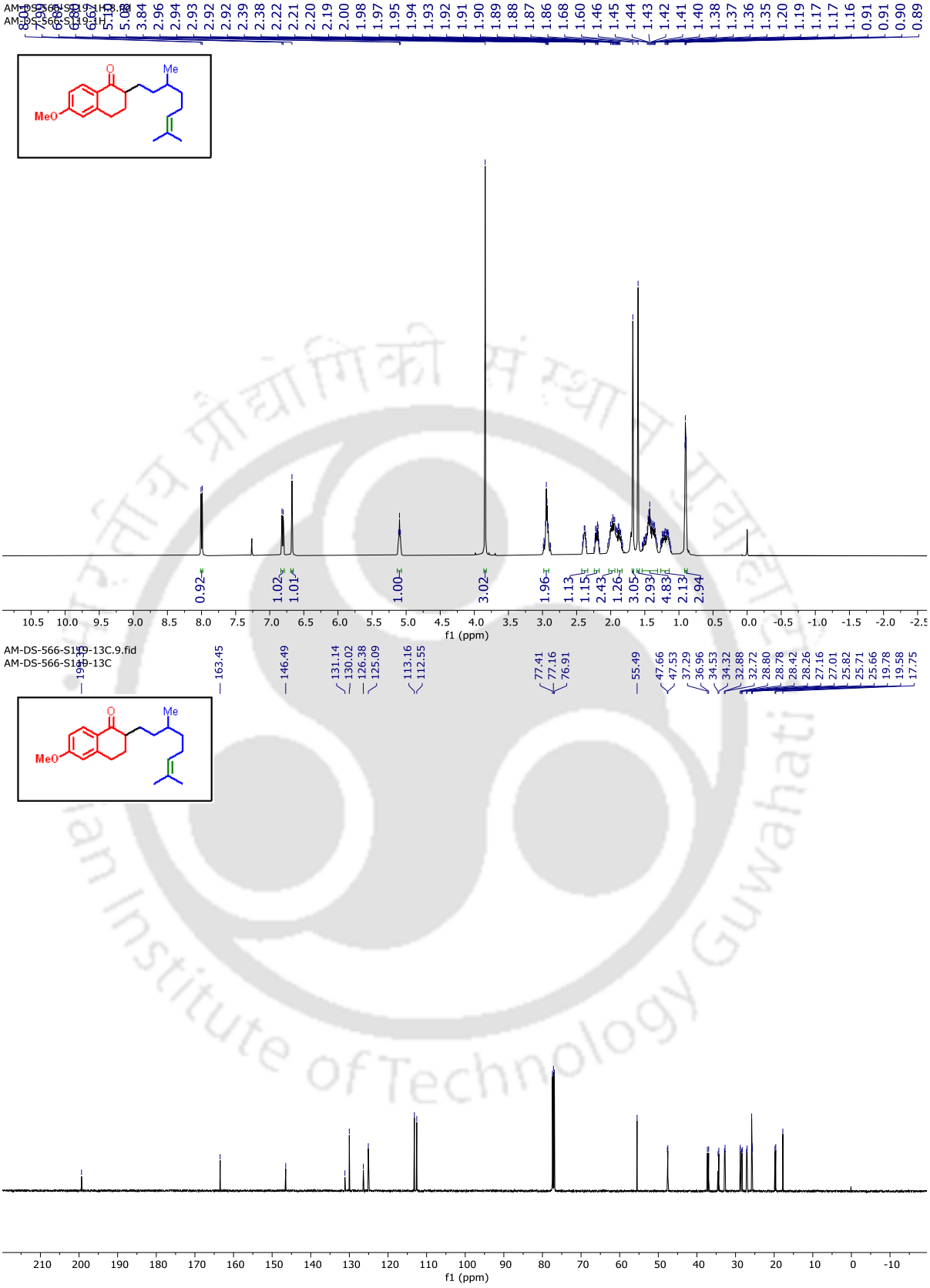


Figure 5.17. ^{1}H (500 MHz) and$^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum **of (5.3ab)** in $CDCl_3$.

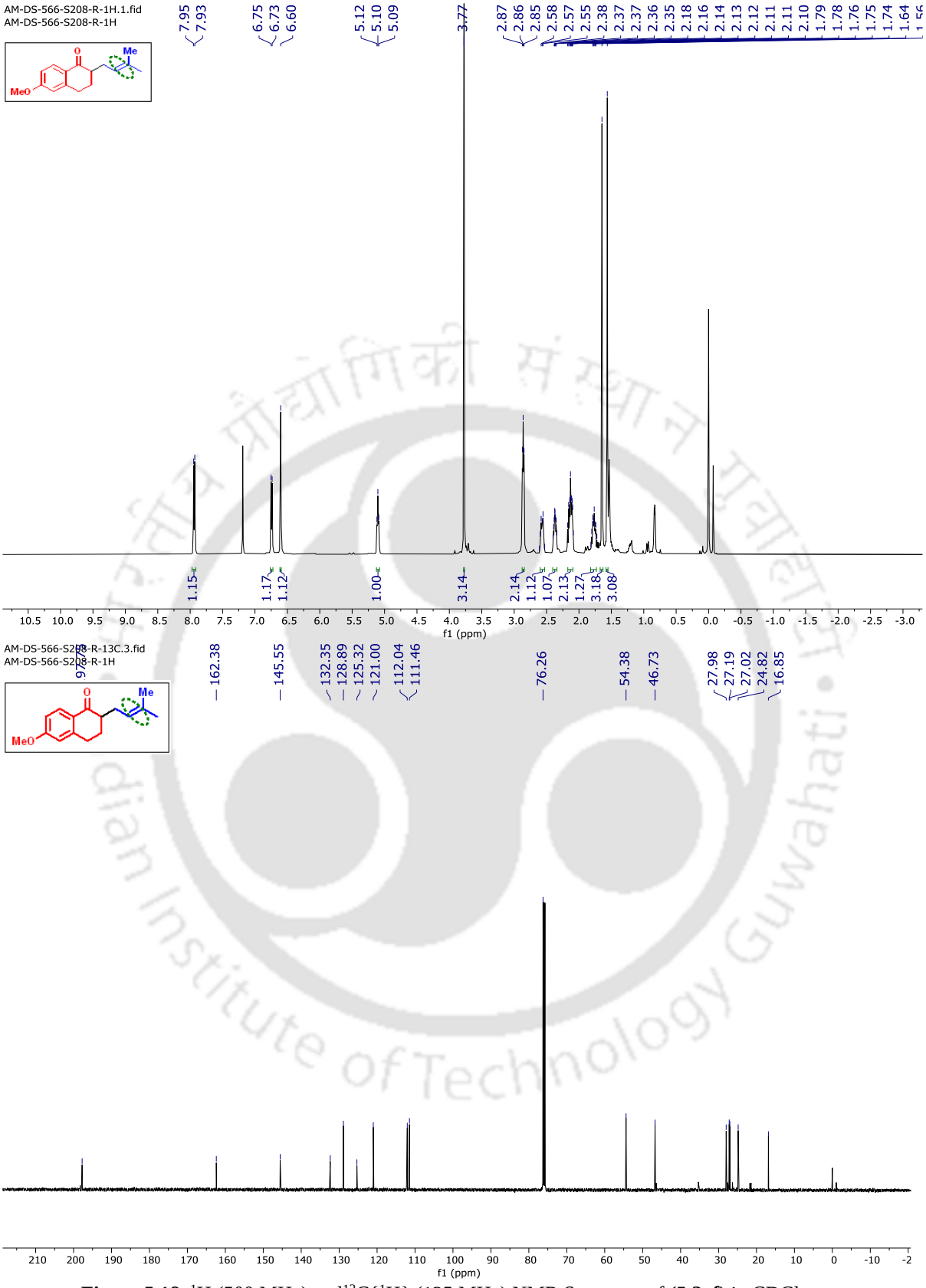


Figure 5.18. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.3af)** in $CDCl_3$.

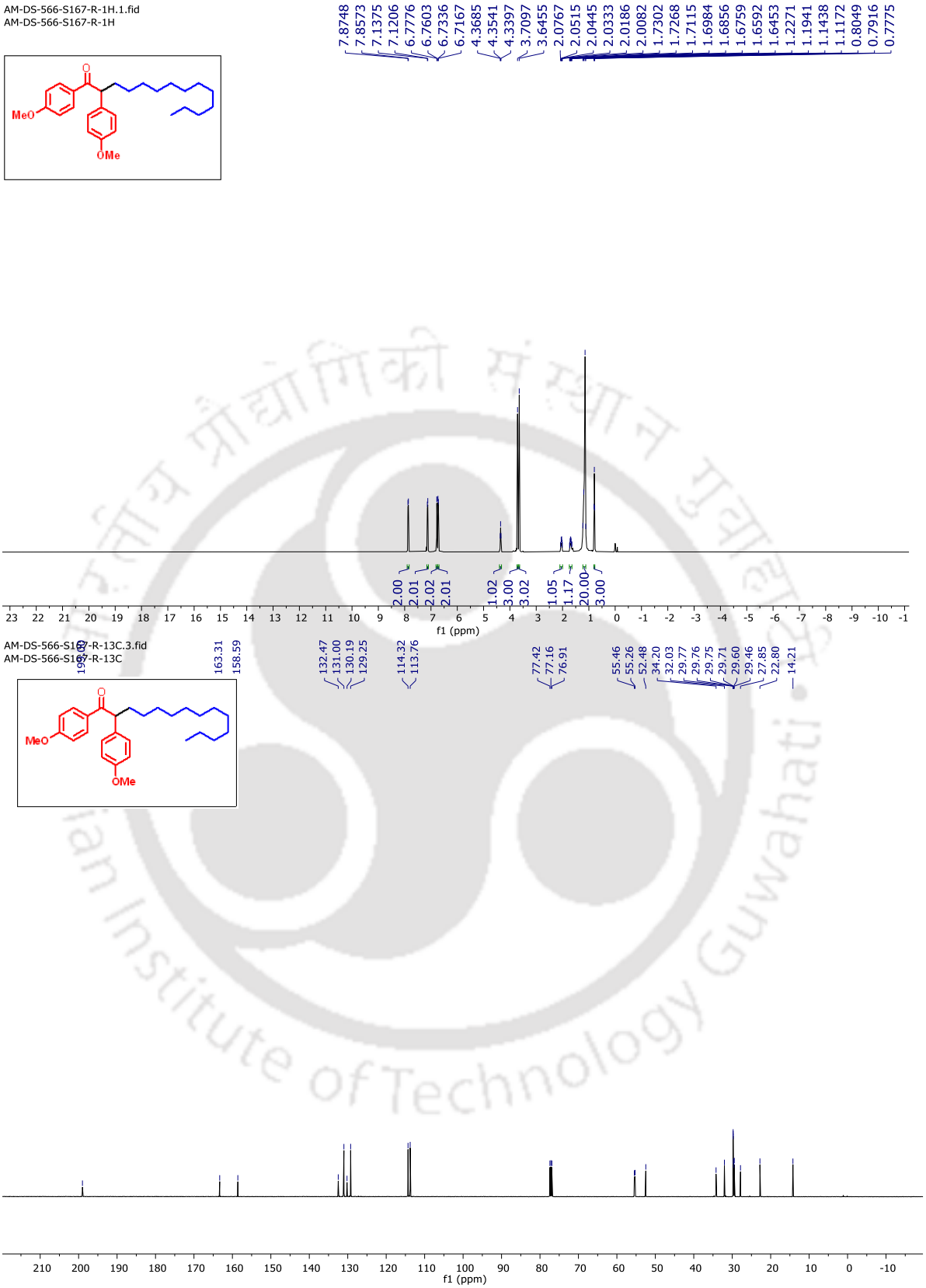


Figure 5.19. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.4c)** in $CDCl_3$.

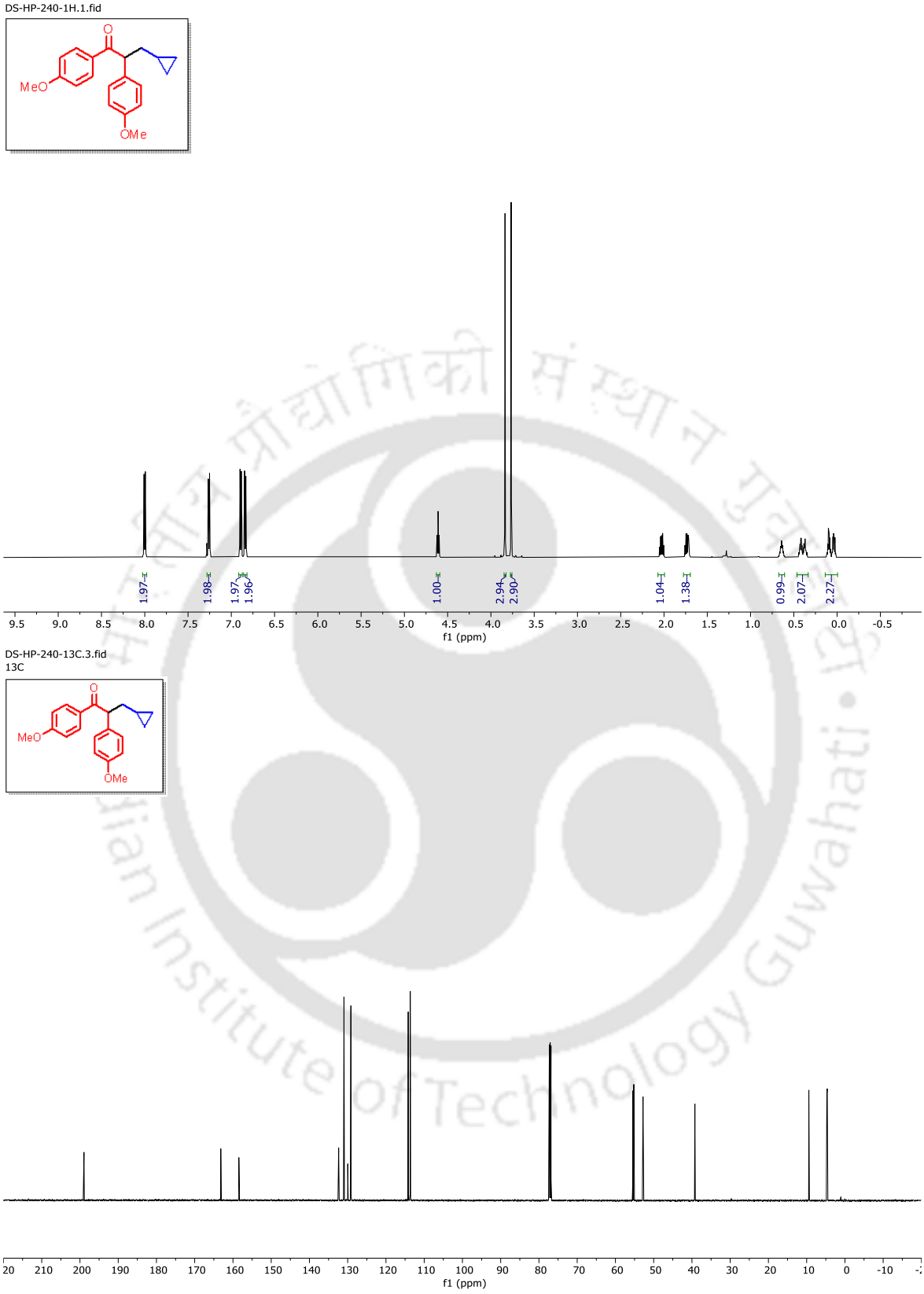


Figure 5.20. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.4g)** in $CDCl_3$.

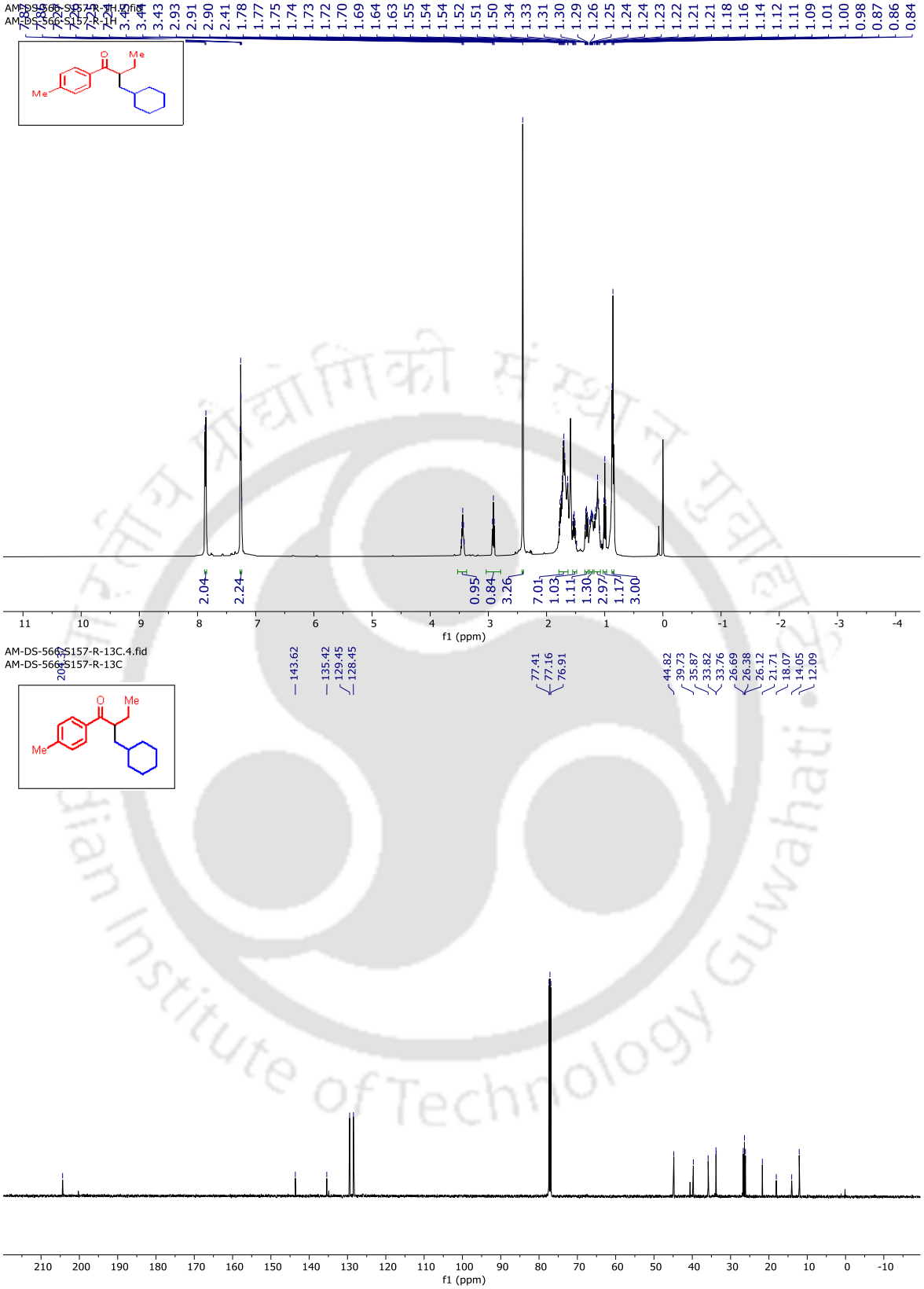


Figure 5.21. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.4h)** in $CDCl_3$.

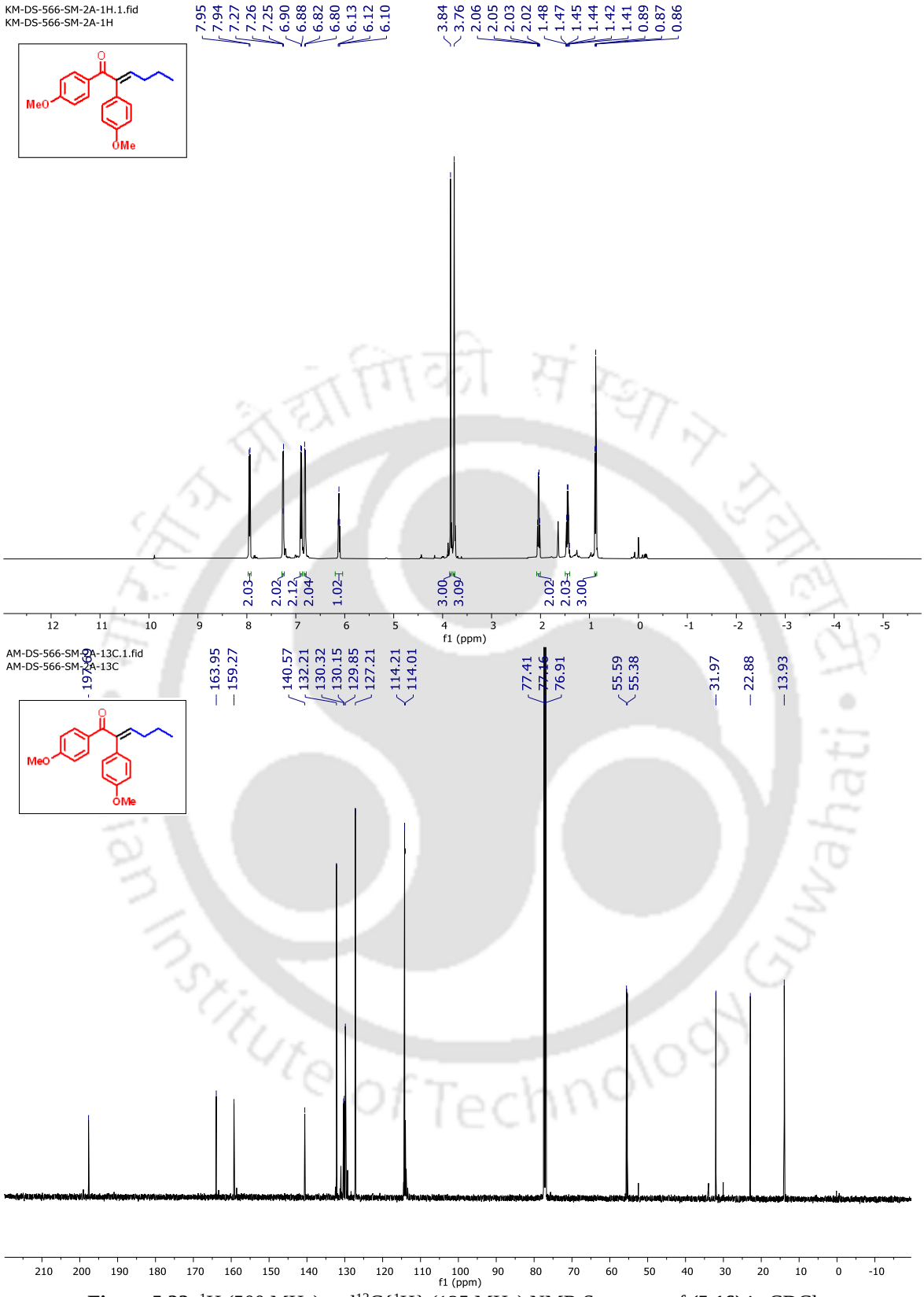


Figure 5.22. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.16)** in $CDCl_3$.

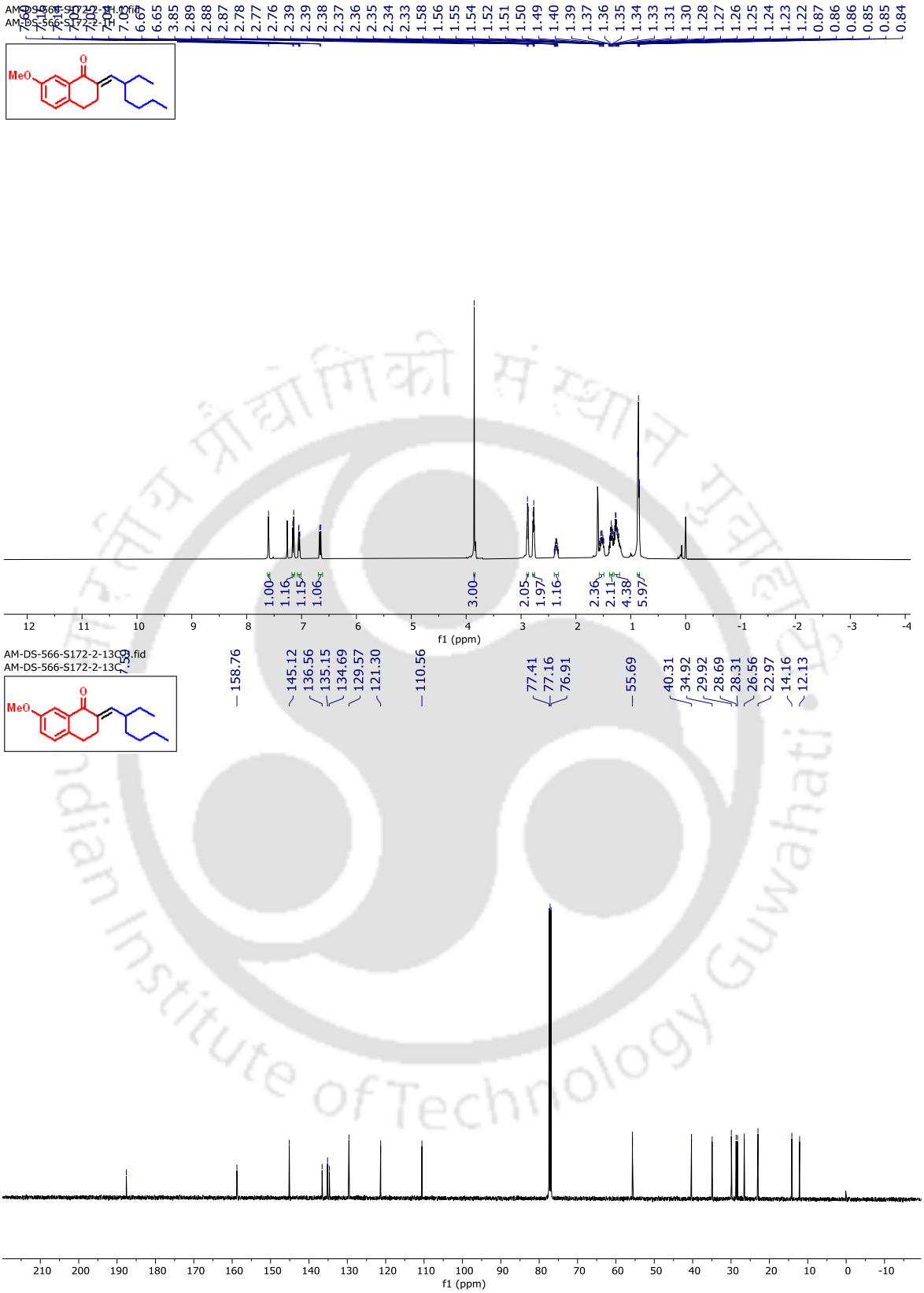


Figure 5.23. ^{1}H (500 MHz) and$^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.16a)** in $CDCl_3$.

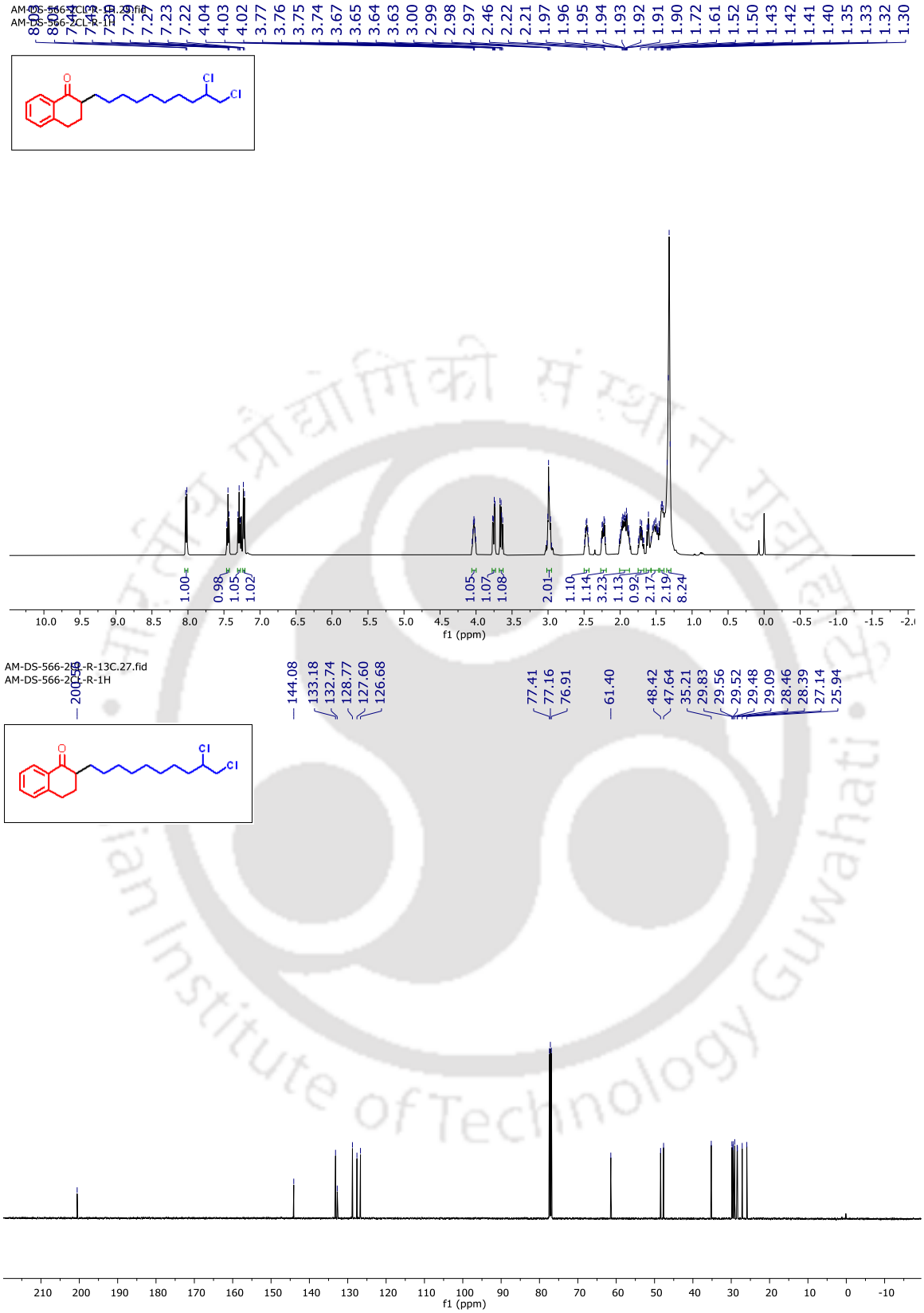


Figure 5.24. ^{1}H (500 MHz) and$^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.8)** in $CDCl_3$

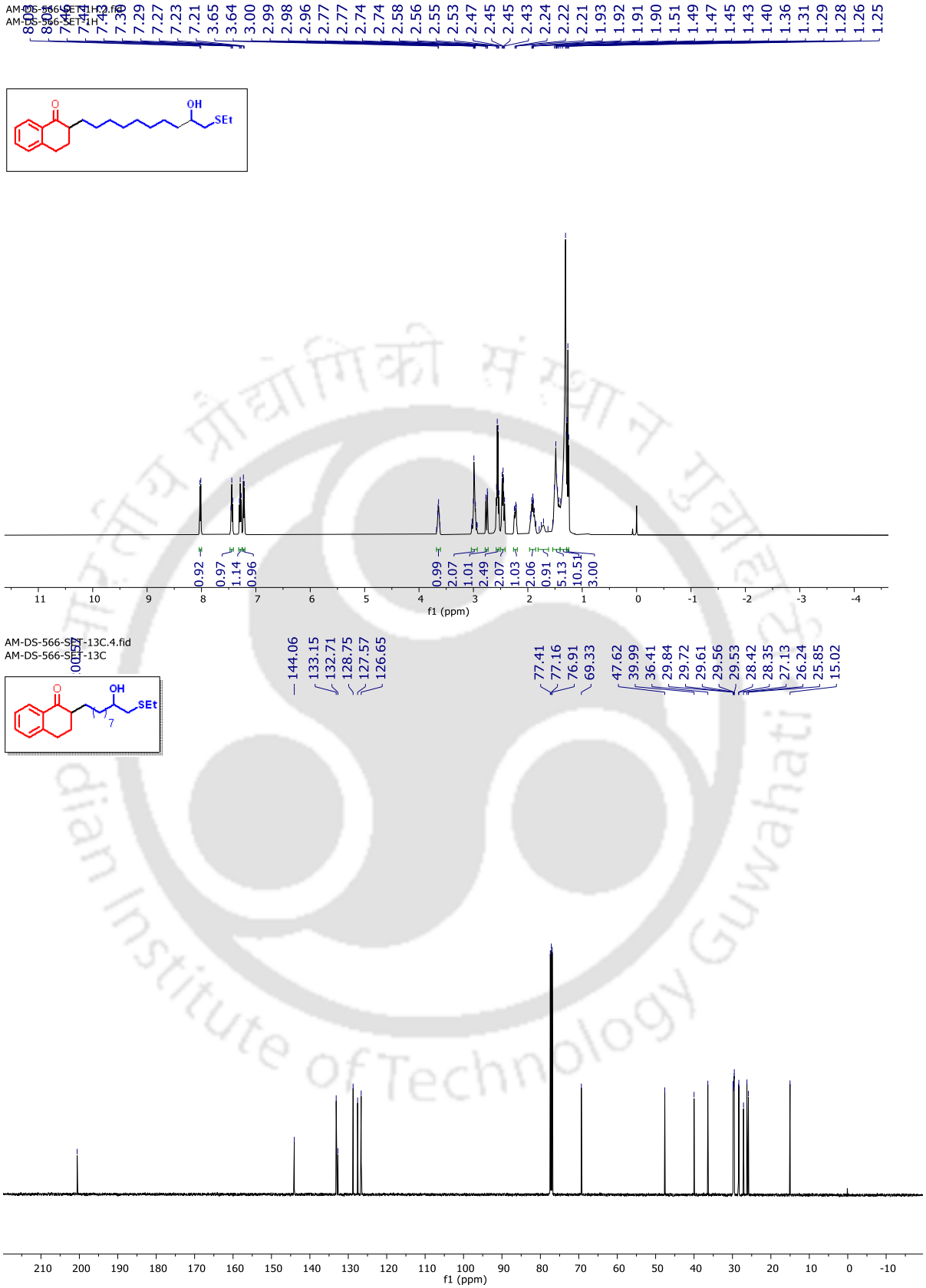


Figure 5.25. ^{1}H (500 MHz) and$^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.9)** in $CDCl_3$.

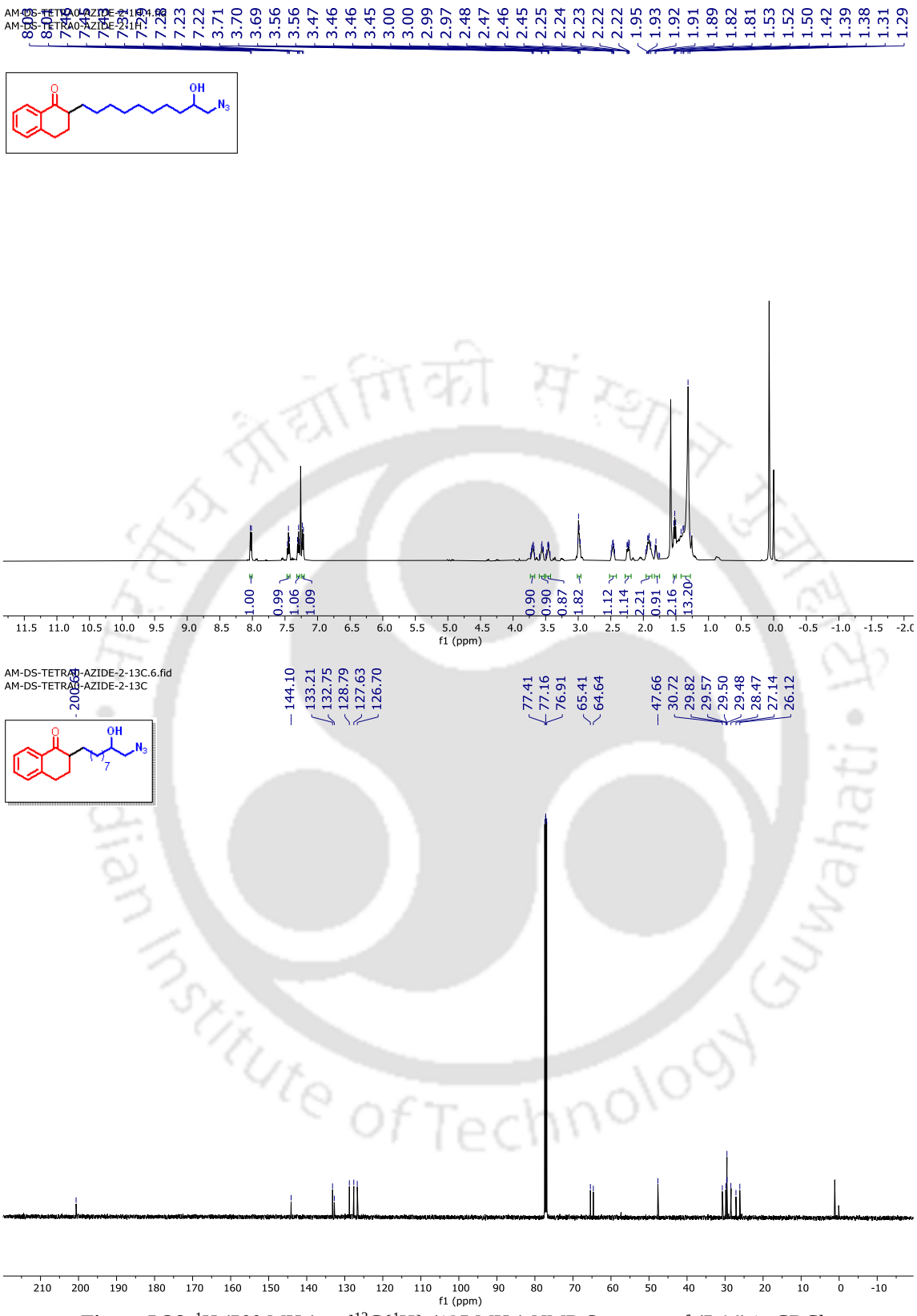


Figure 5.26. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.14)** in $CDCl_3$.

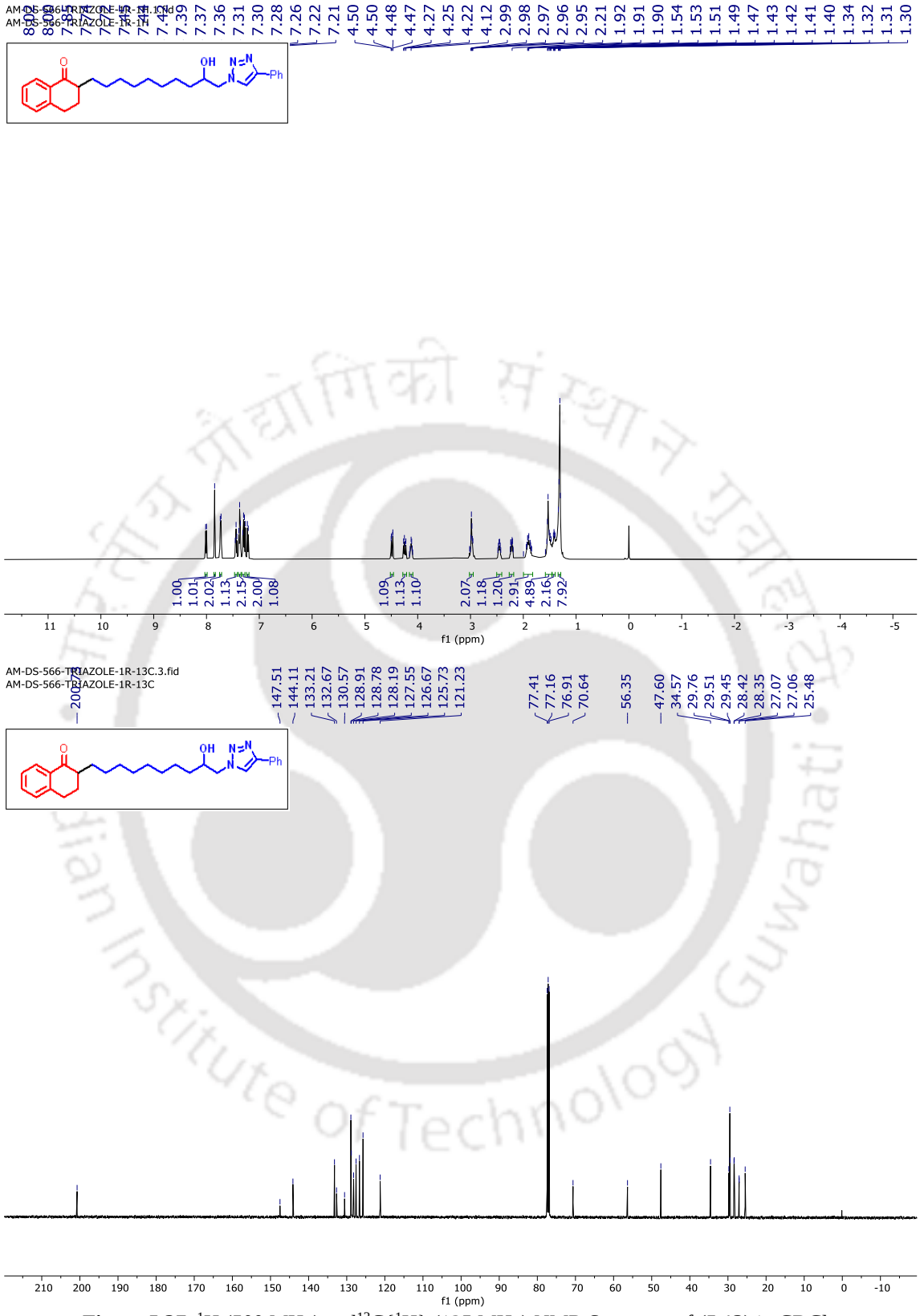


Figure 5.27. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.13)** in $CDCl_3$.

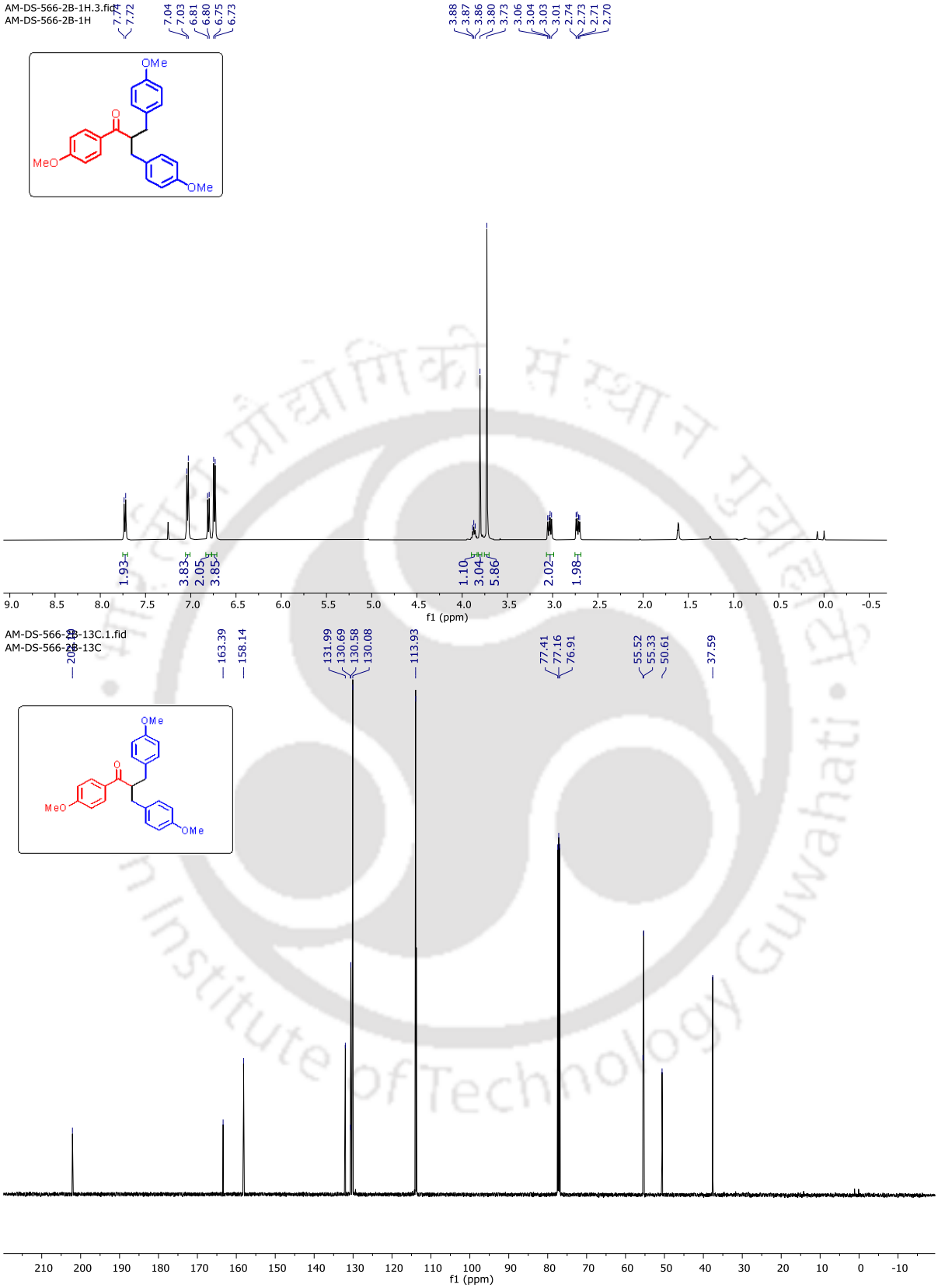


Figure 5.28. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.19a)** in $CDCl_3$.

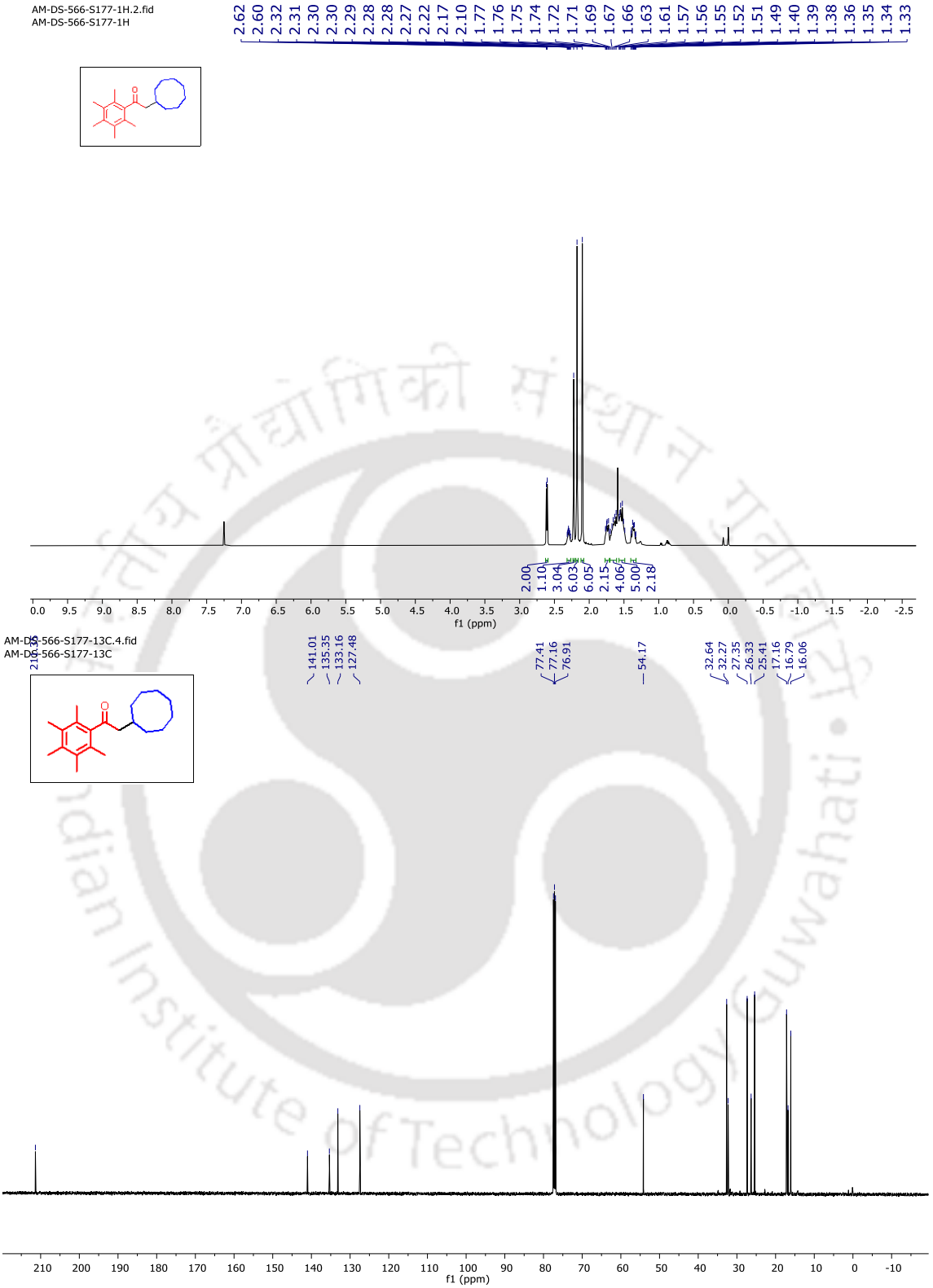


Figure 5.29. ^{1}H (500 MHz) and$^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.22e)** in $CDCl_3$.

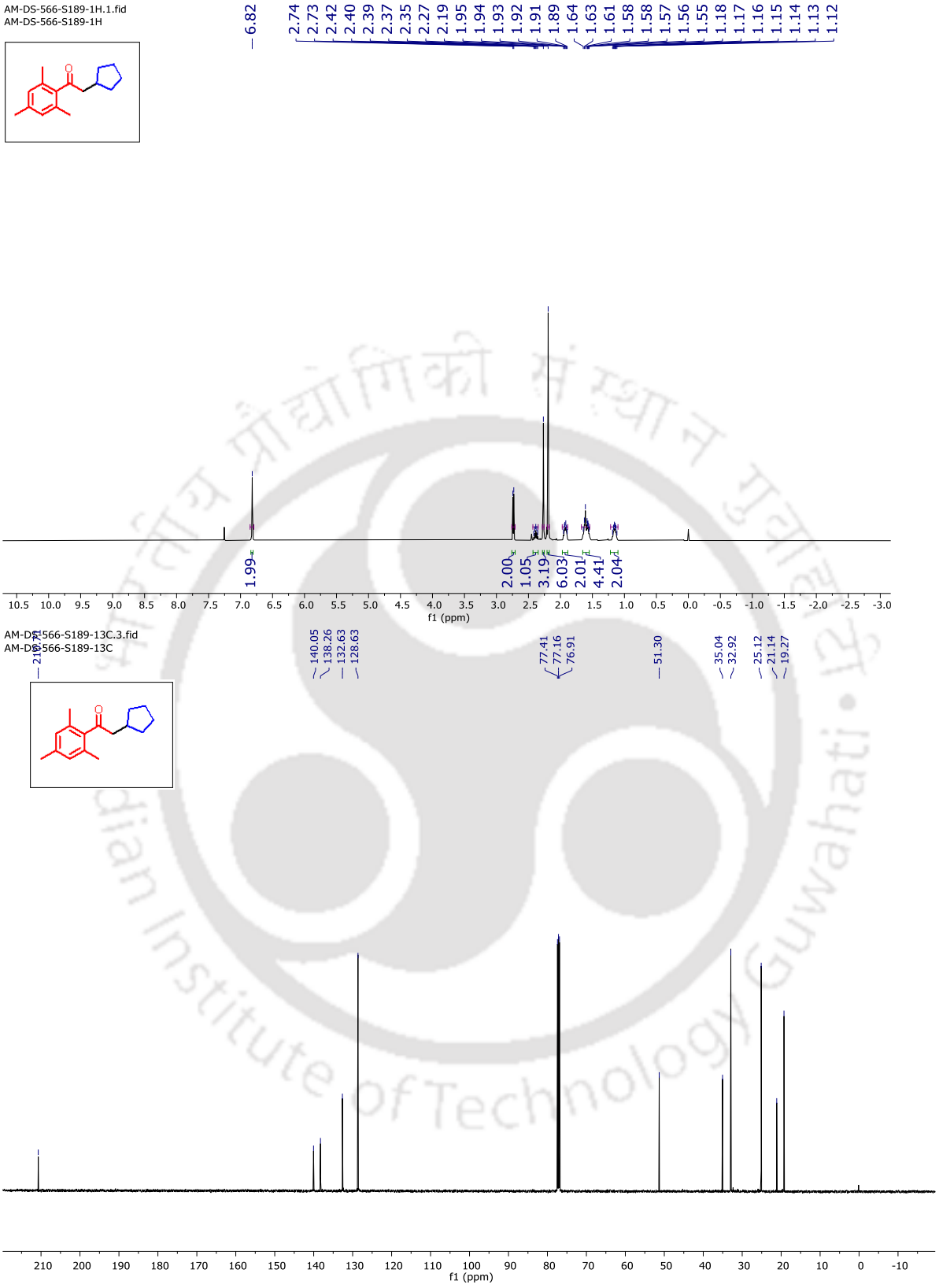


Figure 5.30. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.22b)** in $CDCl_3$.

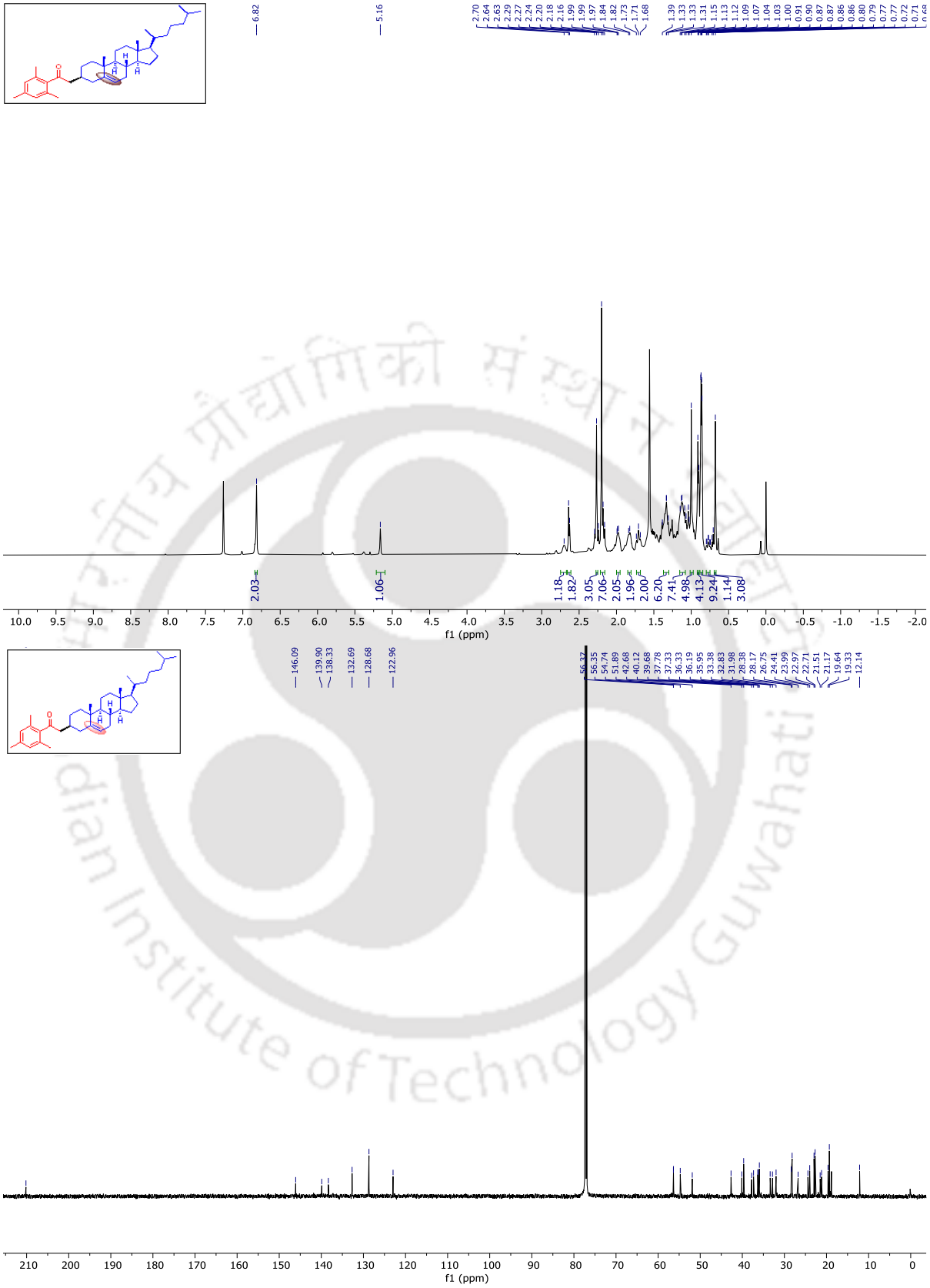
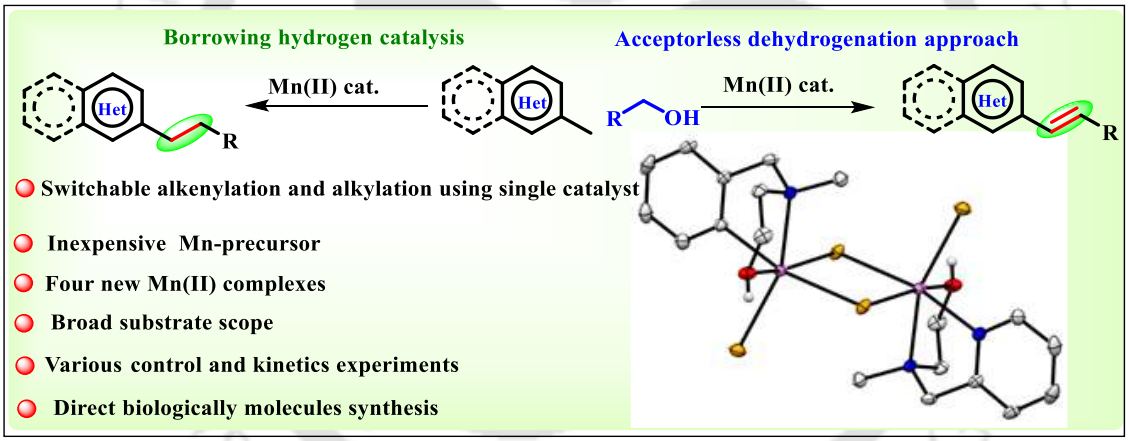


Figure 5.31. ^{1}H (500 MHz) and $^{13}C\{^{1}H\}$ (125 MHz) NMR Spectrum of **(5.22m)** in $CDCl_3$.

CHAPTER 6

Well-defined Mn(II)-complex Catalysed Switchable De(hydrogenative) C(sp^3)-H Functionalization of Methyl Heteroarenes: A Sustainable Approach for Diversification of Heterocyclic Motifs



A. Mondal, H. J. Phukan, D. Pal, S. Kumar, M. Roy, D. Srimani,

Chem. Euro. J. **2024**, *30*, e202303315.

6.1. Introduction: *N*-heteroarenes and its analogous are important class of chemical motifs that are ubiquitous in a variety of essential pharmaceuticals, agrochemical compounds and even used in various approved lifesaving drugs.[1] Different substituents directly impact on the pharmacological properties of heterocyclic compounds.

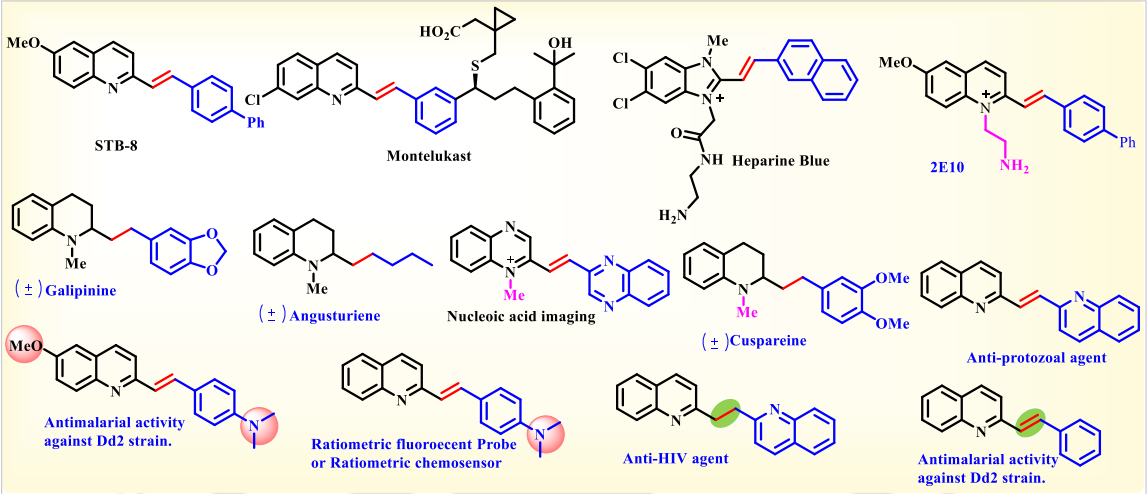


Figure 6.1. Various synthetically and biologically important functionalized methyl quinoline core unit.

Thus, the research involving functionalization or installation of distinct chemical motifs at various positions of heteroarenes is of great interest in organic chemistry. Specifically, many *E*-olefinated or alkylated heteroarene derivatives are extensively used in the fine or bulk chemical industry,[2] polymer industry, various electronic devices[3] and also display effective biological activities for cardiovascular diseases and prevention of cancer.[4] Therefore, the conversion of methyl-N-heteroaromatics to the corresponding olefinated heterocycles or chain-elongated N-heterocycles is value added contribution to industrial and academic research. Traditionally olefinated heterocycles are obtained via Wittig[5a] Peterson's,[5b] Julia,[5c] Horner–Wadsworth–Emmons reactions,[5d] etc.[6] and pre-functionalized electrophiles were used to alkylate methyl-*N*-heteroaromatics.[7] Although these are very powerful technologies in organic chemistry but the lack of diverse range of suitable starting materials, harsh reaction conditions, and generation of mutagenic wastes necessitates the development of green and atom economical strategies to achieve this goal. In this regard, transition metal catalysed acceptorless dehydrogenation (AD) and borrowing hydrogen catalysis (BH) could be one of the convenient and highly useful strategies for this selective functionalization.[8]

6.2. Literature reports:[9-14] A literature survey on the dehydrogenative functionalization of methyl heteroarenes has been discussed in Chapter I Section,1.15. The survey clearly suggested that Mn(I) catalysed olefination of methyl heteroarenes have been reported independently by Kempe and Maji using different Mn(I) catalysts.[12,13] Later, Maji and his group[14] revealed the alkylation of methyl heteroarenes employing more nucleophilic Mn(I) based MACHO complex (**Mn-3**).

Thus, selectively olefinate/alkylate methyl heteroarenes employing a single Mn-catalyst would be significant. Thus, exploring the catalytic applicability using less expansive Mn(II)-based complex would be more advantageous.

6.3. Present approach: In this chapter focuses on synthesizing various cost-effective Mn(II)-based new complexes and explored their catalytic activity in switchable C-alkylation/ olefination of methyl heteroarenes employing single Mn(II)-catalyst. Developed both protocols for olefination and alkylation of methyl heteroarenes afforded good to excellent yields with good selectivity. Series of control and kinetics experiments were performed to understand the catalytic pathway.

Table 6.1. Optimization reaction for Mn(II) catalysed selective functionalization of heteroarenes: Initially, the investigation was started by preparing various NNO-ligands based complexes using commercially available MnX_2 salts and amino-ethanol derived ligands. The detailed preparation method was discussed in experimental section **6.7.2**.

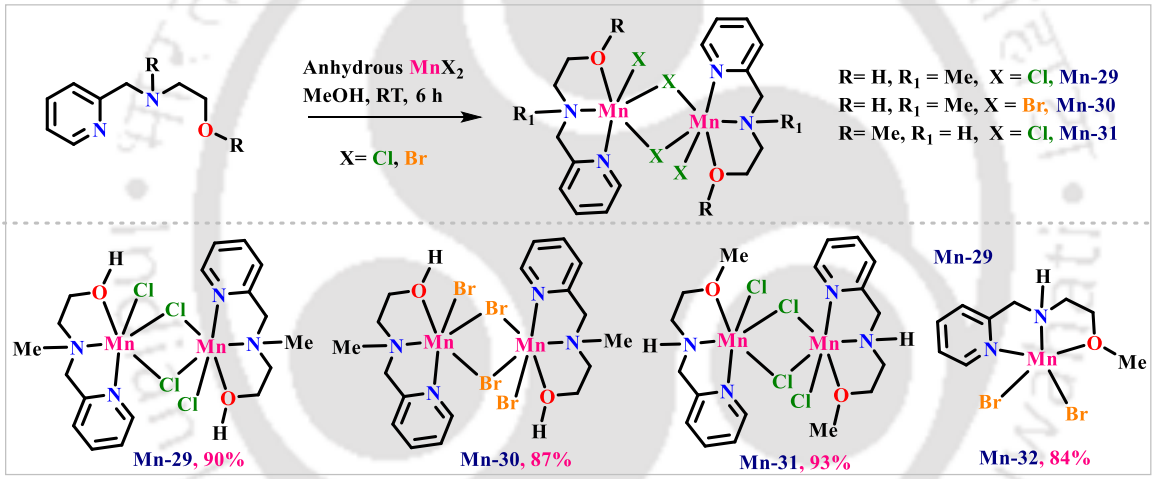
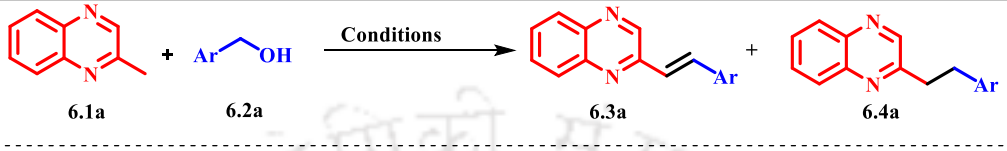


Figure 6.2. Synthesis of NNO Mn(II)-based complexes.

After full-characterization of four complexes with a variety of spectroscopic, spectrometric techniques, potential of these complexes for C(sp^3)-H functionalization of heteroarenes using alcohols were tested. Investigation was initiated by choosing quinoxaline (**6.1a**) and 4-methoxy benzyl alcohol (**6.2a**) as model substrates. When a mixture of quinoxaline (**6.1a**, 1.0 mmol) and 4-methoxybenzyl alcohol (**6.2a**, 1.0 mmol), 1mL benzene, 0.6 mmol KOH was heated at 80 °C in presence of 5 mol% **Mn-29** under the argon atmosphere, 60% of *E*-olefinated product was isolated (Table 6.1, entry 1). Encouraged by this outcome, number of parameters, including temperature, base, reaction time, catalyst loading, etc were we thoroughly examined to get the optimal reaction conditions. When benzene was replaced with toluene and the temperature was increased from 80 °C to 110 °C, the olefinated product increased from 60% to 85% (Table 6.1, entry 2-3). A 12-hour reduction in reaction time had no effect on the product yields, while subsequent reductions in

reaction time led to reduced yields of the olefinated product (Table 6.1, entry 4-5). Keeping other parameters unchanged, only lowering the catalyst loading from 5 mol% to 2.5 mol%, did not affect the yields (Table 6.1, entry 7). However, the yield of the α-olefinated was reduced when the catalyst loading was further decreased (2 mol%) (Table 6.1, entry 7). The catalytic performance of other analogous Mn-complexes was also examined. Notably, **Mn-30** had the highest activity for E-olefination of heteroarenes when compared to **Mn-29, Mn-31**, and **Mn-32** (Table 6.1, entry 8-10).



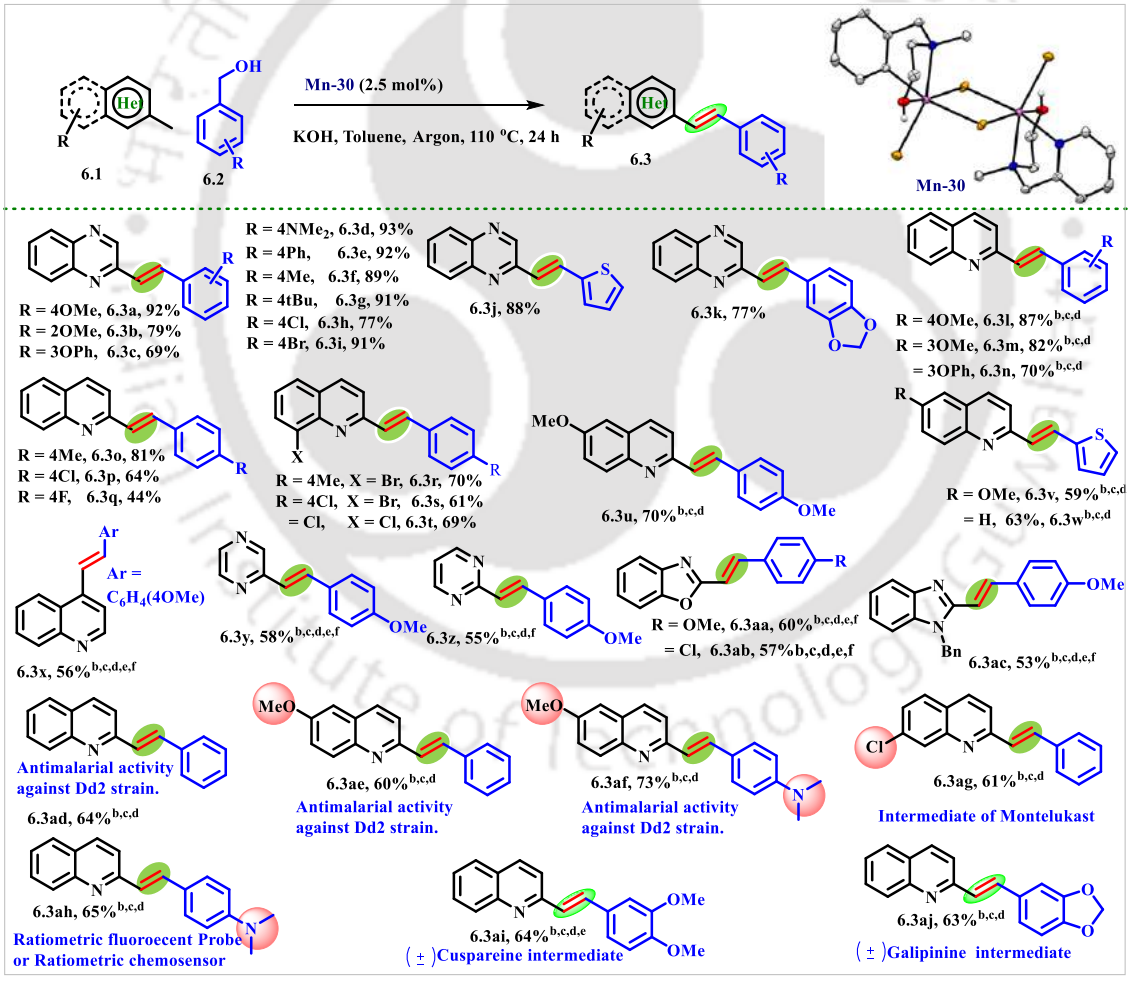
6.1a 6.2a 6.3a 6.4a

Entry	6.1a : 6.2a (Ratio)		Catalyst (mol%)	Base (equiv.)	Solvent (mL)	Time (h)	Temperature (°C)	6.3a (%)[b]	6.4a (%)[b]
1	1.0	1.0	Mn-29 (5.0)	KOH (0.6)	Benzene(1)	36	80	60	..
2	1.0	1.0	Mn-29 (5.0)	KOH (0.6)	Toluene (1)	36	80	61	..
3	1.0	1.0	Mn-29 (5.0)	KOH (0.6)	Toluene (1)	36	110	85	..
4	1.0	1.0	Mn-29 (5.0)	KOH (0.6)	Toluene (1)	24	110	84	..
5	1.0	1.0	Mn-29 (5.0)	KOH (0.6)	Toluene (1)	12	110	60	..
6	1.0	1.0	Mn-29 (2.5)	KOH (0.6)	Toluene (1)	24	110	85	..
7	1.0	1.0	Mn-29 (2.0)	KOH (0.6)	Toluene (1)	24	110	77	..
8	1.0	1.0	Mn-30 (2.5)	KOH (0.6)	Toluene (1)	24	110	92	..
9	1.0	1.0	Mn-31 (2.5)	KOH (0.6)	Toluene (1)	24	110	69	..
10	1.0	1.0	Mn-32 (2.5)	KOH (0.6)	Toluene (1)	24	110	60	..
11	1.0	1.0	Mn-30 (2.5)	KOH (0.5)	Toluene (1)	24	110	81	..
12	1.0	1.0	Mn-30 (2.5)	...	Toluene (1)	24	110	..	..
13	1.0	1.0	...	KOH (0.6)	Toluene (1)	24	110	Trace	..
14	1.0	1.0	Mn-30 (2.5)	$CsOH.H_2O$ (0.6)	Toluene (1)	24	110	85	..
15	1.0	1.0	Mn-30 (2.5)	K_2CO_3 (0.6)	Toluene (1)	36	110	Trace	..
16	1.0	1.0	Mn-30 (2.5)	Na_2CO_3 (0.6)	Toluene (1)	36	110	...	..
17	1.0	1.0	Mn-30 (2.5)	KO^{t}Bu(0.6)	Toluene (1)	36	110	90	Trace
18[c]	1.0	1.5	Mn-30 (2.5)	KOH(1.0)	Toluene (1)	36	140	Trace	82
19[c]	1.0	1.5	Mn-30 (5.0)	KO^{t}Bu(1.0)	Toluene (1)	36	140	...	87
20[c]	1.0	2	Mn-30 (5.0)	KO^{t}Bu(1.0)	Toluene (1)	36	140	...	89
21[c]	1.0	1.5	Mn-30 (5.0)	KO^{t}Bu(1.0)	Toluene (1)	36	140	...	90

[a]**Reaction conditions: 6.1a** (1 mmol), **6.2a** (1-2 mmol), Base (0.5-1.0 mmol), Mn-catalyst loading (2-7 mol %), Under argon, Temperature 80 °C-140 °C, entry 1-17 reactions are carried out in 10 mL round bottom flux, [c]Reaction vessel: 100 mL screw cap tube, [b]Isolated yields.

The product yield was also decreased by lowering the base loading from 0.6 mmol (Table 6.1, entry 11). Control experiments exhibited that the presence of catalyst and base is important to obtain the *E*-olefinated products (Table 6.1, entry 12-13). Weak bases were inferior to KOH (Table 6.1, entry 15-16). But KO^{t}Bu resulted similar yields under identical reaction conditions (Table 6.1, entry 17). Notably, when reaction parameters like temperature, time, the base amount, alcohol concentration and catalyst loading and reaction vessel were modified, selectively *α*-alkylated product of heteroarene was formed (**6.4a**) was isolated in 82% (Table 6.1, entry 18). On changing the base from KOH to KO^{t}Bu keeping other parameters same 87% of C-alkylated methyl quinoxaline was isolated (Table 6.1, entry 19). Further increasing the alcohol concentration and catalyst loading similar yields of desired C-alkylated 2-methylquinazoline was isolated (Table 6.1, entry 20 & 21).

Table 6.2. Well defined tridentate Mn(II) complex catalysed *α*-olefination of heteroarenes[a]

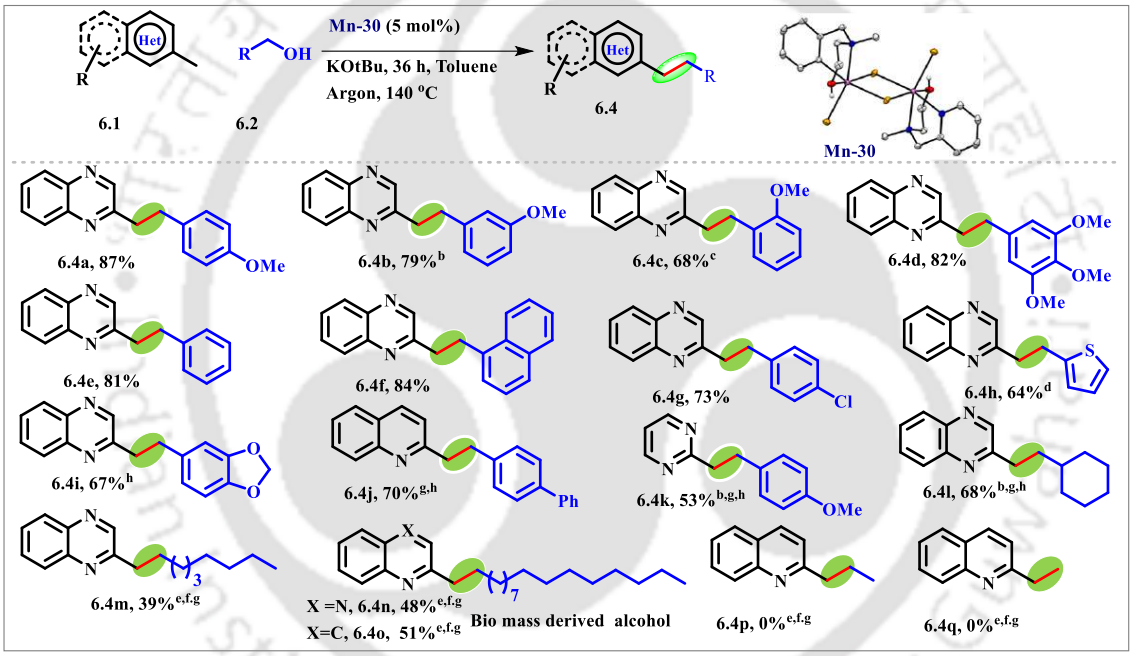


[a]**Reaction conditions: 6.1**(1 mmol), **6.2** (1-1.2 mmol), KOH (0.6-0.8 mmol), **Mn-30** (2.5 mol%), Toluene (1 mL), Temperature 110 °C -130 °C, time 24 h, [b]Mn-12 (5 mol%) [c]Temperature 130 °C, [d]KOH 0.8 equiv., [e]Time: 36 h, [f]KO^{t}Bu 0.8 equivalent.

Initially, applicability of alcohol derivatives was probed under developed protocol. At first, differently substituted primary aromatic alcohols with quinoxalines were tested. Electron rich substituents at *o*-, *m*- & *p*-position all responded smoothly and provided the desired *E*-olefinated products (Table 6.2, 63%, **6.3a**–**6.3g**) with good to excellent yields (69-92%). Halo substituted alcohol at *p*-position with quinoxaline also reacted efficiently and afforded good yields (Table 6.2, **6.3h** & **6.3i**, 77-91%). Notably, these compounds could be further functionalized to various useful scaffolds. Next, the reaction with heteroaromatic alcohols was verified. 2-thiophene methanol, and piperonyl alcohols smoothly underwent dehydrogenative *E*-olefination reaction with 2-methyl quinoxaline. The corresponding olefinated products were obtained in 88% and 77% respectively (Table 6.2, **6.3j** & **6.3k**). Then, the reactivity of different quinalidine derivatives was investigated applying current protocol with primary alcohols. Under slightly modified reaction conditions alcohols bearing electronically rich substituents at *m*, *p*-positions were well tolerated to give excellent yields of α-alkenylated heteroarene products (Table 6.2, **6.3l-6.3o**, 70 & 87%). 4-chloro and 4-fluoro benzyl alcohols were also compatible with the olefination reaction (Table 6.2, **6.3p** & **6.3q**). Electron rich substituent at 6-position and halo substituents at 8-position of quinalidine underwent efficient dehydrogenative coupling with various 4-substituents aromatic alcohols to furnish 61%-70% yields of targeted products (Table 6.2, **6.3r-6.3r**). The catalytic reaction between 2-methyl quinoline derivatives and heteroaromatic 2-thiophene methanol yielded the desired *E*-olefinated products **6.3v** & **6.3w** in 59-63%. Next, the scope of various methyl heteroarenes was explored. Delightfully, other important heteroarenes containing less acidic methyl C-H bonds such lupidine (**6.1x**), pyrazine (**6.1y**), perimidine (**6.1z**) benzoxazole (**6.1aa**) and benzimidazole (**6.1aa**) successfully delivered good yields of olefinated products (Table 6.2, **6.3x-6.3ac**). To further illustrate the practical utility of the developed catalytic process, variety of medicinally and synthetically relevant *E*-olefinated heteroarenes were synthesized. Under the optimized reaction conditions, antimalarial drugs against Dd2 strain[16b] (Table 6.2, **6.3ad-6.3af**) were successfully prepared in excellent yields. Furthermore, medicinally and synthetically important molecule **6.3ag** which is a core unit of Montelukast intermediate and drug UCF-501, used for the treatment of Malaria, Asthma/seasonal allergies were also synthesized.[17] Furthermore, compound **6.3ah**, which is used as important retiometric chemosensor probe[17] was also synthesized in 65% yields. Piperonyl alcohol and 3, 4-dimethoxy benzyl with 2-methyl quinoline were smoothly olefinated under the streamlined protocol afforded 63% and 64% yield expected product (**6.3ai** & **6.3aj**). Notably, **6.3ai** and **6.3aj** are important intermediates of antimalarial drug cuspareine and alkaloid galipinine, which could be prepared from **6.3ai** and **6.3aj** by applying Ni-catalysed hydrogenation and followed by methylation using methylating agent.[18]

Table 6.3. Well defined Mn(II) catalysed C-alkylation of heteroarenes[a]

During the optimization process, it was observed that on switching the reaction conditions selectively C-alkylated quinoxaline was isolated in 87% (Table 6.1, entry 19). Therefore, implementing this reaction conditions various substrate scope was inspected. Introducing 4-methoxy and 3-methoxy benzyl alcohols under standard catalytic conditions with 2-methyl quinoxalines, deliver 87% & 79% yields of the respective alkylated products (Table 6.3, **6.4a** & **6.4b**). Under similar reaction conditions, 2-methoxybenzyl alcohol with 2-methyl quinoxaline gave 68% C-alkylated product and along with 20% olefinated product (Table 6.3, **6.4c**). Highly electron rich 3, 4, 5-trimethoxy benzyl alcohol successfully delivered C-alkylated product in 82% yields (Table 6.3, **6.4d**). Employing the identical reaction conditions polyaromatic 2-naphthyl alcohol was also found suitable for furnishing the desired C-alkylated quinoxalines (Table 6.3, **6.4f**).



[a]**Reaction conditions:6.1**(1 mmol), 6.**2** (1.5-2 mmol), KO^{t}Bu (1 mmol), **Mn-30** (5 mol%), Toluene (1 mL), Temperature 140 °C, time 36 h, [b]**Mn2** trace amount of alkenyl product [c]20% olefinated product, [d]10% olefinated product, [e]Alcohol 3 equiv., [f]Reaction time 48 h, [g]Base 1.5 equivalent, [h]Alcohols 2.5 equivalent, all yields are isolated.

Halo derivatives of benzyl alcohol were also tested. Notably, under the developed reaction conditions without any dehalogenation desired C-alkylated quinoxalines were isolated in 73% yields (Table 6.3, **6.4g**). Heteroaromatic thiophene and piperonyl methanol proceeded effectively to deliver 64% of the targeted C-alkylated product (Table 6.3, **6.4h** & **6.4i**). Then, compatibility of other methyl-N-heteroarenes such as quinalidine and pyrimidine was verified with 4-biphenyl, 4-methoxy benzyl alcohols and 2-thiophene methanol (Table 6.3). Gratifyingly, good yields of the respective C-alkylated products were delivered (Table 6.3, **6.4j** & **6.4k**). Cyclic aliphatic alcohol

like cyclohexamethanol served 68% C-alkylated quinazoline derivative (Table 6.3, **6.4l**). Next, the feasibility of thermodynamically inert aliphatic alcohols was tested. Under extended reaction time, both quinoxaline and 2-methyl quinoline both are coupled with octanol, hexadecanol and octadecanol furnished moderate to good yields of desired C-alkylated products (Table 6.3, **6.4m-6.4o**).

6.4. Mechanistic investigation:

6.4.1. Control experiments: Next to shed light on the mechanism severel control experiments was executed. Reaction between 2-methyl quinazoline (**6.1a**) and 4-methoxy benzaldehyde was performed (**6.5a**) in presence of catalyst and absence of catalyst under standard conditions to understand the role of catalyst at condensation step of this transformation. The experimental outcomes depict that the catalyst not only dehydrogenates the alcohols to aldehyde but also speed up the condensation process (Figure **6.2A**). Under optimal conditions, adding radical quenchers (TEMPO & BHT) has no impact on product yields, which eliminate the role of a single electron in the catalytic cycle (Figure **6.3B**). Halting the C-alkylation process at 12 hours and used NMR to analyse the crude reaction mixture, which revealed that alkenyl methyl-N-heteroarene and aldehyde are the two key intermediates for the process (Figure **6.3C**). The addition of an excess amount of mercury (Hg, 2.2 equiv.) in the standard catalytic system has no effect on the product yield, which indicates the homogeneous nature of current catalytic protocol (Figure **6.3D**). Under the standard catalytic protocol addition of 10 mol% trityl cation quenches the desired product yields by greater than half. This result supports the in situ formation of the Mn-H species[19] that hydrogenates the double bond of the *E*-olefinatedheteroarenes. (Figure **6.3E**).

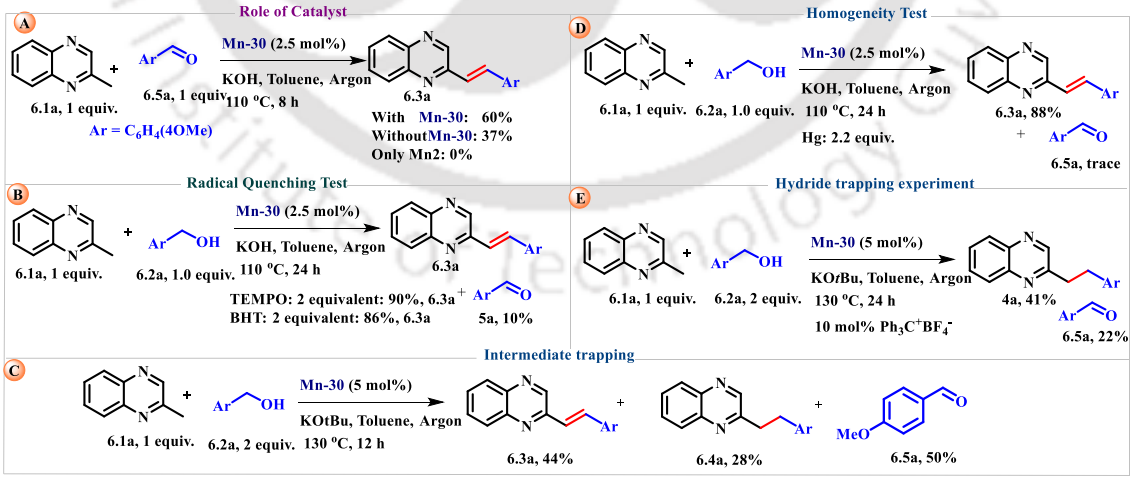


Figure 6.3. Control experiments for selective functionalization of methyl heteroarenes.

6.4.2. Kinetic experiments: The progress of the *E*-olefination reaction was monitored by gas chromatography using mesitylene as internal standard (Figure 6.4, **A**). The concentration of 2-methyl quinazoline (**6.1a**) and 4-methoxy benzyl alcohol (**6.2a**) were gradually decreased on

increasing the reaction time and concurrently *E*-olefinated quinazoline (**6.3a**) product was increased. The concentration of 4-methoxy benzaldehyde (**6.5a**) has remained low and steady during the course of the reaction, which indicates the condensation step is faster compared to the dehydrogenation step. After 24 h the exclusive *E*-olefinated product was formed in 91% yield. The parallel experiment between 4-OMe $PhCH_2OH$ (**6.2a**) and 4-OMe $PhCD_2OH$ **6.2a-d_2**) was carried out which displayed the kinetic isotope effect 2.23 for *E*-olefination reaction. This result indicates that α-C-H bond breaking of the primary alcohol is one of the slowest step in this selective *E*-olefination reaction (Figure 6.3, **B**).

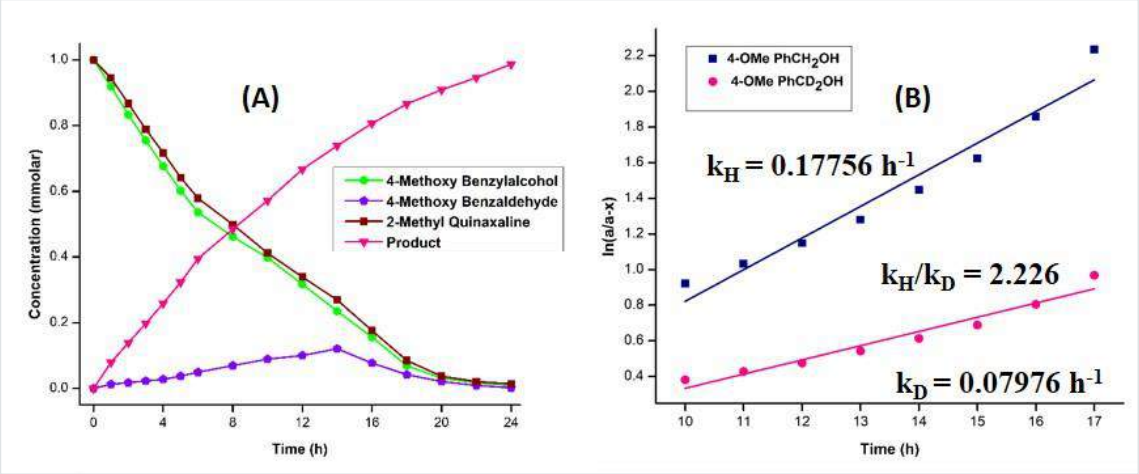


Figure 6.4. [A] kinetics monitoring of E-olefination of methyl heteroarenes; [B] determination of kinetic isotope effect.

6.5. Proposed catalytic cycle: Based on above primary investigation and literature reports[19-22, 16a,b] the catalytic cycle for switchable alkenylation and alkylation of heteroarenes using developed **Mn-30** complex was depicted (Figure 6.5). At first, under standard reaction conditions cleavage of bridging bonds of **Mn-30** complex was occurs and catalytically active monomeric Mn (II) complex (I) was formed. Then anionic oxygen formed hydrogen bonding with alcoholic proton. Alcohol dehydrogenate to its corresponding aldehyde (**6.5a**) and metal hydride (III) species is generated via transition state (TS-I). Then, in presence of base methyl heteroarenes (**6.1**) formed active nucleophile enamine (**6.1***) which reacted with in situ formed aldehyde (**6.5**) and released desired *E*-olefinated products (**6.3**) and water is eliminated as green by-product. The catalytically active complex (I) is regenerated by liberation of molecular hydrogen, which will be further, used for the next catalytic cycle of heteroarene *E*-olefination reaction. On the other hand, upon switching the reaction conditions in situ formed metal hydride (III) hydrogenate trans double bond of *E*-olefinated product to corresponding saturated C-alkylated products (**6.4**) and active catalyst (I) is regenerated to continue the next C-alkylation catalytic cycle.

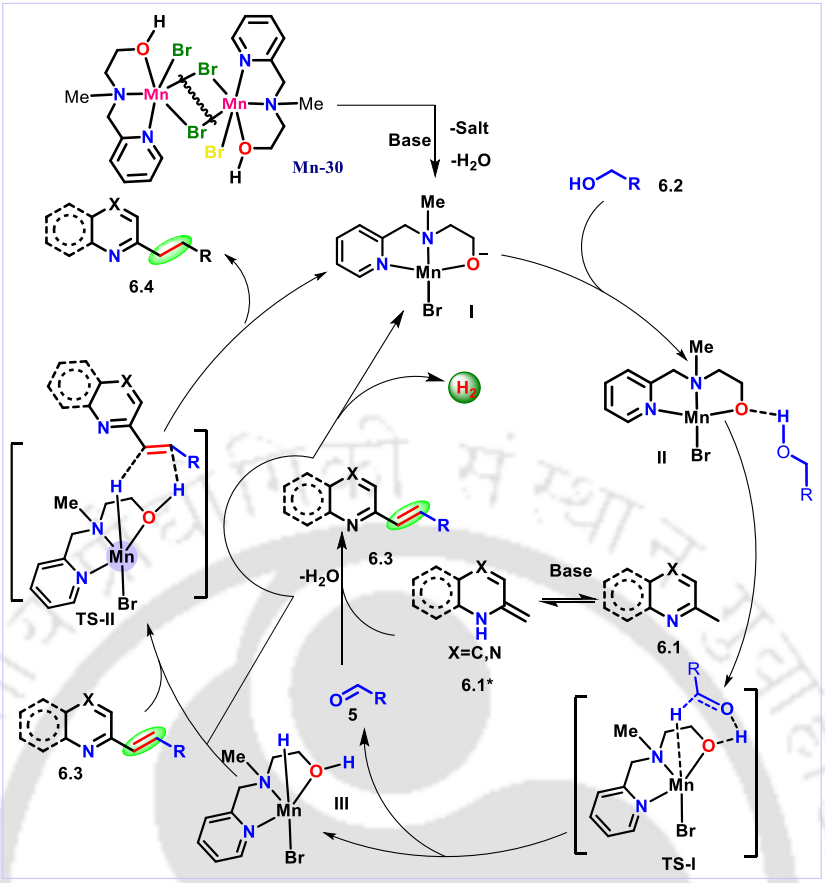


Figure 6.5. Proposed catalytic cycle of switchable functionalization of heteroarenes.

6.6. Conclusions: In this chapter, an efficient, cost-effective and biocompatible manganese (II) catalysis for selective functionalization of methyl-*N*-heteroarenes via ADC and BH strategy employing renewable feedstock has been highlighted. Notably, this convenient protocol could be applicable for functionalization of various methyl heteroarenes using numerous primary aromatic, heteroaromatic and aliphatic alcohols. The potentiality of this developed protocol has been manifested by diversifying various medicinally and synthetically useful molecules in good to excellent yields. In addition, various prepared molecules in this chapter could be directly use to synthesize different drug molecules. The catalyst operates bifunctional mechanism for dehydrogenation of alcohols and hydrogenation of insitu formed alkenyl heteroarenes.

6.7. Experimental Section:

6.7.1. General considerations: Unless otherwise mentioned, all chemicals were purchased from common commercial available sources and used as received. All solvents were dried by using standard procedure. The preparation of catalyst was carried out under open atmosphere with methanol. All catalytic reactions were carried out under argon atmosphere using dried glassware and standard syringe/septa techniques, JACOMAX glove box filled with argon. DRX-400 Varian spectrometer and Bruker Advance III 400 MHz, 500 MHz and 600 MHz spectrometers were used

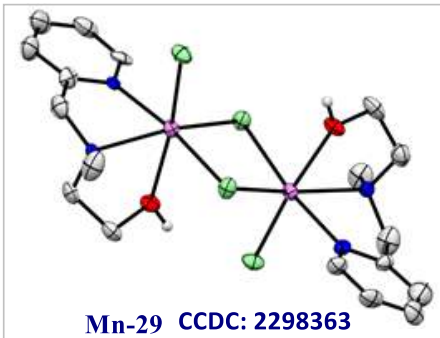
to record ^{1}H and ^{13}C NMR spectra using DMSO-d_6, $CDCl_3$ as solvent and TMS as an internal standard. Chemical shifts (δ) are reported in ppm and spin-spin coupling constant (*J*) are expressed in Hz, and other data are reported as follows: s = singlet, d = doublet, t = triplet, m = multiplet, q = quartet, dt = doublet of triplet, td = triplet of doublet and brs = broad singlet. ATIR data was collected on PerkinElmer IR spectrometer. Q-TOF ESI-MS instrument (Agilent: 6546 LC/Q-TOF) was used for recording mass spectra. PerkinElmer clarus-590 GC instrument using Elite Plot-Q is used for GC analysis. Single crystal X-RAY diffractometer (BRUKER D8QUEST) is used for single crystal data collection. SRL silica gel (100-200 mesh) was used for column chromatography.

6.7.2. Procedure for Syntheses of Mn (II) Complexes (Mn-29-Mn-32): In a round-bottom flask containing anhydrous MnX_2 (1 mmol, 1 equiv.) and methanolic solution of corresponding NNO ligands (1.1 mmol, 1.1 equiv.) was added drop wise. The mixture was stirred at room temperature for 6 h. All volatile components were removed under reduced pressure, and the residue was rinsed with diethyl ether and hexane three times (3×5 mL) to give an off-white solid powder. Then 50 mg of complex was further dissolved in 5 mL methanol and 1 mL diethyl ether was added to it and kept at room temperature. After 24 h colourless block size crystals were come which are suitable for single crystal analysis to obtain molecular structure of the complex.

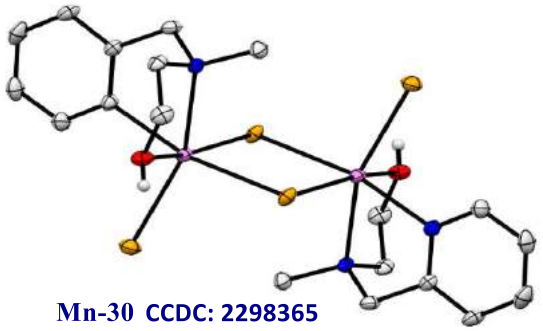
6.7.3. Characterizations of Mn (II) complexes:

6.7.3.1 Solvents solubility chart:

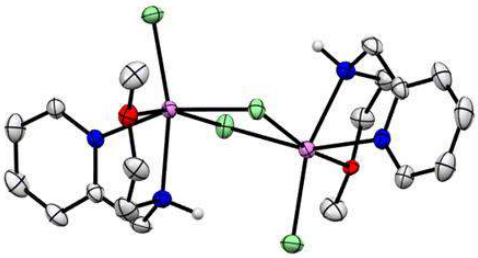
Catalyst / Solvent	MeOH	DCM	$CHCl_3$	Hexane	Ether	ACN	THF	DMF	DMSO
Mn-29	✓	✓	✓	✗	✗	✓	Partially	✓	✓
Mn-30	✓	✓	✓	✗	✗	✓	Partially	✓	✓
Mn-31	✓	✓	✓	✗	✗	✓	✓	✓	✓
Mn-32	✓	✓	✓	✗	✗	✓	✓	✓	✓



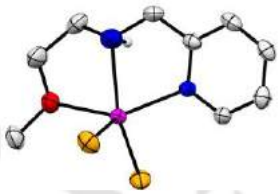
Mn-29 CCDC: 2298363



Mn-30 CCDC: 2298365



Mn-31 CCDC: 2298368



Mn-32 CCDC: 2298369

	Mn-29	**Mn-30**
Empirical formula	C_{19} H_{14} Br Cl_3Mn N_3 O_3	C_{18} H_{28} Br_4 Mn_2 N_4 O_2
Formula weight	573.53	761.96
Crystal system	triclinic	monoclinic
Space group	'P -1'	P 21/c
Unit cell dimensions	a=10.216(2)Å, α=101.979(5)° b= 15.023(3)Å, β= 105.397(5)° c= 16.540(3)Å γ= 03.709(5)°	a=8.3804(5)Å, α=90 ° b=14.2600(9)Å, β=100.035(2)° c=10.7741(7)Å, γ=90°
Volume, V (Å3)	2276.3(8)	1267.86(14)
Z	4	2
Density (calculated),	1.674	1.996
Crystal size, mm3	0.35 0.31 0.30	0.35 0.31 0.30
Theta range for data collection	2.21to 25.57	2.39to 26.36
Index ranges	-12 ≤ h ≤ 12, -17 ≤ k ≤ 17, -19 ≤ l ≤ 19	-9 ≤ h ≤ 9, -16 ≤ k ≤ 16, -12 ≤ l ≤ 12
Final R indices [I>2sigma(I)]	R1 = 0.0446(6022), wR2= 0.1239(7998)	R1 = 0.0240(2030), wR2=0.0569(2232)
R indices (all data)	R1= 0.0712, WR2=0.0967	R1= 0.0282, WR2=0.0547

	Mn-31	**Mn-32**
Empirical formula	C_{18} H_{28} Cl_4 Mn_2 N_4 O_2, C H_4	C_9 H_{14} Br_2Mn N_2 O
Crystal system	monoclinic	monoclinic

Space group	P 1 21 1	P 1 21/n 1
Unit cell dimensions	a= 9.7577(7) Å, α=90 ° b=14.5489(10)Å, β=110.865(8)° c=10.5433(7)Å, γ=90°	a=8.1839(11)Å, α=90 ° b=11.2232(16)Å, β=94.913(4) ° c=14.614(2)Å, γ=90°
Volume, V ($Å^3$)	1398.61(18)	1337.4(3)
Z	2	4
F (000)	632.0	740.0
Crystal size, mm^3	0.36 0.33 0.30	0.33 0.31 0.28
Theta range for data collection	2.7790 to 26.5180	2.29 to 26.17
Index ranges	-12 ≤ h ≤ 12, -18 ≤ k ≤ 18, -13 ≤ l ≤ 13	-10 ≤ h ≤ 10, -14 ≤ k ≤ 14, -18 ≤ l ≤ 18
Goodness-of-fit on F^2	R1 = 0.0438(3784), wR2=0.1111(4559)	R1 = 0.0349(2370), wR2=0.0746(2724)
Final R indices [I>2sigma(I)]	R1= 0.0577, WR2= 0.1011	R1= 0.0423, WR2=0.0717

Complexes	**Elemental analysis**		**HRMS: (ESI)**	
Mn-29	**Calc. for $C_{18}H_{28}Cl_4Mn_2N_4O_2$: C, 37.01; H, 4.83; N, 9.59;**	**Found: C, 36.98; H, 4.656; N, 9.42.**	**Calc'd for. $C_{18}H_{28}Cl_4Mn_2N_4O_2$ [M+Na]+: 604.9625.**	**Found = 604.9623.**
Mn-30	**Anal. Calc. for $C_{18}H_{28}Br_4Mn_2N_4O_2$: C, 28.37; H, 3.70; N, 7.35.**	**Found: C, 28.60; H, 3.421; N, 7.21.**	**Calc'd for. $C_{18}H_{28}Br_4Mn_2N_4O_2$ [M+Na]+: 784.7564.**	**Found = 784.7566.**
Mn-31	**Anal. Calc. for $C_{18}H_{28}Cl_4Mn_2N_4O_2$: C, 37.01; H, 4.83; N, 9.59.**	**Found: C, 38.39; H, 4.150; N, 9.38.**	**Calc'd for. $C_{18}H_{28}Cl_4Mn_2N_4O_2$ [M+Na]+: 604.9625.**	**Found = 604.9614.**
Mn-32	**Anal. Calc. for $C_{18}H_{28}Cl_4Mn_2N_4O_2$: C, 37.01; H, 4.83; N, 9.59.**	**Found: C, 38.39; H, 4.150; N, 9.38.**	**Calc'd for. $C_{18}H_{28}Cl_4Mn_2N_4O_2$ [M+Na]+: 604.9625.**	**Found = 604.9614.**

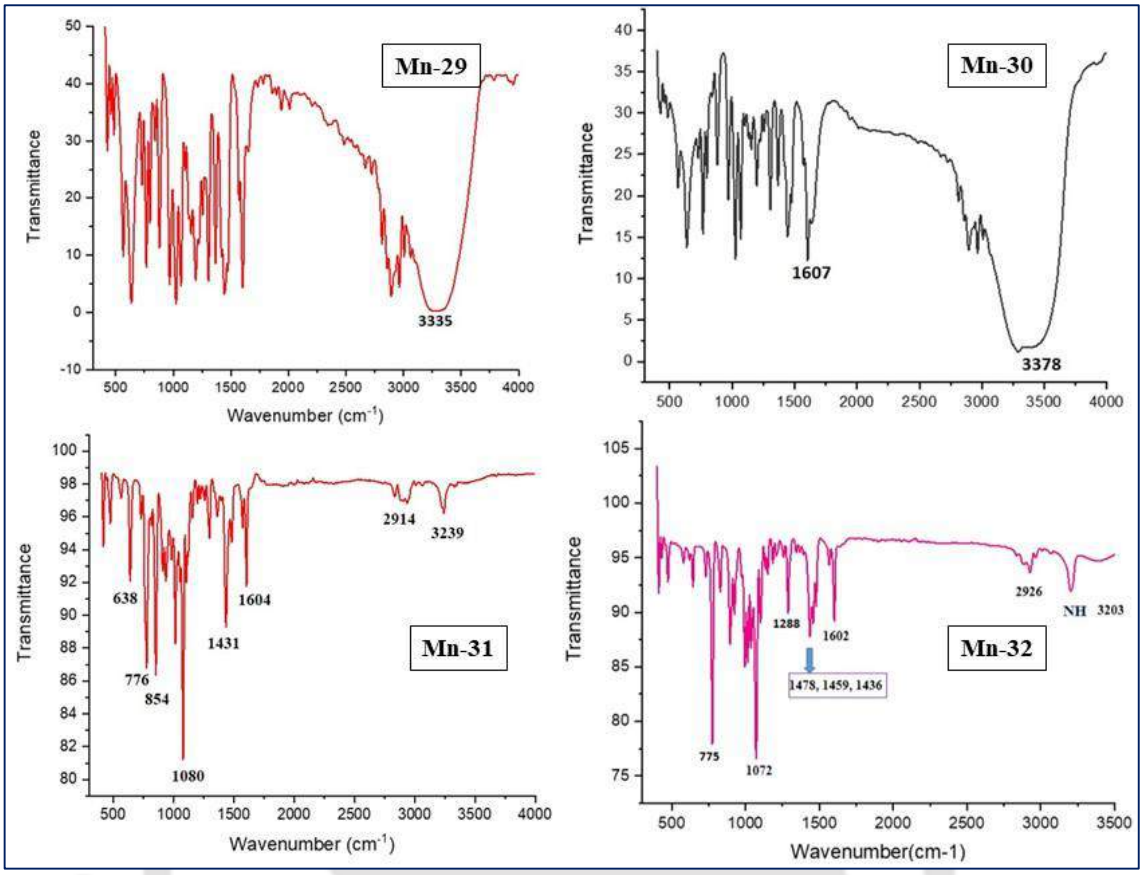


Figure 6.6. IR-spectra of Mn(II)-complexes.

6.7.4. General Procedure for the Synthesis of *E*-olefinated heteroarenes: In a 10 mL oven dried round bottom flask, heteroarenes (1 mmol), primary alcohols (1 mmol), **Mn-30** (2.5 mol %), and KOH (0.6 mmol, 0.6 equiv.) in toluene (1 mL) were taken under an argon atmosphere. The reaction mixture was heated at 110 °C in a preheated oil bath for 24 h followed by cooling to room temperature. Then the reaction mixture was filtered through celite. The resultant volatiles were evaporated under reduced pressure. Final products were purified by silica gel column chromatography (100−200 mesh size) using hexane/ethyl acetate as eluent to get the desired products.

6.7.5. General Procedure for the Synthesis of C-alkylated heteroarenes: In a 100 mL seal tube/ screw cap tube heteroarenes (1 mmol), primary alcohols (1.5 mmol), **Mn-30** (5 mol %), and KO^{t}Bu (1 mmol, 1 equiv.) in toluene (1 mL) were taken under an argon atmosphere. The reaction mixture was heated at 140 °C in a preheated oil bath for 36 h followed by cooling to room temperature. Then the reaction mixture was filtered through celite. The resultant volatiles were evaporated under reduced pressure. Final products were purified by silica gel column chromatography (100−200 mesh size) using hexane/ethyl acetate as eluent to get the desired products.

6.8. Mechanistic studies.

6.8.1 Olefination of 2-methyl quinoxaline (6.1a) with 4-methoxy benzaldehyde without catalyst. 2-methyl quinazoline **6.1a** (1.0 mmol), 4-methoxy benzaldehyde **6.5a** (1.0 mmol) and KOH (0.6 equiv.) in toluene were taken in a 10 mL round bottom flask under argon atmosphere. After that, the reaction mixture was placed in a preheated oil bath at 110 ^{o}C. After 8 h the reaction mixture was diluted by EtOAc and filtered through celite. Then evaporated the all volatiles using rota vapour and 37% the *E*-olefinated product was isolated after column of the residue.

6.8.2 Olefination of 2-methyl quinoxaline (6.1a) with 4-methoxy benzaldehyde with catalyst. 2-methyl quinazoline **6.1a** (1 mmol), 4-methoxy benzaldehyde **6.5a** (1 mmol), **Mn-30** (2.5 mol%) and ^{t}BuOK (1 equiv.) in toluene were taken in a 10 mL round bottom flask under argon atmosphere. After that, the reaction mixture was placed in a preheated oil bath at 110 ^{o}C. After 8 h, the crude reaction mixture was diluted by EtOAc and filtered through celite. Then filtrate was purified by column chromatography using EtOAc/hexane as an eluent. After purification 60% of *E*-olefinated quinazoline was isolated.

6.8.3 Radical trapping test in the catalysis: An oven dried 10 mL round bottom flask 4-methoxy benzyl alcohol, **6.2a** (138 mg, 1 mmol), 2-methyl quinoxaline, **6.1a** (144 mg, 1 mmol), (KOH, 0.6 mmol, 35 mg), TEMPO or BHT (2 mmol, 312 mg or 440 mg), were taken and remove air through vacuum. Then 2 mL toluene and **Mn-30** (2.5 mol%, 19 mg) were added under argon flow. The resulting reaction mixture was allowed to stir at 110 °C for 24 h in an oil bath. The reaction mixture was cooled down to room temperature and passed through celite pad using 20 mL ethyl acetate (EtOAc). Next, the solvent was evaporated under reduced pressure and the reaction mixture was purified using 10-20% ethyl acetate and hexane as an eluent.

6.8.4 Homogeneity test: In an oven dried 10 mL round flask 4-methoxy quinazoline, **6.1a** (1 mmol, 144 mg), 4-methoxy benzyl alcohol, **6.2a** (1 mmol, 138 mg), KOH (0.60 mmol, 35 mg, 60 mol %), and 2.2 equiv. metallic Hg were taken together and connected with high vacuum for 10 minutes. Then 1 mL dry toluene and **Mn-30** (2.5 mol%, 19 mg) are added to the mixture tube under argon. The reaction mixture is heated at 110 °C. After stirring for 24 h, the mixture is cooled down to room temperature. Then, reaction tube was taken out from hot oil bath and cooled to room temperature. Then purified the crude reaction mixture using 10-15% petroleum ether and ethyl acetate as an eluent.

6.8.5 Metal hydride trapping experiment: In an oven dried 100 mL screw cap tube 4-methoxy quinazoline, **6.1a** (1 mmol, 144 mg), 4-methoxy benzyl alcohol, **6.2a** (1.6 mmol, 221 mg), KO^{t}Bu (1 mmol, 112 mg, 1 mmol) 2 mL dry toluene and **Mn-30** (5 mol%, 5 mg) are added sequentially

inside the argon filled glove box. Then reaction mixture is stirred at room temperature. After stirring for 20 mins, 10 mol% (33 mg) of trityliumtetrafluoroborate is added to the previous reaction mixture. Then, the tube was sealed and placed in a preheated oil bath at 130 °C (oil bath temperature) for 36 h. After completion of the reaction, the tube was allowed to cool at room temperature. Then, the solvent was evaporated and the crude residue was purified by silica gel column chromatography using petroleum ether-ethyl acetate as eluent which afforded 37% isolated yields of the desired product. In parentheses crude yields of the *α*-alkylated methyl heteroarenes product was highlighted. This result indicates the insitu formation of **Mn-H** which hydrogenate the *E*-olefinated intermediates to corresponding α-alkylated methyl heteroarenes.

6.8.6 Identification of intermediate for C-alkylation of methyl heteroarenes using Mn(II) catalysts: In an oven dried 100 mL screw cap tube 2-methyl quinazoline, **6.1a** (1 mmol, 144 mg), 4-methoxy benzyl alcohol, **6.2a** (2 mmol, 276 mg), KO^{t}Bu (1 mmol, 112 mg, 100 mol %) 2 mL dry toluene and **Mn-30** (5 mol%, 5 mg) are added sequentially inside the argon filled glove box. Then, the tube was sealed and placed in a preheated oil bath at 14 0 °C (oil bath temperature). After 12 h the reaction mixture was allowed to cool at room temperature. Then, the reaction mixture was diluted by EtOAc and filtered through celite. Then the all volatiles were evaporated and the crude residue was analysed by NMR. The results indicated the insitu formation of E-olefin and aldehyde as an intermediate product in C-alkylation reaction.

6.9. Kinetics experiments:

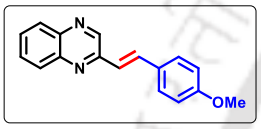
6.9.1 Experimental procedure of full reaction kinetics of E-olefination of methyl heteroarenes: To an oven dried 10 mL 2-neck round bottomed flask, 2-methyl quinazoline **6.1a** (2.0 mmol, 1 equiv.), 4-methoxy benzyl alcohol **6.2a** (2.0 mmol, 1 equiv.), KOH (0.60 mmol, 60 mol%) and **Mn-30** (0.025 mmol, 2.5 mol%), mesitylene (2.0 mmol, 1 equiv.) as an internal standard and toluene as a solvent were added under argon to make up the total volume of the reaction mixture 2 mL. Afterwards, the reaction mixture was kept in a preheated oil bath for stirring at 110 °C. At regular intervals (1 h, 2 h, 3 h, 4 h, 5 h, 6 h, 8 h, 12 h, 14 h, 16 h, 18 h, 20 h, 22 h, 24 h) the reaction mixture was cooled to ambient temperature and an aliquot of mixture was taken in a GC vial. The GC sample was diluted with ethyl acetate and subjected to gas chromatographic analysis. The concentration of the product was determined with respect to mesitylene internal standard. The data was accomplished to draw the concentration of the product (mmolar) *vs* time (h) plot.

6.10. Kinetic isotope effect (KIE) studies:

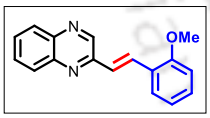
6.10.1 Kinetic isotope effect during Mn-catalysed selective C (sp^3)-H functionalization of 2-methyl quinazoline from parallel experiments: Parallel reactions for the Mn-catalysed selective C (sp^3)-H functionalization of 2-methyl quinazoline (**6.1a**) was carried out in both 4-OMe benzyl alcohol and 4-OMe d2-benzyl alcohol under the streamline reaction condition. Both the oven dried 10 mL 2-neck round bottomed flask were placed in a preheated oil-bath at 110 °C and heated for specified time. The progress of the reaction was analysed by GC using mesitylene as internal standard. All the reactions were repeated twice and the average conversion of **6.3a** at different time intervals was plotted as ln (a/a-x) vs time (h). The ratio of slope of the two plots directly gave the K_H/K_D value.

6.11. NMR data of substrate scope:

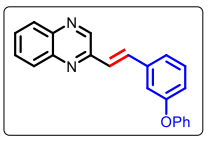
(*E*)-2-(4-methoxystyryl) quinoxalines (6.3a):[24] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 15%) afforded the title compound in 92% yield (241 mg, 0.92 mmol) as yellow solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 9.01 (s, 1H), 8.06 – 8.03 (m, 2H), 7.82 (d, *J* = 16.3 Hz, 1H), 7.76 – 7.72 (m, 1H), 7.69 – 7.66 (m, 1H), 7.60 (d, *J* = 8.7 Hz, 2H), 7.24 (d, *J* = 16.2 Hz, 1H), 6.95 (d, *J* = 8.7 Hz, 2H), 3.85 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.8, 151.2, 144.6, 142.7, 141.6, 136.2, 130.4, 129.3, 129.2, 129.1 (2C), 129.0 123.3, 114.6, 55.5.

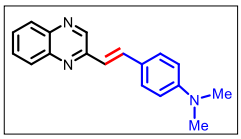


(*E*)-2-(2-methoxystyryl) quinoxalines (6.3b):[24] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 79% yield (207 mg, 0.79 mmol) as yellow gummy oil. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 9.12 (s, 1H), 8.22 (d, *J* = 16.5 Hz, 1H), 8.10 – 8.08 (m, 2H), 7.78 – 7.69 (m, 3H), 7.48 (d, *J* = 16.5 Hz, 1H), 7.37 – 7.34 (m, 1H), 7.05 – 6.96 (m, 2H), 3.97 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 157.9, 151.4, 144.5, 142.4, 141.5, 132.0, 130.6, 130.3, 129.2, 127.9, 126.1, 125.1, 121.0, 111.2, 55.7, 36.7, 30.4.



(*E*)-2-(3-phenoxystyryl) quinoxalines (6.3c):[25] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 69% yield (224 mg, 0.69 mmol) as white solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.92 – 8.91 (m, 1H), 7.97 (t, *J* = 8.0 Hz, 2H), 7.72 (d, *J* = 16.3 Hz, 1H), 7.67–7.59 (m, 2H), 7.30–7.24 (m, 5H), 7.21– 7.20 (m, 1H), 7.06 (t, *J* = 7.4 Hz, 1H), 6.98-6.97 (m, 2H), 6.94 -6.92 (m, 1H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 158.1, 157.0, 150.4, 144.5, 142.5, 141.7, 138.0, 135.9, 130.5, 130.3, 130.0, 129.5, 129.3, 126.1, 123.7, 122.6, 119.7, 119.3, 117.3.

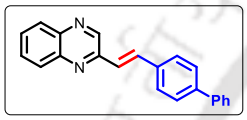


(*E*)-N, N-dimethyl-4-(2-(quinoxalin-2-yl)vinyl)aniline (6.3d)[26] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 15%) afforded the title compound in 93% yield (256 mg, 0.93 mmol) as yellow solid. 

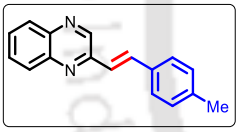
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.91 (s, 1H), 7.95 – 7.93 (m, 2H), 7.72 (d, *J* = 16.2 Hz, 1H), 7.63 (t, *J* = 8.35 Hz, 1H), 7.57 – 7.54 (m, 1H), 7.47 (d, *J* = 8.7 Hz, 2H), 7.08 (dd, *J* = 16.2 Hz, 1.3 Hz, 1H), 6.66 – 6.64 (m, 2H), 2.94 – 2.93 (m, 6H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 151.7, 151.2, 144.7, 142.6, 141.2, 137.1, 130.2, 129.2, 129.1, 128.9, 128.6, 124.2, 120.6, 112.3, 40.4.

(*E*)-2-(2-([1, 1'-biphenyl]-4-yl) vinyl) quinoxalines (6.3e):[27] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 92% yield (283 mg, 0.92 mmol) as yellow solid.

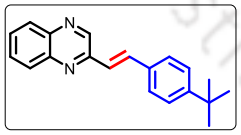
^{1}H NMR (500 MHz, Chloroform-*d*) δ 9.06 (s, 1H), 8.08 (d, *J* = 8.5 Hz, 2H), 7.92 (d, *J* = 16.3 Hz, 1H), 7.78 – 7.70 (m, 5H), 7.68 – 7.66 (m, 2H), 7.65 – 7.63 (m, 2H), 7.47 (t, *J* = 7.4 Hz, 2H), 7.43 (d, *J* = 16.3 Hz, 1H) 7.39 – 7.35 (m, 1H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 150.8, 144.6, 142.7, 142.1, 141.7, 140.5, 140.5, 136.1, 135.2, 130.5, 129.4, 129.3, 129.1, 128.1, 127.8, 127.7, 127.1, 125.4.



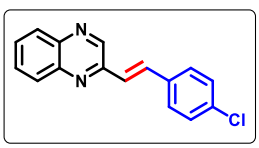
(*E*)-2-(4-methylstyryl) quinoxalines (6.3f):[28] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 10%) afforded the title compound in 89% yield (219 mg, 0.89 mmol) as white solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 9.01 (s, 1H), 8.06 – 8.03 (m, 2H), 7.83 (d, *J* = 16.3 Hz, 1H), 7.73 (t, *J* = 7.2 Hz, 1H), 7.68 (t, *J* = 7.7 Hz, H), 7.54 (d, *J* = 7.7 Hz, 2H), 7.32 (d, *J* = 16.3, 1H), 7.22 (d, *J* = 7.8 Hz, 2H), 2.38 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 150.9, 144.5, 142.6, 141.6, 139.6, 136.5, 133.3, 130.4, 129.7, 129.3, 129.2, 129.2, 127.5, 124.4, 21.5.



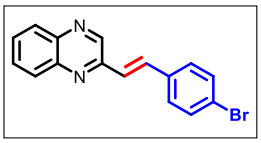
(*E*)-2-(4-(tert-butyl) styryl) quinoxalines (6.3g):[25] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 15%) afforded the title compound in 91% yield (262 mg, 0.91 mmol) as pink solid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 9.03 (s, 1H), 8.07 – 8.04 (m, 2H), 7.85 (d, *J* = 16.3 Hz, 1H), 7.76 – 7.73 (m, 1H), 7.70 – 7.67 (m, 1H), 7.60 (d, *J* = 8.3 Hz, 2H), 7.44 (d, *J* = 8.3 Hz, 2H), 7.35 (d, *J* = 16.3 Hz, 1H), 1.35 (s, 9H). **^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$)** δ 152.8, 151.0, 144.5, 142.6, 141.6, 136.4, 133.3, 130.4, 129.2, 129.2, 127.4, 126.0, 124.7, 34.9, 31.3.



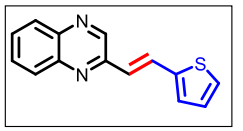
(*E*)-2-(4-chlorostyryl) quinoxalines (6.3h):[29] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 77% yield (204 mg, 0.77 mmol) as white solid. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.89 (s, 1H), 7.96 (t, *J* = 7.1 Hz, 2H), 7.69 (d, *J* = 16.3 Hz, 1H) 7.65 (t, *J* = 7.0 Hz, 1H), 7.61 – 7.58 (m, 1H), 7.45 (d, *J* = 8.3 Hz, 2H), 7.27 (d, *J* = 8.3 Hz, 2H), 7.21 (d, *J* = 16.3 Hz, 1H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 150.3, 144.5, 142.5, 141.8, 135.1, 135.0, 134.6, 130.5, 129.5, 129.3 (2C), 129.2, 128.7, 125.9.



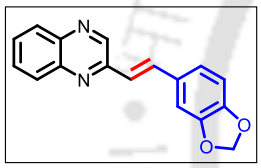
(*E*)-2-(4-bromostyryl) quinoxalines (6.3i):[30] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 91% yield (283 mg, 0.91 mmol) as brown solid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.96 (s, H), 8.01 (d, *J* = 9.1 Hz, 2H), 7.75 (d, *J* = 16.3 Hz, 1H), 7.72 -7.69 (m, 1H), 7.67 – 7.64 (m, 1H) 7.47 (q, *J* = 8.6 Hz, 4H), 7.31 (d, *J* = 16.3 Hz, 1H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 150.3, 144.5, 142.4, 141.8, 135.4, 135.0, 132.3, 130.7, 129.7, 129.3, 129.2, 129.0, 125.8, 123.5.



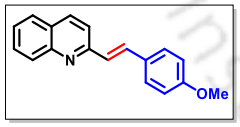
(*E*)-2-(2-(thiophen-2-yl) vinyl) quinoxalines (6.3j):[25] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 88% yield (209 mg, 0.88 mmol) as yellow gummy oil. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.89 (s, 1H), 8.00 -7.98 (m, 1H), 7.96 (d, *J* = 16.1 Hz, 1H), 7.69 - 7.66 (m, 1H), 7.64 – 7.60 (m, 1H), 7.28 – 7.27 (m, 1H), 7.23 – 7.22 (m, 1H), 7.18 (s, 1H) 7.10 (d, *J* = 16.1 Hz, 1H), 7.01– 7.00 (m, 1H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 150.4, 144.6, 142.5, 141.7, 141.6, 130.5, 129.5, 129.4, 129.3, 129.2, 128.2, 127.1, 124.4.



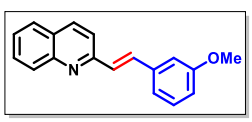
(*E*)-2-(2-(benzo[d] [1,3]dioxol-5-yl)vinyl)quinoxalines (6.3k):[25] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 10% to 25%) afforded the title compound in 77% yield (212 mg, 0.77 mmol) as white solid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.90 (s, 1H), 7.97 – 7.94 (m, 2H), 7.69 (d, *J* = 16.2 Hz, 1H), 7.67 – 7.63 (m, 1H), 7.60 – 7.57 (m, 1H), 7.12 – 7.09 (m, 2H), 7.02 (dd, *J* = 8.0 Hz, *J* = 1.3 Hz, 1H), 6.75 (d, *J* = 8.0 Hz, 1H), 5.92 (s, 2H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 150.8, 149.0, 148.5, 144.6, 142.5, 141.6, 136.4, 130.7, 130.5, 129.3, 129.1, 123.6, 123.5, 108.8, 106.2, 101.6.



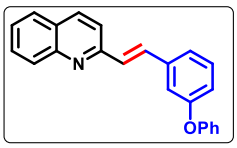
(*E*)-2-(4-methoxystyryl) quinoline (6.3l):[31] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 10%) afforded the title compound in 87% yield (227 mg, 0.87 mmol) as white solid.**^{1}H NMR (600 MHz, Chloroform-*d*) δ** 8.13 (d, *J* = 8.6 Hz, 1H), 8.09 (d, *J* = 8.4 Hz, 1H), 7.80 (d, *J* = 8.0 Hz, 1H), 7.72 – 7.70 (m, 1H), 7.69 – 7.65 (m, 2H), 7.61 (d, *J* = 8.6 Hz, 2H), 7.53 – 7.47 (m, 1H), 7.31 (d, *J* = 16.3 Hz, 1H), 6.96 (d, *J* = 8.7 Hz, 2H), 3.87 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 160.3, 156.5, 148.4, 136.4, 134.2, 129.8, 129.4, 129.2, 128.8, 127.6, 127.4, 127.0, 126.1, 119.3, 114.4, 55.5.



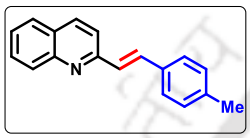
(*E*)-2-(3-methoxystyryl) quinoline (6.3m):[31] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 82% yield (214 mg, 0.82 mmol) as white solid.**^{1}H NMR (600 MHz, Chloroform-*d*) δ** 8.12 (d, *J* = 8.6 Hz, 1H), 8.09 (d, *J* = 8.4 Hz, 1H), 7.79 (d, *J* = 8.0 Hz, 1H), 7.74 – 7.69 (m, 1H), 7.68 – 7.63 (m, 2H), 7.61 (d, *J* = 8.6 Hz, 2H), 7.50 (t, *J* = 7.5 Hz, 1H), 7.31 (d, *J* = 16.3 Hz, 1H), 6.96 (d, *J* = 8.7 Hz, 2H), 3.87 (s, 3H).**^{13}C NMR**



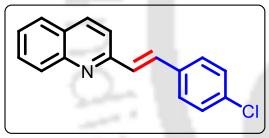
(150 MHz, $CDCl_3$) δ 160.2, 156.5, 148.4, 136.4, 134.2, 129.8, 129.4, 129.2, 128.8, 127.6, 127.3, 126.9, 126.1, 119.3, 114.4, 55.5.

(*E*)-2-(3-phenoxystyryl) quinoline (6.3n):[31] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 69% yield (223 mg, 0.69 mmol) as white solid. 

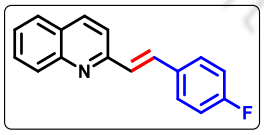
^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.00 (d, *J* = 8.6 Hz, 1H), 7.92 (d, *J* = 8.5 Hz, 1H), 7.66 (d, *J* = 8.1 Hz, 1H),7.61 – 7.58 (m, 1H), 7.54 (d, *J* = 7.5 Hz, 1H), 7.52 (s, 1H), 7.40 – 7.37 (m, 1H), 7.28 – 7.24 (m, 5H), 7.18 (s, 1H), 7.05 – 7.03 (m, 1H), 6.97 – 6.96 (m, 2H), 6.90 – 6.88 (m, 1H).**^{13}C NMR (150 MHz, $CDCl_3$)** δ 157.9, 157.1, 155.8, 148.2, 138.5, 136.6, 134.0, 130.1, 130.0, 129.9, 129.7, 129.2, 127.6, 127.5, 126.4, 123.6, 122.4, 119.4, 119.2, 117.2.

(*E*)-2-(4-methylstyryl) quinoline (6.3o):[32] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 15%) afforded the title compound in 81% yield (198 mg, 0.81 mmol) as white solid. 

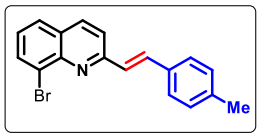
^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.98 – 7.92 (m, 2H), 7.63 – 7.60 (m, 1H), 7.59 – 7.48 (m, 3H), 7.41 (d, *J* = 8.0 Hz, 2H), 7.35 (t, *J* = 7.7 Hz, 1H), 7.25 (d, *J* = 16.3 Hz, 1H), 7.08 (d, *J* = 7.8 Hz, 2H), 2.25 (s, 3H).**^{13}C NMR (150 MHz, $CDCl_3$)** δ 156.2, 148.3, 138.8, 136.3, 134.5, 133.8, 129.7, 129.6, 129.2, 128.1, 127.6, 127.3, 127.3, 126.1, 119.2, 21.4.

(*E*)-2-(4-chlorostyryl) quinoline (6.3p):[33] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 15%) afforded the title compound in 64% yield (170 mg, 0.64 mmol) as white solid. 

^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.98 – 7.95 (m, 2H), 7.65 – 7.63 (m, 1H), 7.60 – 7.57 (m, 1H), 7.52 – 7.46 (m, 2H), 7.43 – 7.40 (m, 2H), 7.39 – 7.36 (m, 1H), 7.25 – 7.21 (m, 3H).**^{13}C NMR (150 MHz, $CDCl_3$)** δ 155.6, 148.3, 136.5, 135.1, 134.4, 133.1, 129.9, 129.5, 129.3, 129.1, 128.5, 127.6, 127.5, 126.4, 119.4.

(*E*)-2-(4-fluorostyryl) quinoline (6.3q): [31] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 10% to 30%) afforded the title compound in 44% yield (109 mg, 0.44 mmol) as yellow oil. 

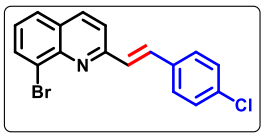
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.13 (d, *J* = 8.5 Hz, 1H), 8.07 (d, *J* = 8.4 Hz, 1H), 7.79 (d, *J* = 8.1 Hz, 1H), 7.72 – 7.69 (m, 1H), 7.67 – 7.64 (m, 2H), 7.63 – 7.60 (m, 2H), 7.51 (t, *J* = 7.5 Hz, 1H), 7.32 (d, *J* = 16.3 Hz, 1H), 7.09 (t, *J* = 8.5 Hz, 2H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 164.1, 155.9, 148.4, 136.6, 133.3, 129.3, 129.1, 129.0, 128.9, 128.8, 127.7, 127.5, 119.4, 116.1, 115.9.

(*E*)-8-bromo-2-(4-methylstyryl) quinoline (6.3r): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 70% yield (226 mg, 0.70 mmol) as brown solid. 

^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.04 (d, *J* = 8.6 Hz, 1H), 8.00 (d, *J* = 8.5 Hz, 1H), 7.70 (d, *J* = 8.1 Hz, 1H), 7.64 – 7.61 (m, 1H), 7.59 – 7.56 (m, 1H),

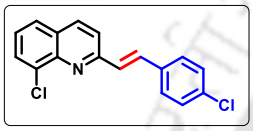
7.46 (d, *J* = 7.9 Hz, 2H), 7.41 (t, *J* = 7.2 Hz, 1H), 7.29 (d, *J* = 16.3 Hz, 1H), 7.13 (d, *J* = 7.8 Hz, 2H), 2.30 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 156.3, 148.3, 138.9, 136.5, 134.7, 133.9, 130.0, 129.9, 129.7, 129.2, 128.1, 127.4, 127.4, 126.2, 119.3, 21.5.HRMS (ESI): Calc'd for **$C_{18}H_{14}BrN$ [M+H]$^+$: 324.0388, Found: 324.0384.**

(*E*)-8-bromo-2-(4-chlorostyryl) quinoline (6.3s):[34] Purification by column chromatography



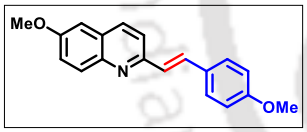
(SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 61% yield (210 mg, 0.61 mmol) as grey solid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.03 (d, *J* = 8.6 Hz, 1H), 8.00 (d, *J* = 8.5 Hz, 1H), 7.69 (d, *J* = 8.1 Hz, 1H), 7.63 (t, *J* = 8.2 Hz, 1H), 7.56 – 7.53 (m, 2H), 7.46 (d, *J* = 8.4 Hz, 2H), 7.42 (t, *J* = 7.8 Hz, 1H), 7.30 – 7.26 (m, 2H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 155.6, 148.2, 136.7, 135.1, 134.4, 133.2, 130.1, 129.5, 129.2, 129.1, 128.5, 127.6, 127.5, 126.5, 119.4.

(*E*)-8-chloro-2-(4-chlorostyryl) quinoline (6.3t):[34] Purification by column chromatography (SiO_2,



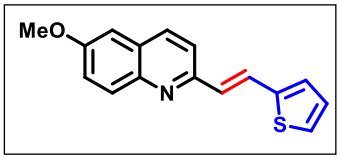
100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 69% yield (207 mg, 0.69 mmol) as white solid.**^{1}H NMR (600 MHz, Chloroform-*d*)** δ 8.03 (d, *J* = 8.6 Hz, 1H), 8.00 (d, *J* = 8.5 Hz, 1H), 7.69 (d, *J* = 8.0 Hz, 1H), 7.63 – 7.61 (m, 1H), 7.56 – 7.53 (m, 2H), 7.46 (d, *J* = 8.4 Hz, 2H), 7.42 – 7.40 (m, 1H), 7.29 – 7.26 (m, 2H).**^{13}C NMR (150 MHz, $CDCl_3$)** δ 155.7, 148.2, 136.6, 135.1, 134.4, 133.2, 129.5, 129.2, 129.1, 128.5, 127.6, 127.5, 126.5, 119.4.

(*E*)-6-methoxy-2-(4-methoxystyryl) quinoline (6.3u): [24] Purification by column chromatography

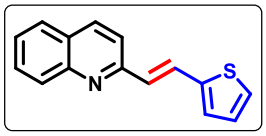


(SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 70% yield (203 mg, 0.70 mmol) as white solid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 7.91 (t, *J* = 8.6 Hz, 2H), 7.53 (d, *J* = 8.5 Hz, 1H), 7.51 – 7.48 (m, 2H), 7.29 – 7.26 (dd, *J* = 9.0 Hz, *J* = 2.8 Hz, 1H), 7.18 (t, *J* = 7.85 Hz, 2H), 6.97 (d, *J* = 2.8 Hz, 1H), 6.85 (d, *J* = 8.6 Hz, 2H), 3.85 (s, 3H), 3.76 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.1, 157.7, 154.1, 144.1, 135.3, 133.2, 130.5, 129.6, 128.6, 128.3, 126.8, 122.4, 119.5, 114.4, 105.5, 55.7, 55.5.

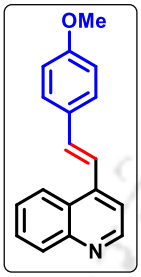
(*E*)-6-methoxy-2-(2-(thiophen-2-yl) vinyl) quinoline (6.3v):[24] Purification by column



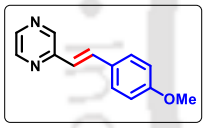
chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 59% yield (157 mg, 0.59 mmol) as yellow solid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.69 – 8.68 (m, 1H), 8.14 – 8.11 (m, 3H), 7.76 (d, *J* = 15.1 Hz, 1H), 7.74 – 7.72 (m, 1H), 7.47 (d, *J* = 7.7 Hz, 1H), 7.30 – 7.27 (m, 1H), 6.98 (d, *J* = 8.8 Hz, 2H), 3.89 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 188.8, 163.8, 153.5, 150.2, 142.1, 137.1, 132.0, 131.2, 130.9, 125.6, 125.5, 124.4, 114.0, 113.8, 67.3, 55.6.

(*E*)-2-(2-(thiophen-2-yl) vinyl) quinoline (6.3w): [24] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 63% yield (149 mg, 0.63 mmol) as yellow solid. 

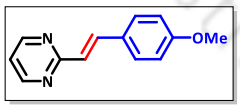
^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.02 (d, *J* = 8.5 Hz, 1H), 7.99 (d, *J* = 8.5 Hz, 1H), 7.77 (d, *J* = 15.3 Hz, 1H), 7.68 (d, *J* = 8.0 Hz, 1H), 7.62 (t, *J* = 8.1 Hz, 1H), 7.50 (d, *J* = 8.5 Hz, 1H), 7.40 (t, *J* = 7.6 Hz, 1H), 7.22 – 7.21 (m, 1H), 7.18 – 7.14 (m, 2H), 6.98 – 6.96 (m, 1H).**^{13}C NMR (150 MHz, $CDCl_3$)** δ 155.7, 148.3, 142.2, 136.6, 130.0, 128.3, 128.2, 128.0, 127.6, 127.6, 127.4, 126.3, 126.2, 119.5.

(*E*)-4-(4-methoxystyryl) quinoline (6.3x): [35] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 56% yield (146 mg, 0.56 mmol) as yellow gummy liquid. 

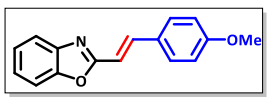
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.81 – 8.80 (m, 1H), 8.15 (d, *J* = 8.4 Hz, 1H), 8.05 (d, *J* = 8.4 Hz, 1H), 7.68 – 7.66 (m, 1H), 7.62 (d, *J* = 16.1 Hz, 1H), 7.53 – 7.50 (m, 4H), 7.24 (d, *J* = 16.0 Hz, 1H), 6.89 (d, *J* = 8.6 Hz, 2H), 3.79 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 160.4, 150.3, 148.8, 143.5, 134.8, 130.2, 129.5, 129.4, 128.7, 126.6, 126.5, 123.6, 120.6, 116.8, 114.5, 55.5.

(*E*)-2-(4-methoxystyryl) pyrazine (6.3y): [36] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 58% yield (123 mg, 0.58 mmol) as yellow liquid. 

^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.54 (s, 1H), 8.45 (brs, 1H), 8.30 – 8.29 (m, 1H), 7.63 (d, *J* = 16.1 Hz, 1H), 7.47 (d, *J* = 8.7 Hz, 2H), 6.95 (d, *J* = 16.1 Hz, 1H), 6.86 (d, *J* = 8.6 Hz, 2H), 3.77 (s, 3H).**^{13}C NMR (150 MHz, $CDCl_3$) δ** 160.5, 151.8, 144.4, 143.6, 142.3, 135.0, 132.3, 128.9, 121.9, 114.4, 55.5.

(*E*)-2-(4-methoxystyryl) pyrimidine (6.3z): [37] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 55% yield (116 mg, 0.55 mmol) as yellow solid. 

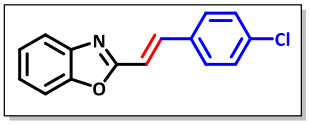
^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.62 (d, *J* = 4.8 Hz, 2H), 7.87 (d, *J* = 16.0 Hz, 1H), 7.50 (d, *J* = 8.6 Hz, 2H), 7.04 (d, *J* = 16.0 Hz, 1H), 6.99 (t, *J* = 6.0 Hz, 1H), 6.85 (d, *J* = 8.6 Hz, 2H), 3.77 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 165.3, 160.7, 157.1, 137.9, 129.3, 128.9, 125.2, 118.3, 114.4, 55.5.

(E)-2-(4-methoxystyryl) benzo[d]oxazoleyield (6.3aa): [38] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 60% yield (150 mg, 0.60 mmol) as yellow solid. 

^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.70 (d, *J* = 16.2 Hz, 1H), 7.67 – 7.65 (m, 1H), 7.50 (d, *J* = 8.5 Hz, 2H), 7.48 – 7.44 (m, 1H), 7.28 – 7.26 (m, 2H), 6.92 – 6.86 (m, 3H), 3.80 (s, 3H).

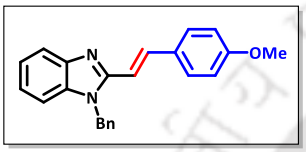
^{13}C NMR (125 MHz, $CDCl_3$) δ 163.4, 161.1, 150.5, 142.4, 139.3, 129.2, 128.1, 125.0, 124.5, 119.8, 114.6, 111.7, 110.3, 55.5.

(*E*)-2-(4-chlorostyryl) benzo [d]oxazole (6.3ab):[39] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 57% yield (145 mg, 0.57 mmol) as white solid.



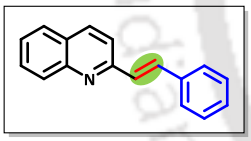
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.57 (s, 1H), 7.77 (d, *J* = 8.4 Hz, 2H), 7.38 (d, *J* = 8.3 Hz, 2H), 7.21 (d, *J* = 7.9 Hz, 1H), 7.13 (t, *J* = 7.7 Hz, 1H), 6.94 (d, *J* = 8.1 Hz, 1H), 6.83 (t, *J* = 7.6 Hz, 1H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 155.7, 152.5, 137.8, 135.3, 134.4, 130.3, 129.4, 129.3, 120.3, 115.9, 115.3.

(*E*)-1-benzyl-2-(4-methoxystyryl)-1H-benzo[d] imidazole (6.3ac): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 53% yield (180 mg, 0.53 mmol) as white solid.



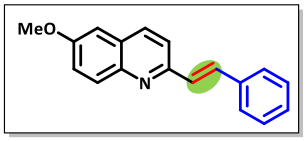
^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.87 (d, *J* = 15.8 Hz, 1H), 7.72 (d, *J* = 7.9 Hz, 1H), 7.39 (d, *J* = 8.7 Hz, 2H), 7.24 – 7.12 (m, 6H), 7.13 (d, *J* = 7.3, 1H), 7.05 (d, *J* = 7.2 Hz, 2H), 6.81 (d, *J* = 8.4 Hz, 3H), 5.37 (s, 2H), 3.74 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 160.6, 151.7, 143.3, 137.5, 136.3, 135.7, 129.2, 128.9, 128.1, 126.4, 122.9, 122.7, 119.4, 114.4, 110.7, 109.6, 55.5, 46.9. HRMS (ESI): Calc'd for **$C_{23}H_{20}N_2O$ [M+H]$^+$: 341.1654, Found: 341.1659.**

(*E*)-2-styrylquinoline (6.3ad):[40] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 64% yield (148 mg, 0.64 mmol) as yellow solid.



^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.07 (d, *J* = 8.5 Hz, 1H), 8.02 (d, *J* = 8.4 Hz, 1H), 7.72 (d, *J* = 8.0 Hz, 1H), 7.65 – 7.62 (m, 2H), 7.61 – 7.60 (m, 1H), 7.58 (d, *J* = 7.3 Hz, 2H), 7.47 – 7.40 (m, 1H), 7.38 – 7.31 (m, 3H), 7.26 (t, *J* = 7.3 Hz, 1H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 156.1, 148.4, 136.7, 136.5, 134.6, 129.9, 129.3, 129.1, 128.9, 128.8, 127.6, 127.5, 127.4, 126.3, 119.4.

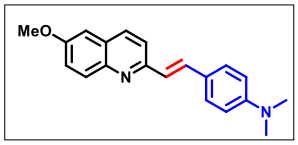
(*E*)-6-methoxy-2-styrylquinoline (6.3ae):[31] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 60% yield (156 mg, 0.60 mmol) as yellow solid.



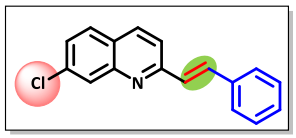
^{1}H NMR (500 MHz, Chloroform-*d*) δ 8.05 (d, *J* = 8.6 Hz, 1H), 8.01 (d, *J* = 9.2 Hz, 1H), 7.72 – 7.58 (m, 4H), 7.47 – 7.37 (m, 4H), 7.34 (t, *J* = 7.3 Hz, 1H), 7.09 – 7.07 (m, 1H), 3.96 (s, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 157.8, 153.9, 144.4, 136.9, 135.3, 133.4, 130.8, 129.2, 128.9, 128.5, 128.5, 127.3, 122.5, 119.7, 105.4, 55.7.

(*E*)-4-(2-(6-methoxyquinolin-2-yl) vinyl)-N, N-dimethylaniline (6.3af):[31] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 73% yield (222 mg, 0.73mmol) as yellow solid.

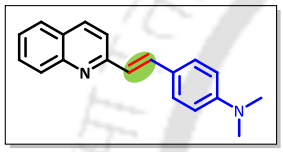
^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.89 (d, *J* = 8.7 Hz, 2H), 7.53 (d, *J* = 8.6 Hz, 1H), 7.48 – 7.44 (m, 3H), 7.27 – 7.25 (m, 1H), 7.12 (d, *J* = 16.2 Hz, 1H), 6.97 – 6.96 (m, 1H), 6.65 (d, *J* = 8.8 Hz, 2H), 3.84 (s, 3H), 2.93 (s, 6H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 157.5, 154.7, 150.9, 144.1, 135.2, 134.1, 130.3, 128.6, 128.1, 125.0, 124.4, 122.2, 119.4, 112.4, 105.6, 55.7, 40.5.



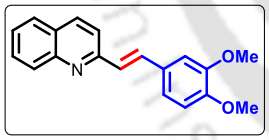
(*E*)-7-chloro-2-styrylquinoline (6.3ag):[31] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 61% yield (162 mg, 0.61 mmol) as white solid. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.10 (d, *J* = 8.6 Hz, 1H), 8.09 – 8.07 (m, 1H), 7.73 (d, *J* = 7.1 Hz, 1H), 7.70 (s, 1H), 7.64 (d, *J* = 8.4 Hz, 3H), 7.46 – 7.37 (m, 4H), 7.36 – 7.32 (m, 1H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 157.1, 148.8, 136.5, 136.3, 135.7, 135.4, 129.0, 128.8, 128.7, 128.4, 127.5, 127.2, 127.0, 125.8, 119.8.



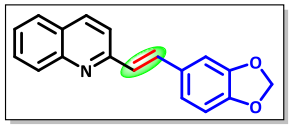
(*E*)-N, N-dimethyl-4-(2-(quinolin-2-yl) vinyl) aniline (6.3ah):[41] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 65% yield (178 mg, 0.65 mmol) as yellow solid. **^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.00- 7.96 (m, 2H), 7.67 (d, *J* = 8.0 Hz, 1H), 7.62 – 7.56 (m, 2H), 7.53 (d, *J* = 16.3 Hz, 1H), 7.47 (d, *J* = 8.5 Hz, 2H), 7.37 (t, *J* = 7.5 Hz, 1H), 7.15 (d, *J* = 16.3 Hz, 1H), 6.66 (d, *J* = 8.5 Hz, 2H), 2.94 (s, 6H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 157.1, 150.9, 148.4, 136.2, 135.0, 129.7, 129.0, 128.7, 127.6, 127.2, 125.7, 124.8, 124.6, 119.1, 112.4, 40.4.



(*E*)-2-(3, 4-dimethoxystyryl) quinoline (6.3ai):[42] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 64% yield (186 mg, 0.64 mmol) as white solid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.10 (d, *J* = 8.5 Hz, 1H), 8.06 (d, *J* = 8.4 Hz, 1H), 7.77 (d, *J* = 8.0 Hz, 1H), 7.71 – 7.66 (m, 2H), 7.60 (d, *J* = 16.3 Hz, 1H), 7.48 (t, *J* = 7.9 Hz, 1H), 7.29 (d, *J* = 16.2 Hz, 1H), 7.23 (s, 1H), 7.16 – 7.15 (m, 1H), 6.88 (d, *J* = 8.2 Hz, 1H), 3.95 (s, 3H), 3.91 (s, 3H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 156.4, 149.9, 149.3, 148.4, 136.4, 134.4, 129.8, 129.7, 129.2, 127.6, 127.3, 127.3, 126.1, 121.4, 119.0, 111.2, 109.0, 56.1, 56.0.

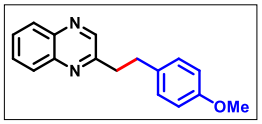


(*E*)-2-(2-(benzo[d][1,3]dioxol-5-yl) vinyl) quinoline (6.3aj):[43] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 63% yield (173 mg, 0.63 mmol) as white solid. **^{1}H NMR (600 MHz, Chloroform-*d*) δ** 8.02 (d, *J* = 8.6 Hz, 1H), 7.99 (d, *J* = 8.5 Hz, 1H), 7.69 (d, *J* = 8.0 Hz, 1H), 7.62 – 7.60 (m, 1H), 7.54 (d, *J* = 8.4 Hz, 1H), 7.52 (d, *J* = 16.2 Hz, 1H), 7.43 – 7.37 (m, 1H), 7.15 (d, *J* = 16.2 Hz, 1H), 7.11 – 7.10 (m, 1H), 7.00 (dd, *J* = 8.0, 1.4 Hz, 1H), 6.75 (d, *J* = 8.0 Hz, 1H), 5.92 (s, 2H).**^{13}C NMR (150 MHz, $CDCl_3$) δ** 156.2, 148.4, 148.4, 148.3, 136.5, 134.3, 131.2, 129.9, 129.2, 127.6, 127.4, 127.3, 126.2, 123.0, 119.3, 108.6, 106.2, 101.4.

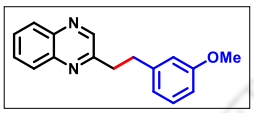


6.13. NMR data of C-alkylated heteroarenes:

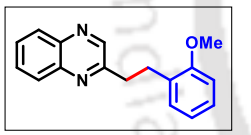
2-(4-methoxyphenethyl) quinoxalines (6.4a):[44] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 87% yield (229 mg, 0.87 mmol) as yellow liquid. **^{1}H NMR (400 MHz, Chloroform-*d*)** δ 8.61 (s, 1H), 8.08 – 7.05 (m, 2H), 7.77 – 7.69 (m, 2H), 7.13 (d, *J* = 8.5 Hz, 2H), 6.81 (d, *J* = 8.6 Hz, 2H), 3.77 (s, 3H), 3.32 – 3.28 (m, 2H), 3.14- 3.10 (m, 2H).**^{13}C NMR (100 MHz, $CDCl_3$)** δ 158.2, 156.7, 146.0, 142.4, 141.4, 132.9, 130.1, 129.5, 129.4, 129.2, 129.0, 114.1, 55.4, 38.5, 34.6.



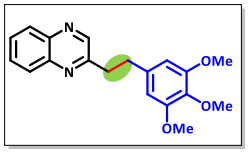
2-(3-methoxyphenethyl) quinoxalines (6.4b):[34] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 79% yield (208 mg, 0.79mmol) as yellow liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.62 (s, 1H), 8.06 (d, *J* = 9.0 Hz, 2H), 7.75 – 7.68 (m, 2H), 7.19 (t, *J* = 7.8 Hz, 1H), 6.81 (d, *J* = 7.6 Hz, 1H), 6.78 – 6.77 (m, 1H), 6.75 – 6.73 (m, 1H), 3.75 (s, 3H), 3.40 – 3.31 (m, 2H), 3.17 – 2.14 (m, 2H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 159.9, 156.5, 145.9, 142.5, 142.4, 141.4, 130.1, 129.6, 129.3, 129.2, 129.0, 121.2, 114.3, 111.8, 55.2, 38.1, 35.3.



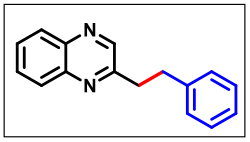
2-(2-methoxyphenethyl) quinoxalines (6.4c)[34] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 68% yield (179 mg, 0.68 mmol) as yellow liquid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.62 (s, 1H), 8.07 – 8.05 (m, 2H), 7.76 – 7.68 (m, 2H), 7.21 – 7.18 (m, 1H), 7.12 – 7.11 (m, 1H), 6.87 – 6.84 (m, 2H), 3.76 (s, 3H), 3.32 – 3.29 (m, 2H), 3.18 – 3.15 (m, 2H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 157.6, 157.3, 146.2, 142.4, 141.3, 130.2, 129.9, 129.3, 129.2, 129.1, 129.0, 127.8, 120.6, 110.4, 55.3, 36.7, 30.4.



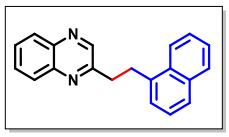
2-(3, 4, 5-trimethoxyphenethyl) quinoxalines (6.4d): Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 82% yield (266 mg, 0.82 mmol) as yellow liquid.**^{1}H NMR (600 MHz, Chloroform-*d*) δ** 8.70 (s, 1H), 8.09 (t, *J* = 8.2 Hz, 2H), 7.83 – 7.69 (m, 2H), 6.46 (s, 2H), 3.83 (s, 3H), 3.81 (s, 6H), 3.38 – 3.31 (m, 2H), 3.20 – 3.09 (m, 2H).**^{13}C NMR (150 MHz, $CDCl_3$) δ** 156.4, 153.3, 145.9, 142.3, 141.4, 136.6, 136.5, 130.2, 129.3, 129.3, 128.9, 105.5, 61.0, 56.1, 38.3, 35.8. **HRMS (ESI): Calc'd** for **$C_{19}H_{20}N_2O_3$ [M+H]$^+$: 325.1552, Found: 325.153.**



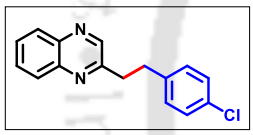
2-phenethylquinoxaline (6.4e):[45] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 81% yield (189 mg, 0.81mmol) as yellow liquid. **^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.62 (s, 1H), 8.07 (d, *J* = 9.0 Hz, 2H), 7.76 – 7.65 (m, 2H), 7.29 – 7.25 (m, 2H), 7.23 – 7.18 (m, 3H), 3.35 - 3.32 (m, 2H), 3.20 – 3.17 (m, 2H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 156.6, 145.9, 142.4, 141.5, 140.9, 130.1, 129.4, 129.2, 129.1, 128.7, 128.6, 126.4, 38.2, 35.4.



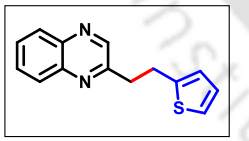
2-(2-(naphthalen-1-yl) ethyl) quinoxalines (6.4f):[45] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 84% yield (239 mg, 0.84 mmol) as brown solid.**^{1}H NMR (600 MHz, Chloroform-*d*) δ** 8.69 (s, 1H), 8.11 (t, *J* = 8.6 Hz, 2H), 7.84 – 7.73 (m, 5H), 7.70 (s, 1H), 7.46 (m, 2H), 7.41 (dd, *J* = 8.4, 1.6 Hz, 1H), 3.48 – 3.44 (m, 2H), 3.41 – 3.36 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 156.5, 145.9, 142.4, 141.5, 138.4, 133.8, 132.3, 130.2, 129.4, 129.3, 129.0, 128.3, 127.8, 127.6, 127.2, 126.8, 126.2, 125.5, 38.2, 35.5.



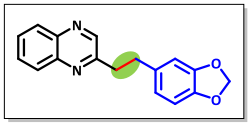
2-(4-chlorophenethyl) quinoxalines (6.4g):[45] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 73% yield (195 mg, 0.73 mmol) as brown liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.61 (s, 1H), 8.08- 8.04 (m, 2H), 7.77 – 7.70 (m, 2H), 7.25 – 7.23 (m, 2H), 7.14 (d, *J* = 8.2 Hz, 2H), 3.32 – 3.29 (m, 2H), 3.18 – 3.15 (m, 2H). **^{13}C NMR (125 MHz, $CDCl_3$)** δ 156.1, 145.8, 142.4, 141.5, 139.4, 132.2, 130.2, 130.0, 129.4, 129.3, 129.0, 128.8, 37.9, 34.6.



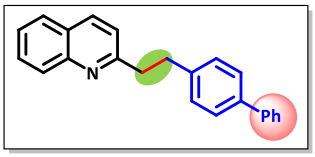
2-(2-(thiophen-2-yl) ethyl) quinoxalines (6.4h):[46] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 64% yield (153 mg, 0.64 mmol) as yellow liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.65 (s, 1H), 8.08 – 8.05 (m, 2H), 7.77 – 7.70 (m, 2H), 7.12 – 7.10 (m, 1H), 6.90 – 6.88 (m, 1H), 6.81 – 6.80 (m, 1H), 3.45 – 3.42 (m, 2H), 3.40 – 3.36 (m, 2H). **^{13}C NMR (150 MHz, CDCl3) δ** 155.9, 145.9, 143.5, 142.4, 141.5, 130.2, 129.4, 129.3, 129.1, 127.0, 125.0, 123.7, 38.3, 29.2.



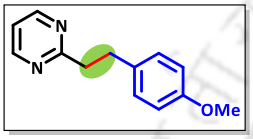
2-(2-(benzo[d][1,3]dioxol-5-yl) ethyl) quinoxalines (6.4i):[46] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 67% yield (186 mg, 0.67 mmol) as brown oil.**^{1}H NMR (600 MHz, Chloroform-*d*) δ** 8.52 (s, 1H), 8.01 – 7.90 (m, 2H), 7.68 – 7.63 (m, 1H), 7.63 – 7.58 (m, 1H), 6.65 – 6.59 (m, 2H), 6.54 (d, *J* = 7.9 Hz, 1H), 5.81 (s, 2H), 3.22 – 3.15 (m, 2H), 3.03 – 2.98 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$) δ** 156.4, 147.7, 146.0, 145.9, 142.3, 141.3, 134.6, 130.0, 129.3, 129.1, 128.9, 121.4, 109.0, 108.3, 100.9, 38.4, 35.1.



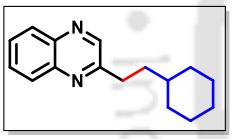
2-(2-([1,1'-biphenyl]-4-yl)ethyl)quinoline (6.4j):[47] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 71% yield (219 mg, 0.71 mmol) as white solid.**^{1}H NMR (400 MHz, Chloroform-*d*) δ** 8.01 (d, *J* = 8.5 Hz, 1H), 7.97 (d, *J* = 8.4 Hz, 1H), 7.70 (d, *J* = 8.0 Hz, 1H), 7.63 (t, *J* = 7.7 Hz, 1H), 7.50 (d, *J* = 7.2 Hz, 2H), 7.45 – 7.42 (m, 3H), 7.35 (t, *J* = 7.4 Hz, 2H), 7.27 – 7.22 (m, 3H), 7.18 (d, *J* = 8.3 Hz, 1H), 3.27 – 3.24 (m, 2H), 3.15 – 3.11 (m, 2H). **^{13}C NMR (125 MHz, $CDCl_3$) δ** 161.9, 148.1, 141.2, 140.8, 139.1, 136.4, 129.6, 129.1, 129.0, 128.8, 127.7, 127.3, 127.2, 127.1, 127.0, 126.0, 121.7, 41.0, 35.7.



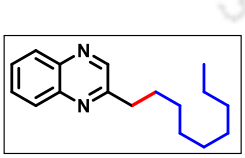
2-(4-methoxyphenethyl) pyrimidine (6.4k)[48] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 53% yield (113 mg, 0.53 mmol) as yellow solid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.60 (d, *J* = 4.9 Hz, 2H), 7.08 (d, *J* = 8.4 Hz, 2H), 7.06 – 7.04 (m, 1H), 6.74 (d, *J* = 8.4 Hz, 2H), 3.70 (s, 3H), 3.23 – 3.14 (m, 2H), 3.08 – 2.94 (m, 2H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 170.8, 158.0, 157.1, 133.5, 129.4, 118.7, 113.9, 55.4, 41.6, 33.9.



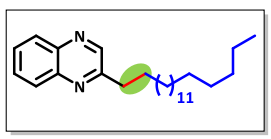
2-(2-cyclohexylethyl) quinoxalines (6.4l):[45] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 61% yield (146 mg, 0.61 mmol) as pink liquid. **^{1}H NMR (400 MHz, Chloroform-*d*) δ** 8.64 (s, 1H), 8.03 – 7.87 (m, 2H), 7.68 – 7.54 (m, 2H), 3.04 – 2.78 (m, 2H), 1.74 –1.71 (m, 2H), 1.69 – 1.61 (m, 4H), 1.62 – 1.50 (m, 1H), 1.26 (m, 1H), 1.19 – 1.02 (m, 3H), 0.96 – 0.78 (m, 2H).**^{13}C NMR (150 MHz, $CDCl_3$) δ** 158.1, 145.91, 142.3, 141.2, 129.9, 129.2, 128.9, 37.7, 37.2, 34.1, 33.3, 26.7, 26.4.



2-nonylquinoxaline (6.4m):[34] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 39% yield (99 mg, 0.39 mmol) as pink liquid.**^{1}H NMR (500 MHz, Chloroform-*d*)** δ 8.73 (s, 1H), 8.08 – 8.02 (m, 2H), 7.75 – 7.68 (m, 2H), 3.01 (t, *J* = 7.8 Hz, 2H), 1.88 – 1.81 (m, 2H), 1.45 – 1.41 (m, 2H), 1.37 – 1.34 (m, 2H), 1.29 – 1.25 (m, 8H), 0.87 (t, *J* = 6.6 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$)** δ 157.9, 146.0, 142.4, 141.4, 130.1, 129.3, 129.0, 129.0, 36.7, 32.0, 29.7, 29.6, 29.6, 29.6, 29.4, 22.8, 14.2.

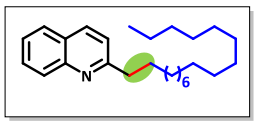


2-heptadecylquinoxaline (6.4n):[48] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 48% yield (177 mg, 0.48 mmol) as pink solid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 8.66 (s, 1H), 7.99 (d, *J* = 8.1 Hz, 1H), 7.96 (d, *J* = 8.2 Hz, 1H), 7.66 – 7.59 (m, 2H), 2.93 (t, *J* = 7.8 Hz, 2H), 1.76 (p, *J* = 7.7 Hz,



2H), 1.37 – 1.31 (m, 2H), 1.28 – 1.26 (m, 2H), 2.22 – 1.17 (m, 25H), 0.79 (t, *J* = 6.7 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 157.8, 145.9, 142.3, 141.3, 130.0, 129.3, 129.0, 128.9, 36.6, 32.0, 29.1, 29.8, 29.8, 29.7, 29.7, 29.7, 29.6, 29.6, 29.5, 29.5, 22.8, 14.2.

2-heptadecylquinoline (6.4o):[46] Purification by column chromatography (SiO_2, 100–200 mesh, eluent: AcOEt/ petroleum ether 5% to 20%) afforded the title compound in 51% yield (150 mg, 0.51 mmol) as white solid.**^{1}H NMR (500 MHz, Chloroform-*d*) δ** 7.97 (d, *J* = 8.4 Hz, 2H), 7.68 (d, *J* = 8.1 Hz, 1H), 7.59 (t, *J* = 7.6 Hz, 1H), 7.39 (t, *J* = 7.5 Hz, 1H), 7.21 (d, *J* = 8.4 Hz, 1H), 2.98 (t, *J* = 7.9 Hz, 2H), 1.72 (q, *J* = 7.7 Hz, 2H), 1.36 – 1.30 (m, 3H), 1.26 – 0.1.17 (m, 25H), 0.80 (t, *J* = 6.8 Hz, 3H).**^{13}C NMR (125 MHz, $CDCl_3$) δ** 163.3, 148.1, 136.3, 129.4, 129.0, 127.6, 126.9, 125.7, 121.5, 39.5, 32.1, 30.2, 29.8, 29.8, 29.8, 29.8, 29.7, 29.7, 29.7, 29.5, 22.8, 14.2.



6.12. References:

[1] G. Diaz, I. L. Miranda and M. A. N. Diaz, Phytochemicals-Isolation, Characterization and Role in Human Health, InTech, **2015**.

[2] H.-J. Arpe, IndustrielleOrganischeChemie, 6th ed., Wiley-VCH, Weinheim, **2007**.

[3] J. H. Burroughes, D. D. C. Bradley, A. R. Brown, R. N. Marks, K. Mackay, R. H. Friend, P. L. Burns, A. B. Holmes, *Nature* **1990**, *347*, 539 – 541.

[4] a) K. Hagiwara, N. Kosaka, Y. Yoshioka, R.-u. Takahashi, F. Takeshita, T. Ochiya, *Sci. Rep.* **2012**, *2*, 314; b) J. Dai, Z.-Q. Liu, X.-Q. Wang, J. Lin, P.-F. Yao, S.-L. Huang, T.-M. Ou, J.-H. Tan, D. Li, L.-Q. Gu, Z.-S. Huang, *J. Med. Chem*. **2015**, *58*, 3875.

[5] a) R. Dumeunier, I. E. Markl in Modern Carbonyl Olefination: Methods and Applications (Ed.: T. Takeda), Wiley-VCH, Weinheim, **2004**; b) J. Clayden, S. Warren, *Angew. Chem. Int. Ed*. Engl. **1996**, *35*, 241; *Angew. Chem*. **1996**, *108*, 261.

[6] Handbook of Metathesis, Vol. 1, 2, 3 (Ed.: R. H. Grubbs), Wiley-VCH, Weinheim, **2003**.

[7] B. M. Trost, *Science*, **1991**, *254*, 147.

[8] B. G. Reed-Berendt, D. E. Latham, M. B. Dambatta, L. C. Morrill, *ACS Cent. Sci*. **2021**, *7*, 570–585.

[9] B. Blank, R. Kempe, *J. Am. Chem. Soc*. **2010**, *132*, 924.

[10] a) J. Org. Chem. 2012, 77, 9429; b) Y. Obora, S. Ogawa, N. Yamamoto, *J. Org. Chem*. **2012**, *77*, 9429–9433; c) Y. Nakamura, A. Azuma, S. Kato, Y. Oe, T. Ohta, *Chem. Lett.* **2019**, *48*, 1192–1200; d) M. Onoda, K.-I. Fujita, *Org. Lett*. **2020**, *22*, 7295–7299.

[11] a) J. Rana, R. Babu, M. Subaramanian, E. Balaraman, *Org. Chem. Front.* **2018**, *5*, 3250–3255; b) M. Vellakkaran, J. Das, S. Bera, D. Banerjee, *Chem. Commun*. **2018**, *54*, 12369–12372; c) J. Das, M. Vellakkaran, D. Banerjee, *Chem. Commun*. **2019**, *55*, 7530–7533; d) L. M. Kabadwal, S. Bera, D. Banerjee, *Chem. Commun*. **2020**, *56*, 4777–4780; e) J. Das, M. Vellakkaran, M. Sk, D.

Banerjee, *Org. Lett*. **2019**, *21*, 7514–7518; f) A. Mishra, A. D. Dwivedi, S. Shee, S. Kundu, *Chem. Commun*. **2020**, 56, 249–252.

[12] M. K. Barman, S. Waiba, B. Maji, *Angew. Chem., Int. Ed*. **2018**, 57, 9126–9130.

[13] G. Zhang, T. Irrgang, T. Dietel, F. Kallmeier, R. Kempe, *Angew. Chem., Int. Ed*. **2018**, *57*, 9131–9135.

[14] A. Jana, A, Kumar, B. Maji, *Chem. Commun.* **2021**, *57*, 3026–3029.

[15] P. T. Anastas and J. C. Warner, Green Chemistry: Theory and Practice, Oxford University Press, New York, **1998**.

[16] a) M. A Lipkowitz, T. Navarra, The Encyclopedia of Allergies, 2nd ed., Facts on File, New York, **2001**, p. 178; b) S. Achelle, A. Barsella, C. Baudequin, B. Caro, F. R.-l. Guen, *J. Org. Chem*. **2012**, *77*, 4087−4096.

[17] S. G. Davies, A. M. Fletcher, I. T. T. Houlsby, P. M. Roberts, J. E. Thomson, D. Zimmer, *J. Nat. Prod.* **2018**, *81*, 2731–2742.

[18] J. R. Carney, B. R. Dillon, L. Campbell, S. P. Thomas, *Angew. Chem. Int. Ed*. **2018**, *57*, 10620–10624; *Angew.Chem*. **2018**, *130*, 10780–10784.

[19] a) V. Yadav, E. Balaraman, S. B. Mhaske, *Adv. Synth. Catal.* **2021**, *363*, 4430–4439; b) 4 J. Rana, P. Nagarasu, M. Subaramanian, A. Mondal, V. Madhu, E. Balaraman, *Organometallics* **2021**, *40*, 627–634.

[20] S. A. Stoian, Yi-Ru Peng, C. C. Beedle, Y.-J. Chung, G.-H. Lee, E.-C. Yang, S. Hil, *Inorg. Chem*. **2017**, *56*, 10861−10874.

[21] S. Hazra, V. Tiwari, A. Verma, P. Dolui, A. J. Elias, *Org. Lett*. **2020,** *22*, 5496−5501.

[22] D. J. Dahatonde, A. Ghosh, S. Bar*ta, Eur. J. Org. Chem.* **2021,** 2746–2751.

[23] S. A. Stoian, Yi-Ru Peng, C. C. Beedle, Y.-J. Chung, G.-H. Lee, E.-C. Yang, S. Hil, *Inorg. Chem*. **2017**, *56*, 10861−10874.

[24] S. Hazra, V. Tiwari, A. Verma, P. Dolui, A. J. Elias, *Org. Lett*. **2020,** *22*, 5496−5501.

[25] D. J. Dahatonde, A. Ghosh, S. Bar*ta, Eur. J. Org. Chem.* **2021,** 2746–2751.

[26] S. Achelle, A. Barsella, C. Baudequin, B. Caro, F. R.-l. Guen, *J. Org. Chem***. 2012,** *77*, 4087−4096.

[27] W. Tang, L. Xu, Q.-H. Fan, J. Wang, B. Fan, Z. Zhou, K.-h. Lam, A. S. C. Chan, *Angew. Chem. Int. Ed.* **2009**, *48*, 9135 –9138.

[28] B. M. Ramalingam, I. Ramakrishna, M. Baidya, *J. Org. Chem.* **2019,** *84*, 9819−9825.

[29] G. Balamurugan, R. Ramesh, *Chem Cat Chem*. **2022,** *14*, e202101455.

[30] M. S. F. Franco, M. H. d. Paula, P. C. Glowacka, F. Fumagalli, G. C. Clososki, F. d. S. Emery, *Tetrahedron Letters* **2018**, *59*, 2562–2566.

[31] M. K. Barman, S. Waiba, B. Maji, *Angew. Chem. Int. Ed.* **2018**, *57*, 9126 –9130.

[32] Q. Li, J.-S. Lee, C. Ha, C. B. Park, G. Yang, W. B. Gan, Y.-T. Chang, *Angew. Chem. Int. Ed.* **2004**, *43*, 6331 –6335.

[33] G. Zhang, T. Irrgang, T. Dietel, F. Kallmeier, R. Kempe, *Angew. Chem. Int. Ed.* **2018**, *57*, 9131 –9135.

[34] X, Qing; L. Shuangyan, C. Jianhui, Y. Xueqin, Z. Zhengping, China, CN104529889 A **2015**-04-22.

[35] Z. I. M. Allaoui, E. Gall, A. Fihey, R. P.-Pedroche, C. Katan, F. Å. R.-le Guen, J. R.-López, S. Achelle, *Chem. Eur. J.* **2020,** *26*, 8153 –8161.

[36] R. G.-Doria, S. Achelle, C. Bruneau, F. R.-le Guen, V. Dorcet, T. Roisnel, *J. Org. Chem*. **2018,** *83*,1462−1477.

[37] R. M.-Centelles, J. Murga, E. Falomir, M. Carda, J. A. Marco, *Med. Chem. Commun*. **2015**, *6*, 1809–1815.

[38] M. Jacubert, O. Provot, J.-F. Peyrat, A. Hamze, J.-D. Brion, M. Alami**,** *Tetrahedron* **2010**, *66*, 3775–3787.

[39] X. Chang, Y. Yang, C. Shen, K.-S. Xue, Z.-F. Wang, H. Cong, H.-Y. Tao, L. W. Chung, C.-J. Wang, *J. Am. Chem. Soc*. **2021,** *143*, 3519−3535.

[40] H. T. Dang, T. N. Lieu, T. Truong, N. T.S. Phan, *J. Mol. Catal. A, Chem* **2016**, *420*, 237–245.

[41] P. R. Thorve, B. Maji, *Org. Lett.* **2021,** *23*, 542−547.

[42] J. Das, M. Vellakkaran, D. Banerjee, *Chem. Commun.* **2019**, *55*, 7530-7533.

[43] A. Mishra, A. D. Dwivedi, S. Shee, S. Kundu, *Chem. Commun*. **2020**, *56*, 249-252.

[44] E. Balaraman, J. Rana, M. Subaramanian, IN201811040236 A *2020*-08-14.

[45] L. M. Kabadwal, S. Bera, D. Banerjee, *Chem. Commun*. **2020**, *56*, 4777-4780.

[46] A. Jana, A. Kumar, B. Maji, *Chem. Commun*. **2021**, *57*, 3026–3029.

[47] S. K. Bera, R. Bhanja, P. Mal, *Beilstein J. Org. Chem.* **2022**,*18*, 639–646.

[48] Y. Z.Y. Hu, X.-C. Li, L. Wu, X.-X. Guo, *Org. Lett.* **2022**, *24*, 8392−8396.

6.13. Selected ^{1}H &^{13}C NMR spectra of the compounds:

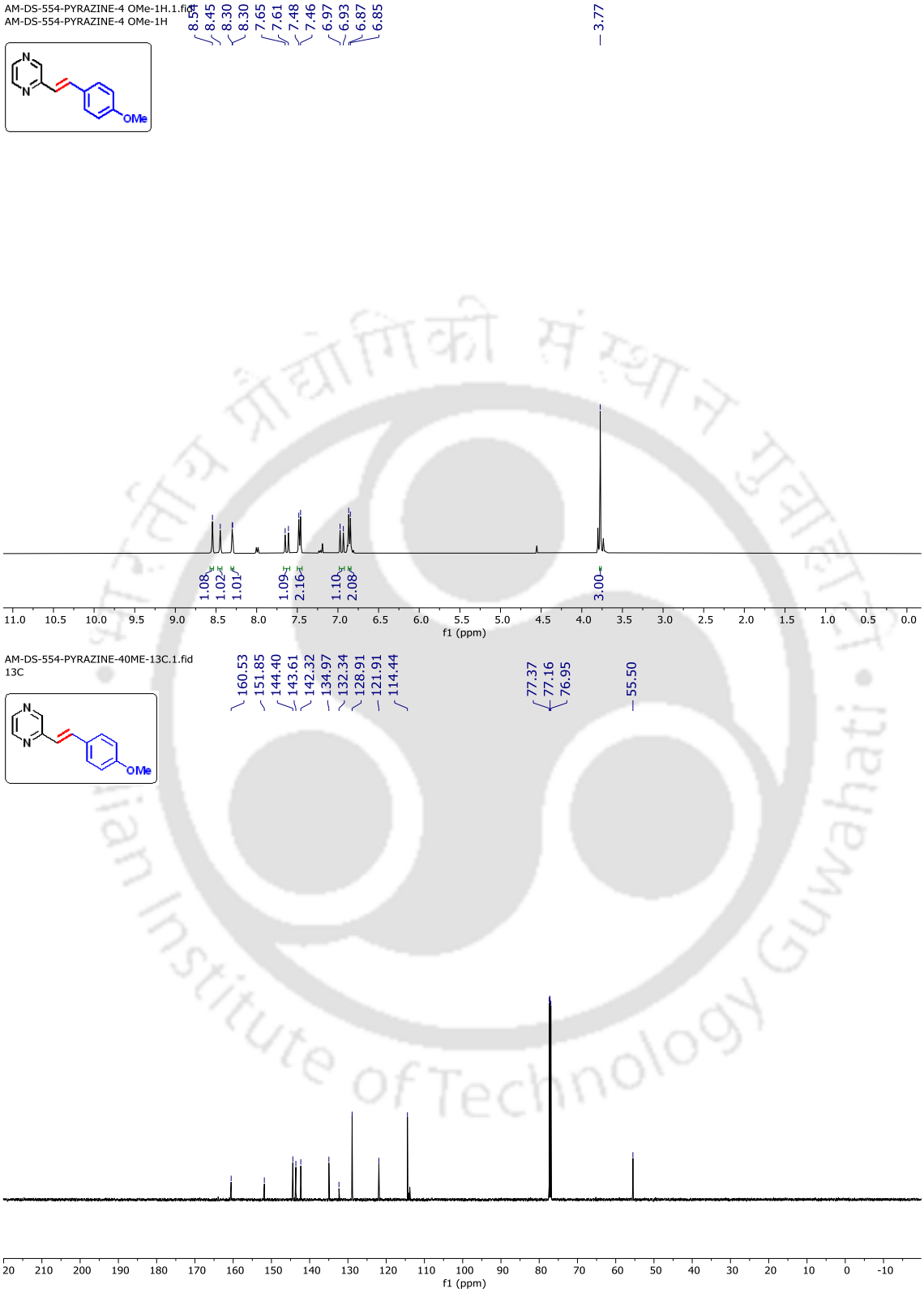


Figure 6.7.^{1}H (400 MHz) and ^{13}C {^{1}H} (150 MHz) NMR Spectrum **(E)-2-(4-methoxystyryl) pyrazine (6.3y)** in $CDCl_3$.

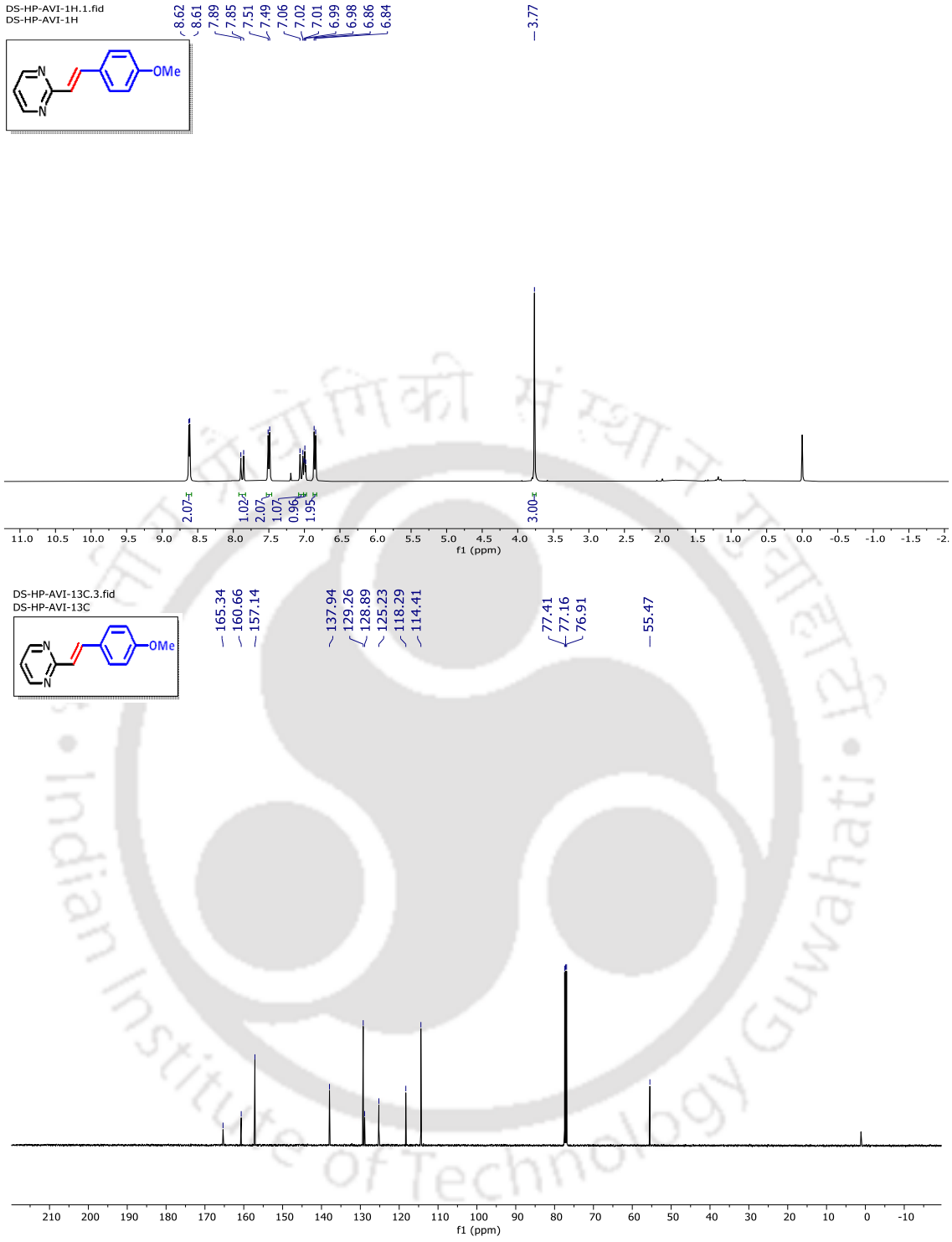


Figure 6.8. ^{1}H (400 MHz) and ^{13}C $\{^{1}H\}$ (125 MHz) NMR Spectrum **(E)-2-(4-methoxystyryl) pyrimidine (6.3z)** in $CDCl_3$.

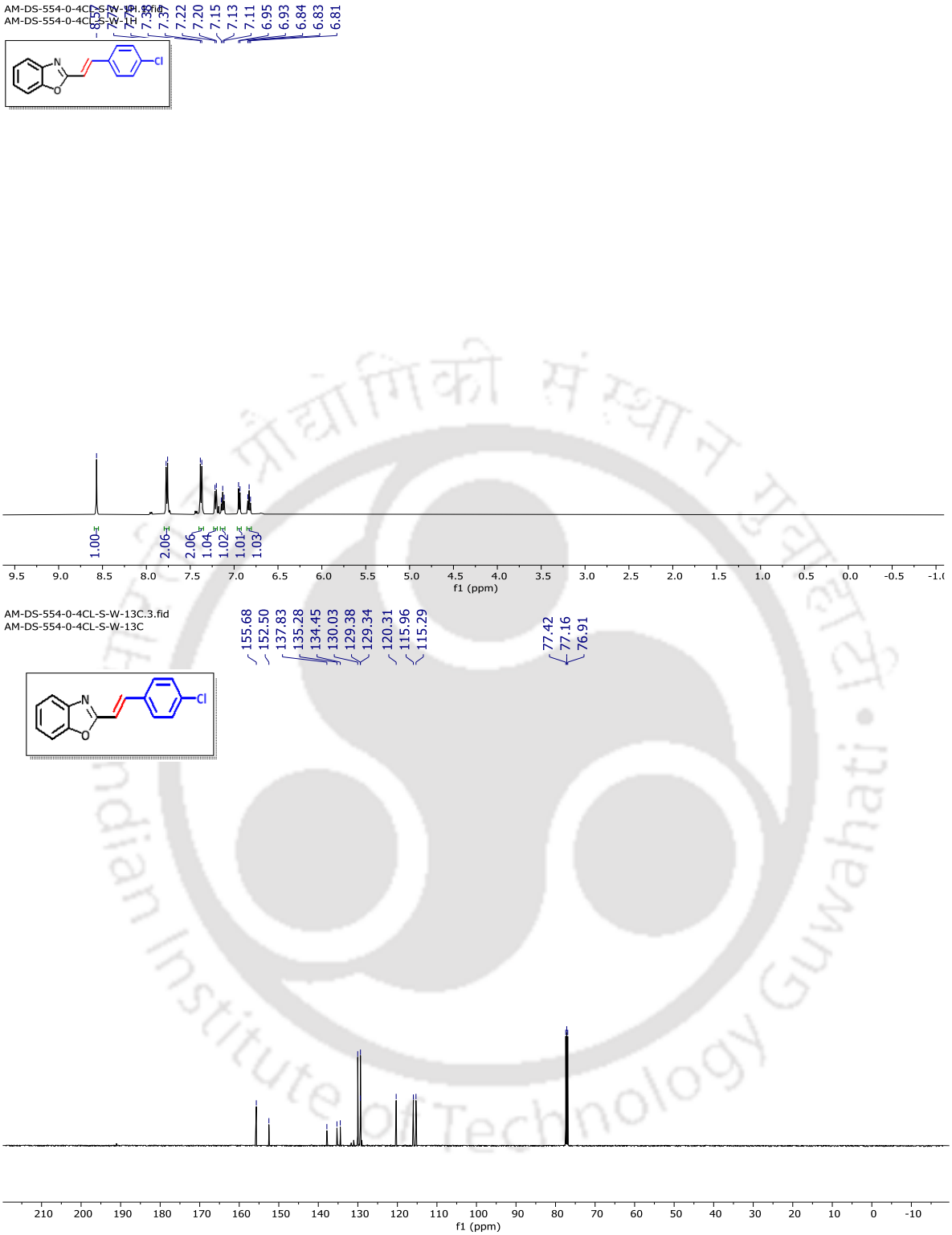


Figure 6.9. ^{1}H (500 MHz) and ^{13}C {^{1}H} (125 MHz) NMR Spectrum **(E)-2-(4-chlorostyryl) benzo[d] oxazole (6.3ab)** in $CDCl_3$.

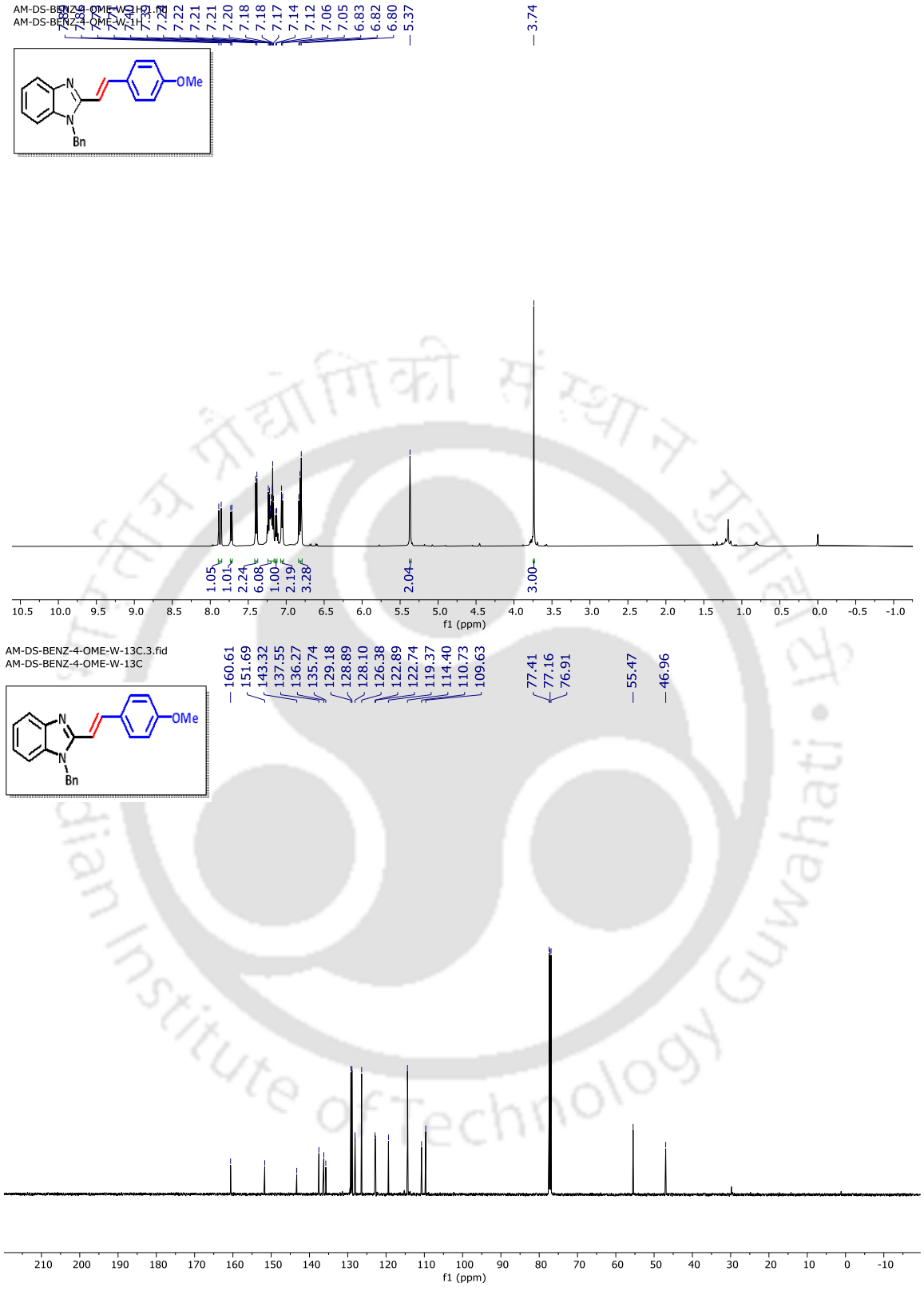


Figure 6.10. ^{1}H (500 MHz) and ^{13}C {^{1}H} (125 MHz) NMR Spectrum **(E)-1-benzyl-2-(4-methoxystyryl)-1H-benzo[d]imidazole (6.3ac)** in $CDCl_3$.

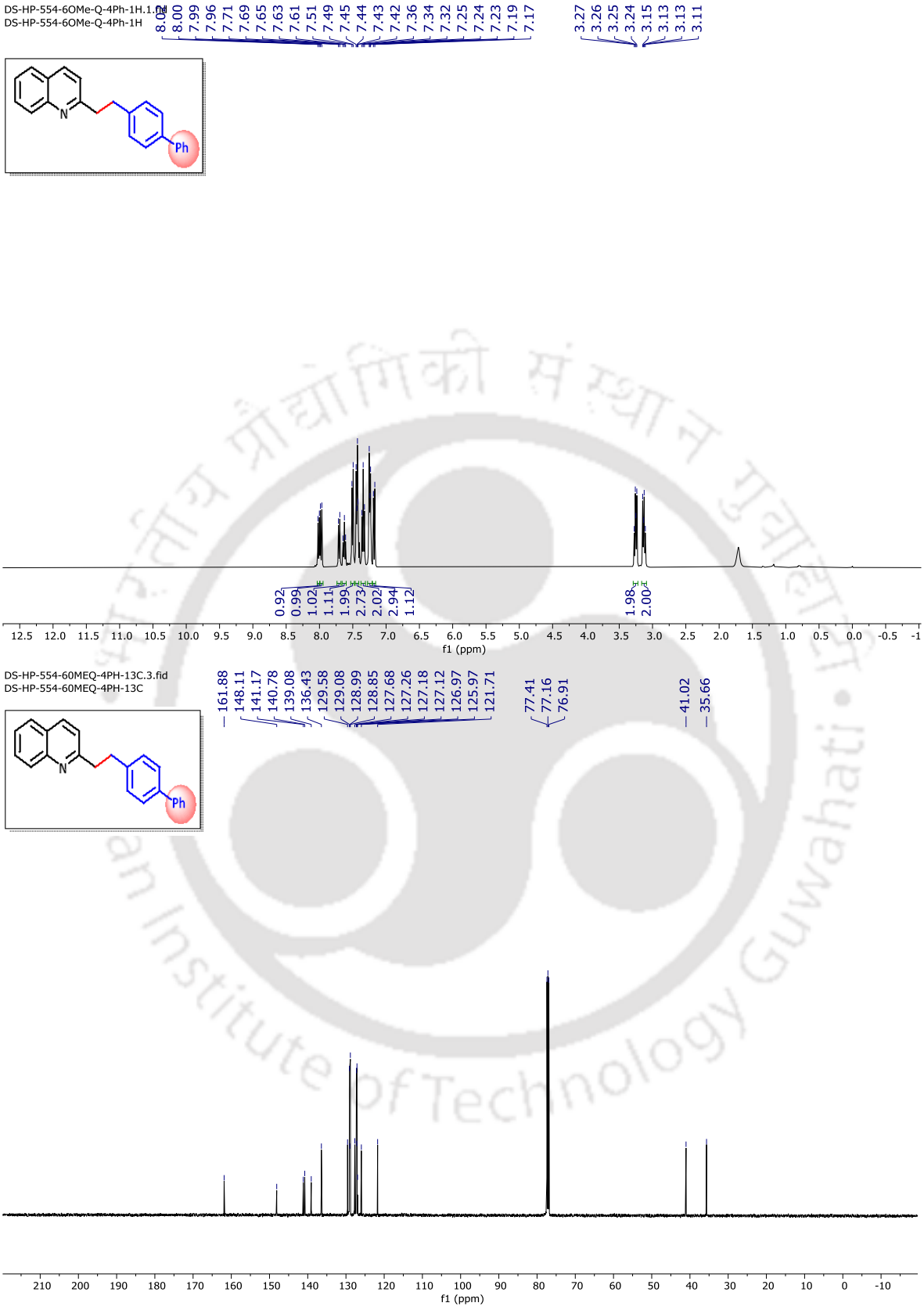


Figure 6.11. ^{1}H (400 MHz) and ^{13}C {^{1}H} (125 MHz) NMR Spectrum **2-(2-([1,1'-biphenyl]-4-yl)ethyl) quinoline (6.4j)** in $CDCl_3$.

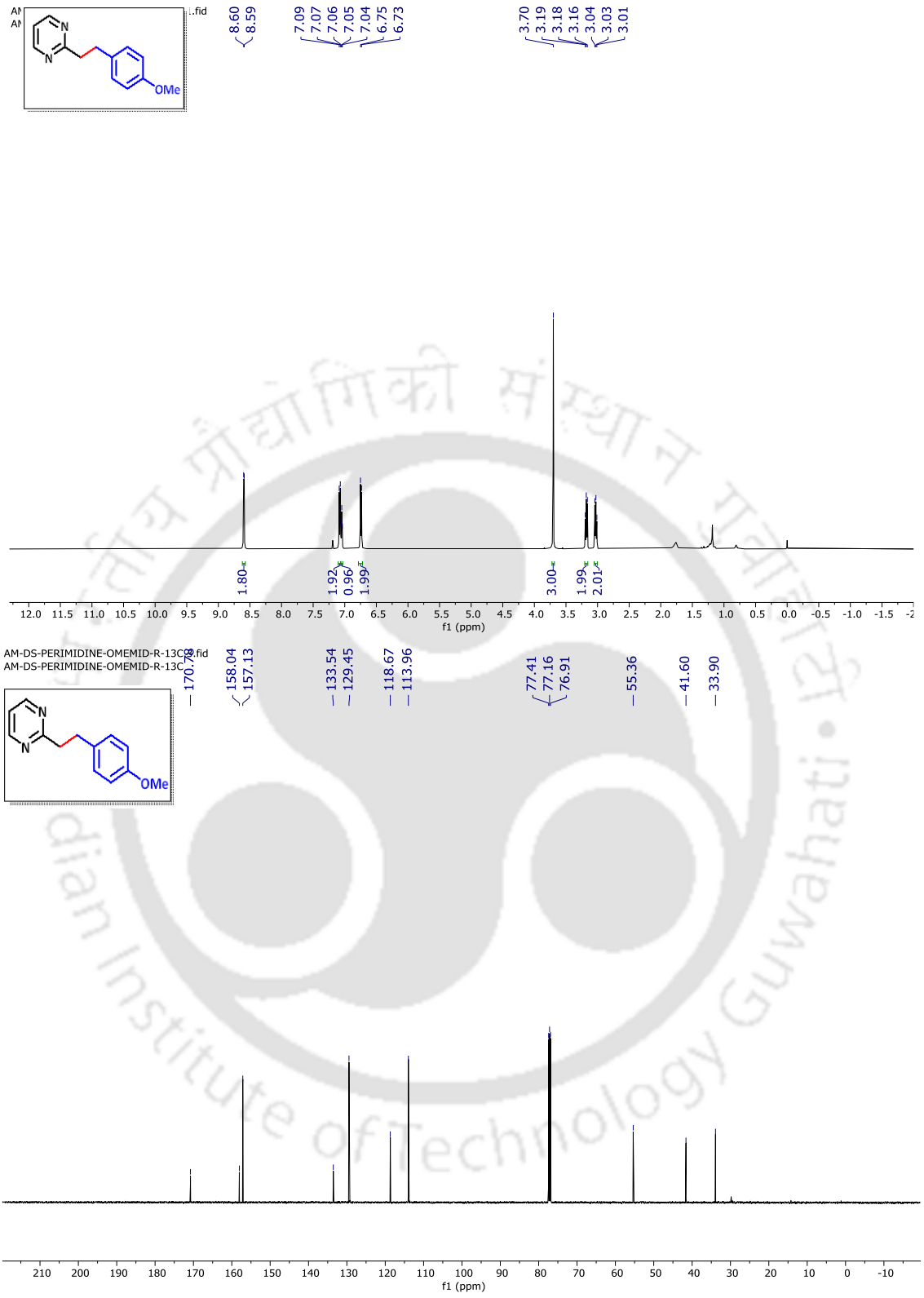


Figure 6.12. ^{1}H (500 MHz) and ^{13}C {^{1}H} (125 MHz) NMR Spectrum **2-(4-methoxyphenethyl) pyrimidine (6.4k)** in $CDCl_3$.

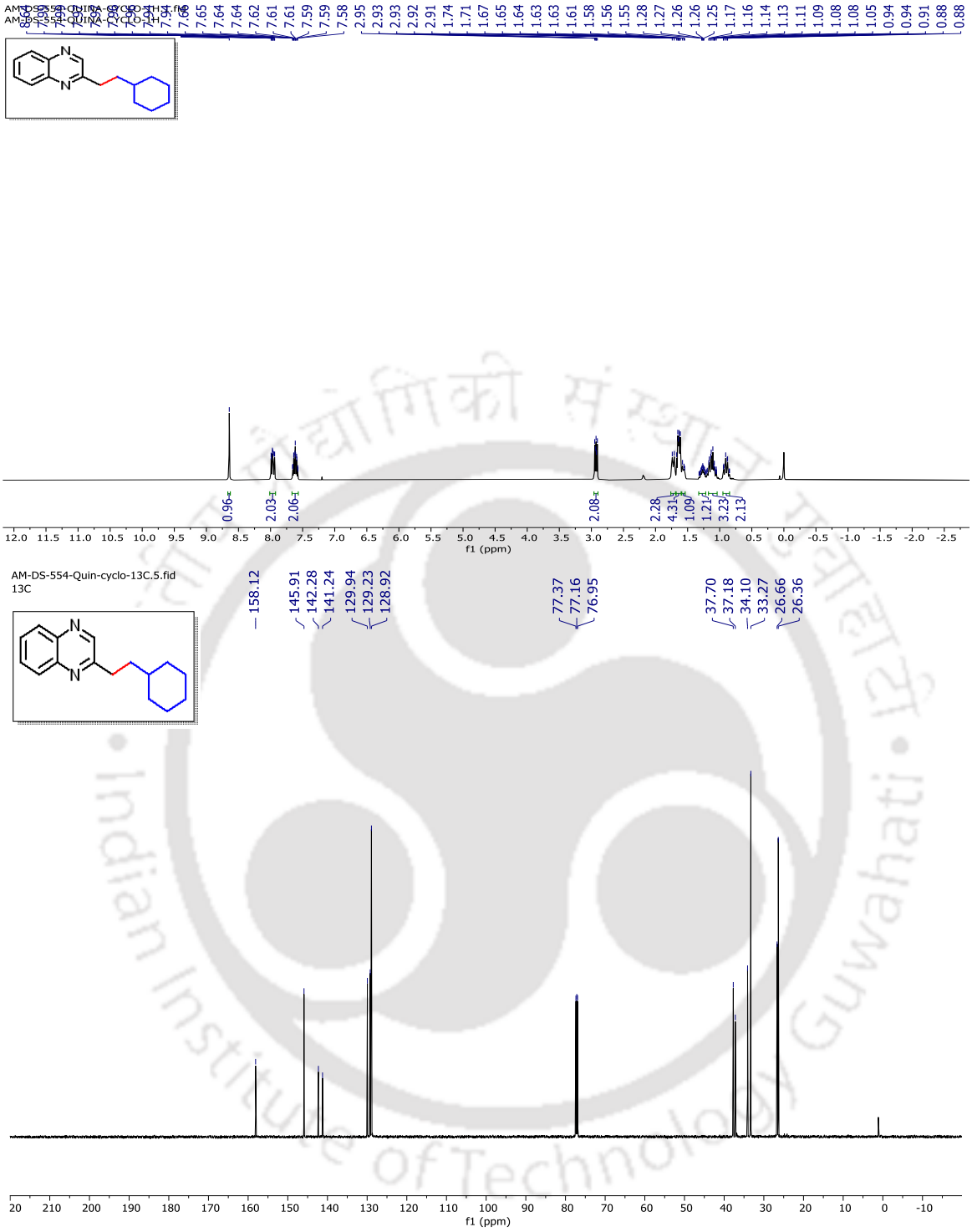


Figure 6.13. ^{1}H (500 MHz) and ^{13}C $\{^{1}H\}$ (125 MHz) NMR Spectrum **2-(2-cyclohexylethyl) quinoxalines pyrimidine (6.4k)** in $CDCl_3$

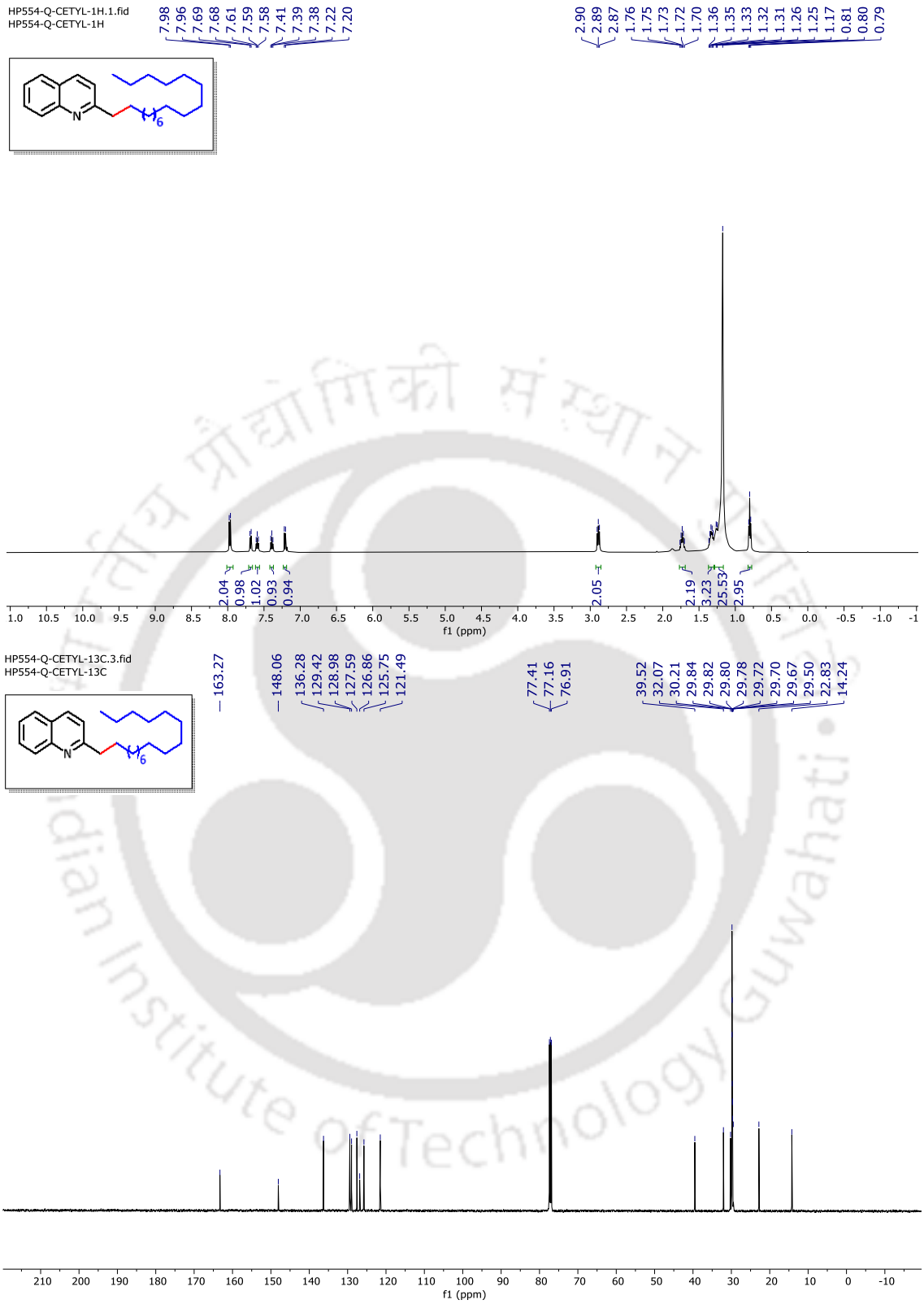
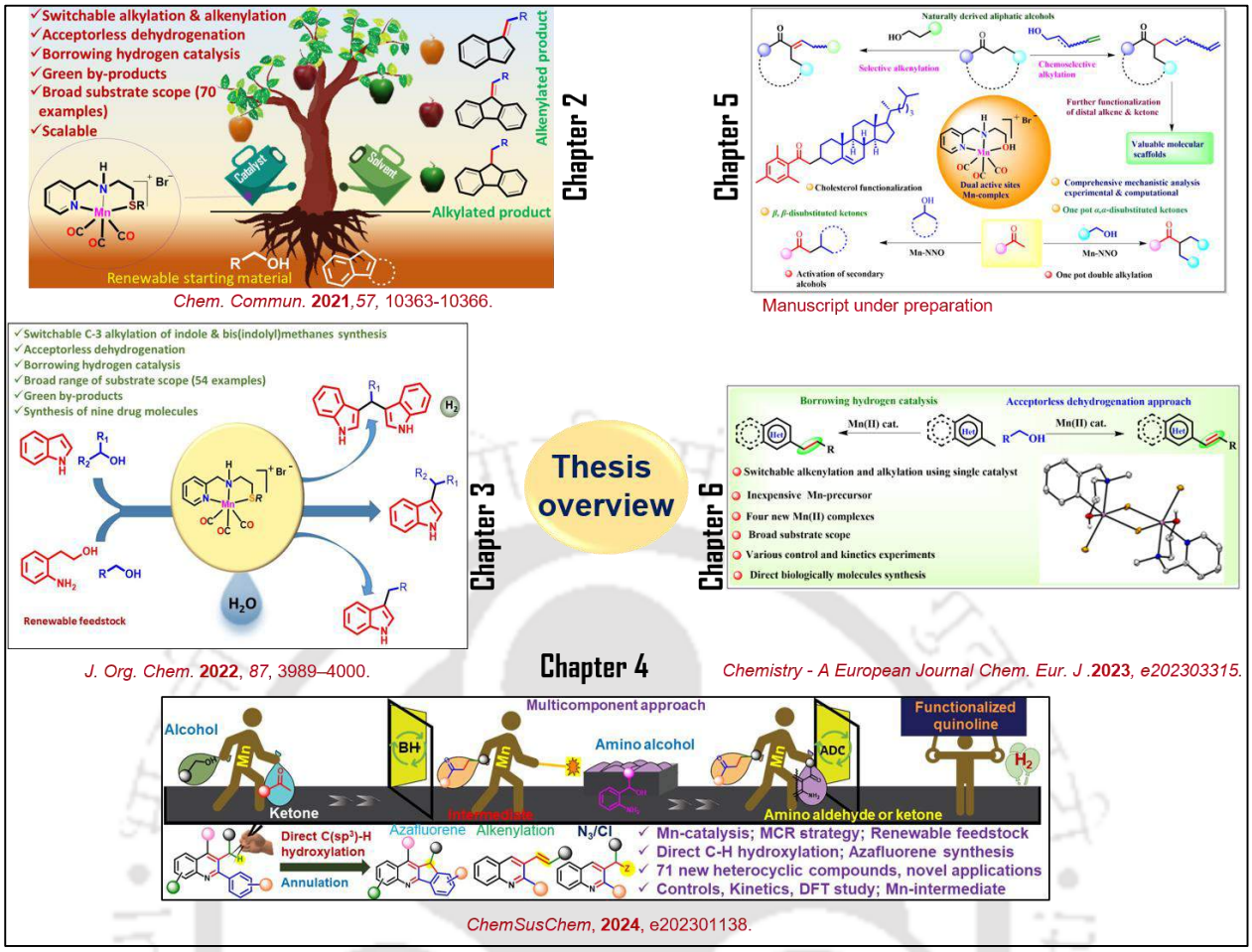


Figure 6.14. ^{1}H (500 MHz) and ^{13}C $\{^{1}H\}$ (125 MHz) NMR Spectrum **2-heptadecylquinoxaline (6.4o)** in $CDCl_3$.



List of publications:

Thesis works:

1. **A. Mondal**, R. Sharma, D. Pal and D. Srimani*, Manganese Catalyzed Switchable C-Alkylation/Alkenylation of Fluorenes and Indene with Alcohols. *Chem. Commun*. **2021**, *57*, 10363-10366.

2. **A. Mondal**, R. Sharma, B. Dutta D. Pal and D. Srimani*, Well-Defined NNS-Mn Complex Catalyzed Selective Synthesis of C-3 Alkylated Indoles and Bisindolylmethanes Using Alcohol. *J. Org. Chem*. **2022**, *87*, *6*, 3989–4000.

3. **A. Mondal**, H. J. Phukan, D. Pal, S. Kumar, M. Roy and D. Srimani*, Well-defined Mn(II)-complex Catalyzed Switchable De(hydrogenative) C(sp^3)-H Functionalization of Methyl Heteroarenes: A Sustainable Approach for Diversification of Heterocyclic Motifs. *Chem. Eur. J.* **2023**, e202303315.

4. **A. Mondal,** D. Pal, H. J. Phukan, M. Roy, S. Kumar, S. Purkayastha, A. K. Guha,* and D, Srimani* Manganese Complex Catalyzed Sequential Multi-Component Reaction: Enroute to a Quinoline-Derived Azafluorenes, *ChemSusChem*, **2024**, e202301138.

5. **A. Mondal**, H. J. Phukan, K. Mohar, D. Pal, and D. Srimani*, Engineering of a Multi-tasking Mn(I) Complex to Overcome the Steric Encumbrance of Bulky Partner For Unlocking Chemo selective C(sp^3)-C(sp^3) Bond Formation and its Strategic Applications, ***Manuscript is ready for submission.***

Non-thesis works:

6**. A. Mondal**, R. Sharma, D. Pal and D. Srimani*, Recent Progress in the Synthesis of Heterocycles via Base Metal-catalyzed Acceptorless Dehydrogenative and Borrowing Hydrogen Approach. *Eur. J. Org. Chem*. **2021**, 2021, 3690.

7. K. Das, **A. Mondal**, D. Srimani*, Selective Synthesis of 2-Substituted and 1,2-Disubstituted Benzimidazoles Directly from Aromatic Diamines and Alcohols Catalyzed by Molecularly Defined Nonphosphine Manganese(I) Complex. *J. Org. Chem.* **2018**, *83*, 9553-9560.

8. K. Das, **A. Mondal**, D. Srimani*, Phosphine Free Mn-complex catalysed dehydrogenative C-C and C-Heteroatom bond formation: a sustainable approach to synthesize quinoxaline, pyrazine, benzothiazole and quinoline derivatives. *Chem. Commun*. **2018**, *54*, 10582-10585.

9. K. Das, **A. Mondal**, D. Pal, H. K. Srivastava* and D. Srimani*, Phosphine-Free Well-Defined Mn(I) Complex-Catalyzed Synthesis of Amine, Imine, and 2,3-Dihydro1H-perimidine via Hydrogen Autotransfer or Acceptorless Dehydrogenative Coupling of Amine and Alcohol. *Organometallics* **2019**, *38*, 1815-1825.

10. K. Das, **A. Mondal**, D. Pal and D. Srimani*, Sustainable Synthesis of Quinazoline and 2-Aminoquinoline via Dehydrogenative Coupling of 2-Aminobenzyl Alcohol and Nitrile Catalyzed by Phosphine-Free Manganese Pincer Complex. *Org. Lett*. **2019**, *21*, 3223–3227.

11. R. Jamatia, **A. Mondal** and D. Srimani*, Visible-Light-Induced Manganese-Catalyzed Reactions: Present Approach and Future Prospects. *Adv. Synth. Catal*. **2021**, *363*, 2969-2995.

12. D. Pal, **A. Mondal** and D. Srimani*, Well-defined Manganese Complex Catalyzed Dehydrogenative Synthesis of Quinazolin-4(3H)-ones and 3,4-Dihydro-2H-1,2,4- benzothiadiazine 1,1-Dioxides. *Catal. Sci. Technol*. **2022**, *12*, 3202-3208.

13. R. Sharma, **A. Mondal**, A. Samanta, N. Biswas, B. Das and D. Srimani*, Well-defined Ni-SNS Complex Catalysed Borrowing Hydrogenative α-Alkylation of Ketones and Dehydrogenative Synthesis of Quinolines. *Adv. Synth. Catal*. **2022**, *364*, 2429–2437.

14. R. Sharma, **A. Mondal**, A. Samanta, D. Srimani*, A Strategic Approach For C(sp^3)-H Functionalization of 9H-Fluorene: A Acceptorless Dehydrogenation and Borrowing Hydrogen Approach. *Catal. Sci. Technol*. **2023**, *13*, 611-617.

15. D. Pal, **A. Mondal,** R. Sarmah, D. Srimani*, Designing Cobalt(II) Complexes for Tandem Dehydrogenative Synthesis of Quinoline and Quinazoline Derivatives, *Org. Lett*. **2024**, *26*, 2, 514–518.

16. A. Samanta, P. Behera, A. Chaubey, **A. Mondal**, D. Pal, K. Mohar, L. Roy*, and D. Srimani*, Experimental and Theoretical Insights for Designing Zn^{2+} Complexes to Trigger Chemo-selective Hetero-Coupling of Alcohols, *Chem. Commun*., **2024**, *60*, 4056-4059.

Conferences and workshop:

1. **Poster presentation with entitled** "A sustainable Way for the Synthesis of Quinazoline and 2-Aminoquinoline via Acceptorless Dehydrogenative Coupling of 2-Aminobenzyl Alcohols and Nitriles Using NNS-Mn(I) Complexes." **PFEOS-2021.**

2. **Oral presentation with entitled** "Manganese Catalyzed Switchable C-Alkylation/Alkenylation of Fluorenes and Indene with Alcohols." **JNOST-2022.**

3. **Poster presentation with entitled** "Well-Defined NNS-Mn Complex Catalyzed Selective Synthesis of C-3 Alkylated Indoles and Bisindolylmethanes Using Alcohols." **CRSI-2022**

4. **Poster presentation with entitled** "A Sustainable Approach for the Synthesis of Heterocyclic Compounds via Hydrogen Autotransfer or Acceptorless Dehydrogenative Coupling by Phosphine-Free Manganese Complex." **NERC-2022.**

5. The 2 days' online workshop on **"Nuclear Magnetic Resonance: Technique and its Application"** held from 23rd to 24th August 2021, organized by **North East Centre for Biological Sciences and Healthcare Engineering**, Indian Institute of Technology Guwahati, Assam in collaboration with **Bruker**, **India**, with support of Department of Biotechnology, Govt. of India as part of **Azadi ka Amrit Mahotsav**.

6. **Best Oral Presenter on Science, Technology & Innovation II 2024 with entitled**

"A Rational Design of Manganese-Catalyzed Multicomponent Approach: A Strategic Route to Quinoline Based Azafluorenes."

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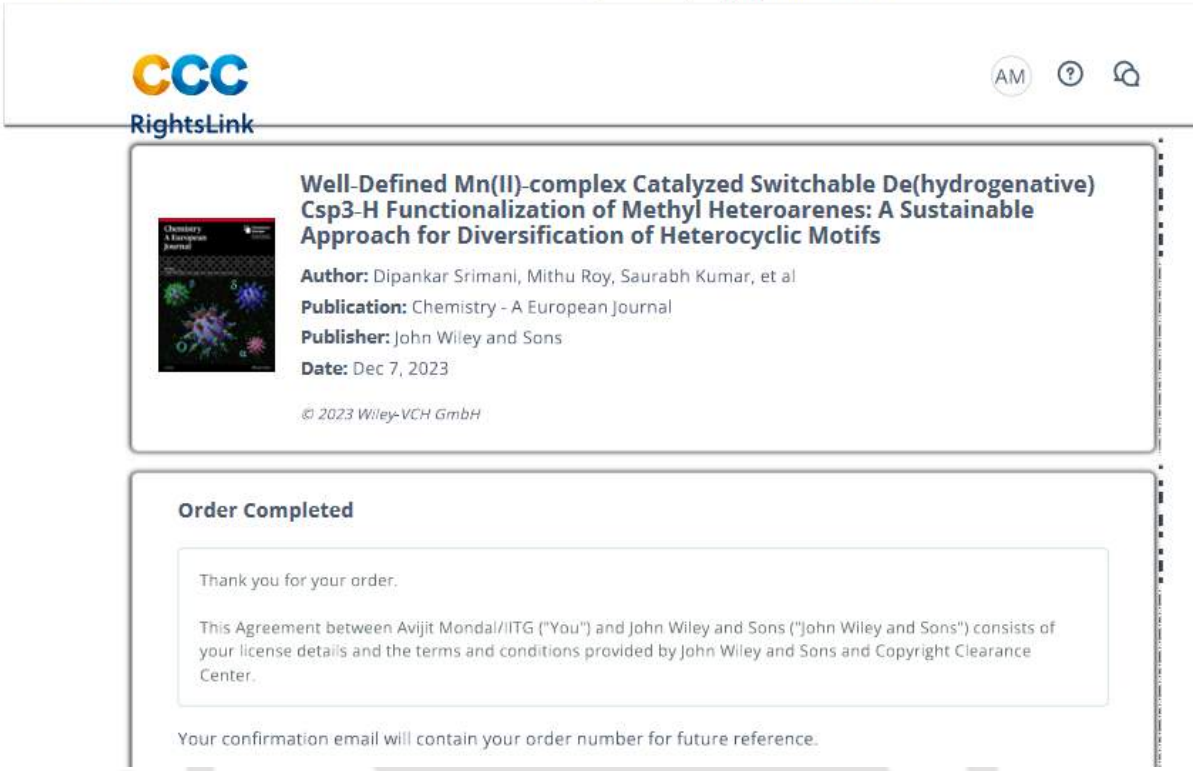

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Well-Defined Mn(II)-complex Catalyzed Switchable De(hydrogenative) Csp3-H Functionalization of Methyl Heteroarenes: A Sustainable Approach for Diversification of Heterocyclic Motifs

Author: Dipankar Srimani, Mithu Roy, Saurabh Kumar, et al

Publication: Chemistry - A European Journal

Publisher: John Wiley and Sons

Date: Dec 7, 2023

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