CHAPTER 1

Introduction and Literature Review

1.1 Schiff bases

The synthesis of novel molecules exhibiting diverse significant applications has always been a challenging task. Therefore survey and investigation of new molecules and compounds could be deemed as one of the fascinating areas of current chemical research, especially when there is a requirement to endorse resolution over present research inadequacies in an innovative and capable approach. Another important aspect of consideration of concerned researchers is the 'EEE' factor, i.e., Efficiency, Effectiveness, and Economy of new methodologies and investigations on their principal relevance.

1.2 Chemistry of Schiff's bases

Being the condensation product of of primary amines and carbonyl compounds, they were revealed by Hugo Schiff in 1864 who is a German chemist & Nobel Prize winner. Architecturally, Schiff base (also known as azomethine or imine) is an analogue of a ketone or an aldehyde in which the carbonyl group (>C=O) has been interchanged by an imine or azomethine group. Schiff base ligands are highly indispensable in the arena of coordination chemistry, predominantly in the extension of complexes of Schiff bases as these compounds are proficient of developing stable complexes with metal ions [Ambike *et al.* (2007)]. Huge amount of Schiff base complexes were categorized by an exceptional catalytic activity in a diversity of reactions at high temperatures (>100ºC) and in the company of moisture. In contemporary years, there have been plentiful informations of their consumption in homogeneous and heterogeneous catalysis. Metal complexes of Schiff bases were used as catalysts in innumerable biological systems, dyes, and polymers. Additionally, it stands inveterate that these compounds can also act as enzyme preparations [Patange *et al.* (2015)].

Owing to the exceptional stability, discernment, and sensitivity of Schiff bases for explicit metal ions such as Cu(II), Ni(II), , Pb(II), Ag(II), Co(II) Gd(III), Al(III), Hg(II), and Zn(II) Y(III), a hefty numeral of diverse Schiff base ligands have been castoff as cation transporters in potentiometric sensors [Shamsipur *et al.* (2001)]. Studies in rapports of catalytic possessions of Schiff bases revealed the catalytic activity in hydrogenation of olefins [Alexander *et al.* (2009)]. More remarkable solicitations of these compounds is the probability to consume them as corrosion inhibitors. This manifestation is the unprompted formation of a monolayer on the external surface which is to be protected.

1.3 Structure

The occurrence of an alkyl or phenyl group fashions the Schiff bases as stable imine. These compounds are gifted of coordinating through metal ions with the imine nitrogen and additional groups associated to the Schiff base. Because of the adaptability in the active groups, these compounds can comprise as per the necessity; with presence of multiple donor atoms like O, N, S, etc they are called privileged ligands. A huge numeral of metal complexes of multi-dentate Schiff base ligands using O, N, S donors have been described with plentiful solicitations [Gong *et al.* (2011), Manna *et al.* (2019)]. Chemists formulate now a day's soundly designed bridged Schiff bases which are exemplified as shown in figure 1.1.

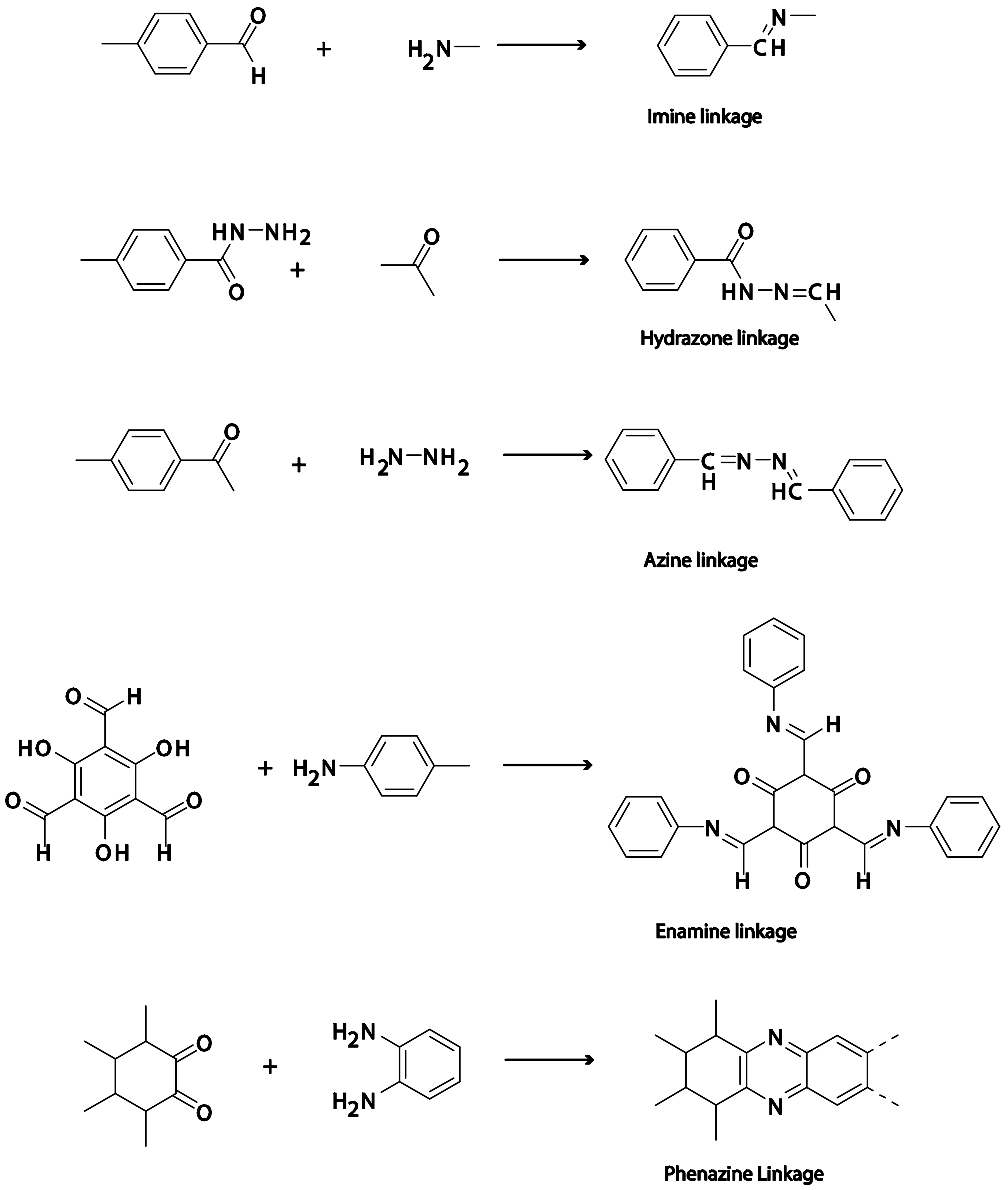


Figure 1.1 Schematic representation of dynamic reactions cast-off for the preparation of a diversity of Schiff bases [Gong *et al.* (2011), Manna *et al.* (2019)]

Schiff bases are derivative of condensation from an amine and a carbonyl compound (Figure 1.2). They are well known, versatile chelating agents with multiple donor atoms like O, N, S, etc. A large amount of metal complexes of multi-dentate Schiff base ligands with O, N, and S donors have been testified with numerous solicitations.

Schiff bases are compounds with functional groups containing carbon-nitrogen Double Bond [Savalia *et al*. (2013), Berkesi *et al*. (2003)]. Schiff bases are very easy to made and easy to handle the class of compounds showing a large range of fluorescence, optical, biochemical, and nanomaterials [Wang *et al*. (2012), Fenzl *et al.* (2014), Liu *et al*. (2010)].

Figure 1.2 Schematic representation of the construction of Schiff Base

Schiff bases are considered by presence of an imine group **–N=CH-,** which aids to clarify the mechanism of transamination and racemization reaction in the biological system. It exhibits antibacterial and antifungal effects in their biological properties. Metal-imine complexes remained widely investigated due to antitumor and herbicidal use [Abdel *et al.* (2016), Hassan *et al.* (2016)]. They can work as models for biologically important species**.**

1.4 Types of Schiff base

This family can be isolated into two groups of symmetric and asymmetric Schiff's bases (Figure 1.3).

1. Salens and salophen could be symmetric or asymmetric.
2. hydrazones are the members of the asymmetric Schiff's bases.

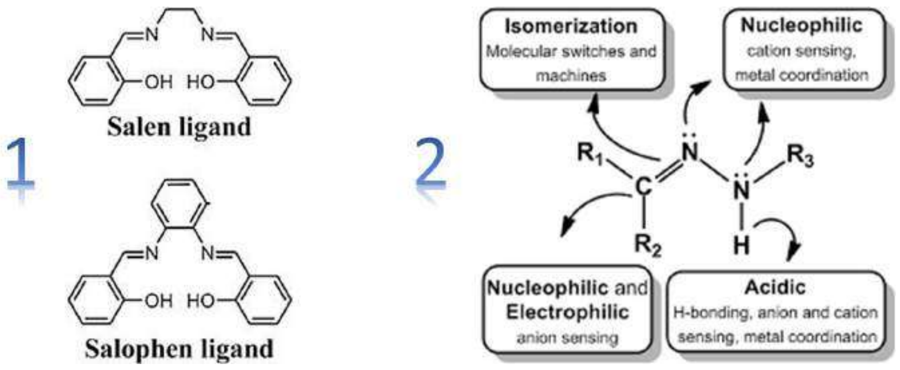


Figure 1.3 Types of Schiff Base Ligands (XAFS investigations of copper(II) complexes with tetradentate Schiff base ligands)

1.4.1 Salen and Salophen type

Salen refers to a tetradentate C_2-Symmetric ligand synthesized from salicylaldehyde (sal) and ethylenediamine (en). Salen ligands are notable for coordinating a wide range of different metals, which they can often stabilize in various oxidation states [Cozzi *et al.* (2004), Chaudhuri *et al.* (2001), Limberg (2009)]. These metal salen complexes primarily find use as catalysts and other biomedical applications [Darensbourg *et al.* (2004), Luinstra *et al.* (2005)]. Salen compounds are unsolvable in aqueous solutions, and they decompose easily in acidic solutions, restraining their use to basic conditions only. Salophen or acetylparamidophenyl salicylate is a Schiff's base with non-toxic properties, which is an active supernumerary for salicylic acid [Faridbod *et al.* (2008)].

1.4.2 Hydrazone type

Hydrazones are a class of organic compounds with the structure $R_1R_2C=NNH_2$. They are interrelated to ketones and aldehydes by replacement of the oxygen with the NH_2 functional moiety. They are frequently designed by the reaction of hydrazine on ketones or aldehydes. Schiff`s bases can coordinate metals through imine nitrogen, and there is wide use of these metal complexes as catalysts [Cozzi *et al.* (2004), Pradeep *et al.* (2013)]. They are easy to synthesize and cost-effective (simple and cheap) and could be multi-dentate. Replacements at the aromatic ring can amend the electronic and steric chattels of the resulting complexes (fine-tuning) as it can form metal complexes of various sizes because of its open structure [Sebastian (2010), Carnes *et al.* (2014), Junge *et al.* (2019)].

The interest in metal complexes in which the Schiff bases play a role as the ligands are increasing, as evidenced by the number of publications appearing annually (approximately 500). So much interest in imines can be explained by the fact that they are extensively distributed in many biological systems, and are utilized in organic synthesis and chemical catalysis, pharmacy, chemical analysis and medicine as well as to novel technologies [Qin *et al.* (2013), Ooi *et al.* (2002), Tidwell *et al*. (2008), Shibuguchi *et al*. (2007)].

1.5 Schiff's base ligands

Chelating capacity of the Schiff's bases pooled with the simplicity of synthesis and suppleness in varying the chemical atmosphere around the imino group (>C=N-) marques it as a fascinating ligand in coordination chemistry [Lorcy *et al.* (2009), Britovsek *et al.* (1999), Pytlakowska *et al.* (2013), Liu *et al*. (2014)]. 2,4-dibromo-6-[(2-morpholin-4-ylethylimino)methyl]phenol (DBP), 2-bromo-4-chloro-6-[(2-piperidin-1-ylethylimino)methyl]phenol (BCP) Salen ligands are Schiff bases, usually organized by the condensation of a salicylaldehyde with an amine [Li *et al.* (2013), You *et al.* (2009), Adhikary & Koner (2010)].

1.5.1 Schiff's base metal complexes

Enormous amount of Schiff bases and related complexes have been strategically used for their motivating and imperative assets, e.g., their capacity to bind oxygen reversibly, transfer of an amino group and catalytic activity in hydrogenation of olefins, complexing ability to some toxic metals and photochromic properties [Soliman (2001), Soliman & Linert (1999), Dede *et al.* (2009)]. The great kinship towards chelation of the Schiff bases headed for the transition metal ions are applied in formulating their solid complexes. The chelating Schiff base ligands obtained from diamines such as 1,2 ethanediamine, 1,3-propanediamine, and 1,4-butanediamine and various carbonyl compounds cover a highly amazing class of compounds [Mohamed *et al.* (2005), Kocyigit *et al*. (2010)]. The occurrence of groups like carbonyl or hydroxyl nearby the azomethine moiety upsurges the coordinating outcome due to lone pair of electrons thus stability of the metal complexes has been enhanced [Karousis *et al.* (2010), Mukherjee *et al.* (2010), Melaimi *et al.* (2010)]. Thus, Schiff bases having functionally substitution supplement the donor groups and embody the most imperative class of hetero-polydentate ligands [Kushwah *et al.* (2019)].

Most of the transition metal complexes are designed with Schiff base ligands. These complexes treasure a wide assortment of applications in synthetic, catalytic, clinical, analytical, and biochemical areas and besides, they possess sizeable physiological activities [Raman *et al.* (2009), Adsule *et al.* (2006), Liu *et al.* (2018)]. Transition metal complexes of Schiff base are among the most compliant and meticulously studied systems. They are of both stereochemical and magneto-chemical concern because of their preparative convenience, diversity and organizational variability. The consequences of studies on Schiff base complexes deliver understanding about coordination sphere effects produced by the range of ligands which are employed, such as the influence of the net total charge, the steric hindrance, and electronic effects of the ligands on the structures, properties, and the reactivity of the complexes [Lowry & Bernhard (2006), Gothard *et al*. (2012), Werner *et al.* (2008)].

Schiff base metal complexes are commonly organized by reacting metal salts with Schiff base ligands beneath proper experimental conditions. However, aimed at catalytic application, Schiff base metal complexes are primed in the reaction system in situ. Cozzi, in his review, has sketched about five synthetic courses that are commonly engaged for the synthesis of Schiff base metal complexes comprises metal alkoxides [M(OR)n]. Alkoxides of

3d transition metals (M = Ti, Zr) are commercially accessible and easy to use. The usage of other alkoxide derivatives are hard, that too in the case of extremely moisture-sensitive derivatives of lanthanides. Similarly metal amides [$M(NMe_2)_4$] (M = Ti, Zr) are also used as the predecessors in preparation of Schiff base metal complexes [Franceschini *et al.* (2003), Woodman *et al.* (1999)]. The reaction results via the elimination of proton of the acidic phenolic Schiff bases through the synthesis of volatile $NHMe_2$ [Cozzi (2004)].

Additional synthetic courses include reaction of metal alkyl complexes with Schiff bases or with the corresponding metal acetate under reflux [Vigato & Tamburini (2004), Nath & Saini (2011)]. Deprotonation of the acidic phenolic hydrogen could be effectually finished by spending NaH or KH in coordinating solvents, and excess sodium or potassium hydride could be eradicated by filtration. The deprotonation stage is generally swift at room temperature, but elevating the temperature of reaction mixture on reflux does not reason decomposition. An elegant discussion on synthesis and characterization of Schiff base metal complexes are not done here, since abundant literature reviews are present on these facets.

1.6 Applications of Schiff base metal complexes

The Schiff base complexes retain several other applications, which are discoursed briefly in this section.

1.6.1 As electroluminescent materials

Tang and Van Styke were testified high performance organic electroluminescent (EL) devices for the first time, and since then, the organic electroluminescent devices are employed in novel-type flat-panel displays [Van Slyke *et al.* (1996), Kim *et al.* (2005)]. The multilayer device structure having a receiving layer and an emitting layer was the actual basis for this wonderful discovery. Organic electroluminescent (EL) devices are generally fabricated by three major organic materials, such as chelate metal complexes, organic dyes, and polymers. The materials for RGB (red, green, and blue) emission are based on the high luminescent blue-emitting nature of chelate complexes. Schiff bases of calixarene were used for the preparation of complexes of blue luminescent zinc (Zn) and beryllium (Be) [Anis *et al*. (2013), Wang *et al.* (2005)].

Thin films for these Schiff bases can be easily achieved and are soluble to a good extent in normal solvents. The crystal structure, optoelectronical properties, and thermal stability of bis[salicylidene (4-dimethylamino) aniline]Zn(II) were reported by [Xie *et al.* (2005)]. Among organic light-emitting diodes (OLEDs), this complex is found to have excellent light-emitting and charge transforming properties. The solicitation of Schiff base complexes in the full-color flat-panel display is pointed out by these experimental reports as light-emitting materials [Anis *et al.* (2013), Yu *et al.* (2007)].

1.6.2 In non-linear optical devices

The interactions of various materials with applied electromagnetic fields are dealt with non-linear optics (NLO) for introducing new electromagnetic fields, with different physical properties like frequency and phase [Papadopoulos *et al.* (2006)]. The dynamic image processing, optical communication, and optical computing utilize such types of materials in manipulating photonic signals in an efficient manner, which enhances their significance. The ability of transition metal complexes to tailor metal-organic interactions and various oxidation states of metals present in such systems makes these complexes as possible building blocks for nonlinear optical materials [Xu *et al*. (2014), Ratera & Veciana (2012), Long *et al.* (2010), Wang *et al.* (2011)].

The large variety of structural novelty, assortment of tunable electronic behaviors on account of the coordinated metal center and the possibility of enhancing the thermal stability of metal complexes as associated to the further common organic molecules, makes a place for them to be used as non-linear optics (NLO) materials with characteristic electrochemical and magnetic properties. Several research groups are pursuing investigations on non-linear optics (NLO) properties of metal complexes [Rocha *et al.* (2011), Chakraborty *et al.* (2007)]. When a metal complex is a constituent of the polarisable bridge in a D–π–A structure, two limiting cases can be identified: (i) The related uncomplexed D/A-substituted bridge already possesses second-order nonlinearity; (ii) complexation generates new NLO structures, from those originally with vanishing or small nonlinearity [Liu *et al*. (2006), Nayar & Ravikumar (2014)]. In these two cases, the metal ion can play two different functions: (a) it enhances the bridge conjugation and, hence, the nonlinearity; (b) it 'switches on' or enhances the NLO response Push-pull metalloporphyrins are prototypical examples of the case (i).

The Coordination of a metal ion in porphyrins is always accompanied by an enhanced nonlinearity due to a more pronounced conjugation [Senge *et al*. (2007), Guerchais *et al.* (2007)]. In fact, the push-pull arylethynyl(porphinato) Zn(II) derivative exhibits the largest hyper-polarisability reported to date for a metal complex. This substantially higher nonlinearity, compared to that of analogous push-pull porphyrins, is due to the strong electronic coupling between the coplanar donor/ acceptor arylethynyl moieties and the polarizable porphinato bridge [Priyadarshy *et al*. (1996), LeCours *et al.* (1996)]. Unsymmetrically substituted metallophthalocyanines can be regarded similarly. For example, related arylethynyl metallophthalocyanine structures are expected to be promising candidates for large first hyperpolarizabilities. Their potentially large second-order molecular response remains, however, still unexplored (a prototypical example of case ii) is represented by bis(salicylaldiminato) M(II) (M = Ni, Co, Cu, Zn) Schiff base complexes whose second-order NLO properties have been recently reviewed by Di Bella and by Lacroix [Bella (2001)]. In this case, complexation is accompanied by the formation of geometrically constrained acentric, generally planar, structures. It always involves an enhancement of optical nonlinearity, compared to that of related free ligands, and, in some cases, a 'switching on' of the NLO response.

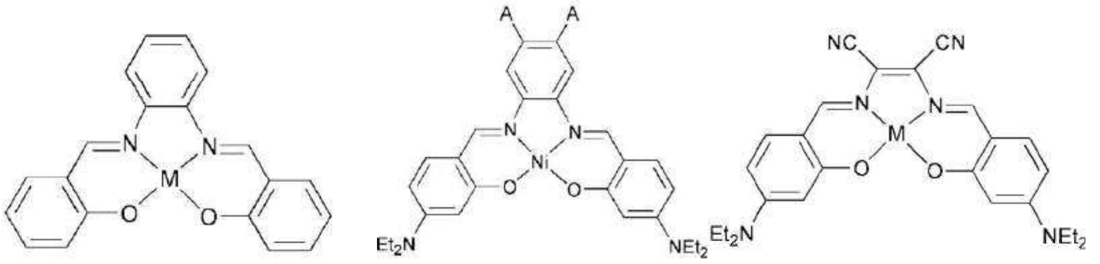


Figure 1.4 some examples of Schiff base complexes with NLO properties (*J. Mater. Chem. C*, 2018,**6**, 8999-9009)

1.6.3 In electrochemical sensors

The determinations of cations and anions have been done by employing Schiff bases as potentiometric sensors [Singh *et al.* (2007), Gupta *et al.* (2006), Afkhami *et al.* (2012)]. Polyvinylchloride (PVC) based chloride membrane sensors were fabricated by using Ru(III) complexes of Schiff bases. Near Nernstian behavior is displayed by the sensor with a wide range of concentration and composition of 62% benzyl acetate, 30% PVC, 5% Ru(III), and

3% hexadecyltrimethyl ammonium bromide Schiff base complex. The sensor was effectively employed for the quantification of chloride ions in serum because it is selective towards chloride ions over a variety of organic and inorganic anions. The potentiometric titration of Cl^- ions with $AgNO_3$ is carried out by employing such type of sensor as indicator electrodes [Mahajan *et al.* (2003), Pinzauti *et al.* (1983), Mohamed *et al.* (2010)]. It was efficaciously applied for the direct determination of Al(III) in industrial, biological and environmental samples. Electrode could be applied to the range of pH 2.0–9.0 and mixtures comprehending up to 20% (v/v) non-aqueous content. They have been used as an indicator electrode in the potentiometric titration of aluminum ion with EDTA. The preparation of Mn^{2+} selective sensor employs the use of Schiff base, N,N,N”,N”’-1,5,8,12- tetraazadodecane-bis(salicylaldiminato) as ionophore [Gupta *et al.* (2017), Tiwari *et al.* (2013)]. The sensor can be utilized for analyzing Mn^{2+} selectively in various samples by direct potentiometry as it is sufficiently selective for Mn^{2+} over several alkalies, alkaline and heavy metal ions.

1.6.4 In medicinal chemistry

The Medical importance of Schiff bases is quite clear from the literature, and this is the reason that they are used for designing medicinal compounds. The chelation of Schiff bases with metals either enhances or minimizes their activity. The complexes of electrophoretic mobility studies which reflected that either a simple coordination mode followed by formation of DNA complex ionic adduct or their performance as nucleases for degradation is involved in such type of interactions [Zhao *et al.* (2014), Travascio *et al.* (2001), Desbouis *et al.* (2012)].

Many Schiff bases are known to be medicinally significant and used to enterprise medicinal compounds. It was perceived that biological activity of Schiff bases either upsurge or decline upon chelation with metal ions. Metal complexes of Schiff bases and their derivatives are the well investigated areas of chemistry. Being exceedingly useful in the field of industrial catalysts, analytical reagents, medicines, agrochemicals, and other industrial goods, they behave as jack of all trades to scientific community [Gurung *et al.* (2013)].

Azomethine functional group-containing the class of compounds with active bonding capability towards metal are called Schiff bases where a carbon-nitrogen double bond (>C=N-) is present, nitrogen being attached to an alkyl or aryl group, but not hydrogen. [Jafari *et al.* (2013), Wu *et al.* (2018), Athanasopoulou (2015)].

1.6.4.1 Antibacterial properties

Mortality escalation caused by infectious diseases is unswervingly associated to the bacteria having multiple resistances to antibiotics. The development of new antibacterial drugs augmented by inventive and effective mechanisms of action is an urgent medical necessity. Schiff bases are encouraging antibacterial agents (Figure 1.5). For example, N-(Salicylidene)-2-hydroxyaniline is active against Mycobacterium tuberculosis Indoline-2,3-dione, and 2-amino benzoic acid Schiff base and isatin complexes exhibited antibacterial activity against S. aureus [Souza *et al.* (2007)]. The results linked with the standard drug (imipinem) have revealed that compounds were active, but activity was lesser than that of the standard drug. This activity must be because of presence of a hydroxyl and phenyl group. The amplified activity of organotin complexes might be due to the co-ordination and polarity of Sn(IV) atom with the oxygen of the ligand [Iskander *et al.* (1989), Tariq *et al.* (2013)].

Complexes of Co(II), Cu(II), Ni(II), Mn(II) and Cr(III) with Schiff bases resultant from 2,6-diacetylpyridine and 2-pyridine carbonaldehyde with 4-amino, 2,3-dimethyl,1-phenyl,3-pyrazoline-5-one displayed antibacterial and antifungal activities against S. aureus, E. coli, Klebsiella pneumonia, Pseudomonas aeruginosa, Mycobacterium smegnatics, Bacillus megateriumand, Micrococcus letens Enterococcus cloacae. Metal complexes impart superior effect than the Schiff base ligands against nearly all bacteria. The Schiff base 4-chloro-2-(2-morphiolinoethylimino)methylphenolato-methanol and its Zn(II) complexes were selected for antibacterial activity against gram positive bacterial strains (B. subtilis, S. aerus) and gram negative bacterial strain (E. coli and P. fluorescence) by the MTT assay. The Schiff base displayed substantial activity against gram positive bacterial strains with MIC of 12.5 μgm L^{-1} but were inactive against gram negative strains [Shi *et al.* (2009), Lv *et al.* (2006)]. The Zn complex disclosed a wide array of bactericidal activity which counter gram-positive and gram-negative bacteria. They are more potent than or similar to commercial antibiotics (Kanamycin and Penicillin).

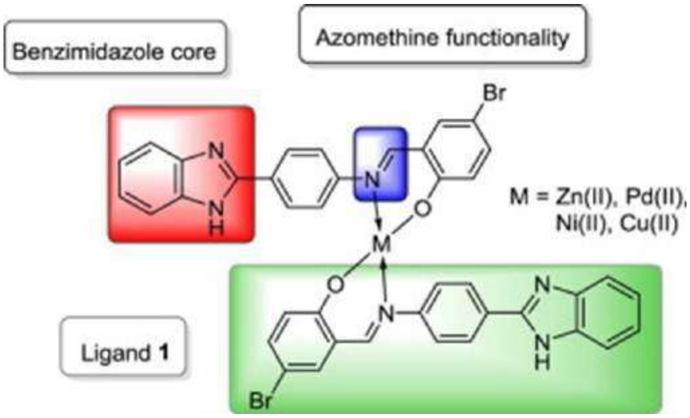


Figure 1.5 Schiff base complex used in antibacterial activity [Souza *et al.* (2007)]

Bidentate complexes of Co(II), Cu(II), Cd(II), Ni(II), and Hg(II) with benzofuran-carbohydrazide and benzaldehyde (BPMC) or 3,4-dimethoxybenzaldehyde [BDMePMC] revealed biological activities. Co(II) and Cd(II) complexes of BPMC are ascetically active toward E. coli, whereas Zn(II), Cu(II), and Ni(II) complexes of BDMeOPMC are further active against S.aerous when compared to free ligands. None of the complexes are active against Aspergillus nigerbut in the case of A. fumigatus, Cu(II), Ni(II), Co(II) and Cd(II) complexes of [BDMeOPMC] are active than the paternal ligands. Amino acid Schiff base derived from 2-hydroxy-5-methylacetaphenone and glycine and its transition metal complexes displayed antibacterial properties. The ligand was bacteriostatic against bacterial strains of Shigellaflexneriand Bacilluscoagulans and Proteus Vulgaris. All complexes are either resistant or less sensitive against P. Vulgaris. When, compared to antibacterial activity of standard antibiotics streptomycin, the activity shown by the ligand and metal complexes stayed minor. The metal complexes showed greater activity than free ligand against the same organism beneath same experimental conditions, and such amplified activity could be enlightened based on chelation theory [Garoufis *et al.* (2009), Ali & Iqbal (2017)].

1.6.4.1.1 Chelation theory

The in-vitro antimicrobial activity of compounds were experienced against bacteria such as S. *aureus*, K. *pneumonia*e, E. *coli*, and also fungi C. *albicans* and R. *stolonifer* by the serial dilution method. The minimum inhibitory concentration (MIC) standards of the compounds against the development of microorganisms are briefed. Comparative study of the ligand and its complexes (MIC values) shown that the complexes demonstrate somewhat higher antimicrobial activity than the ligand. Such improved activity of the complexes can be elucidated based on overtone's model and Tweedy's Chelation theory [Panchal *et al.* (2006)].

According to Overtone's model of cell permeability, the lipid membrane surrounding the cell helps the passage of only lipid-soluble materials owing to which liposolubility is an imperative aspect, which pedals the antimicrobial activity.

Polarity of the metal ion will be abridged to a greater extent upon chelation due to overlap of the ligand orbital and incomplete sharing of the positive charge of metal ion with donor groups. Additionally, it upsurges the delocalization of π-electrons over the entire chelate ring and enriches the lipophilicity of the complexes. This augmented lipophilicity boosts the diffusion of the complexes into lipid membranes and obstruction of the metal-binding sites in the enzymes of microorganisms. These complexes interrupt the respiration course of the cell and hence block the synthesis of the proteins that check further growth of the organism. Furthermore, the approach of action of the compound include the formation of a hydrogen bond using the azomethine group with the active center of cell ingredients, causing in interference to the normal cell process. Mixed ligand complexes with 2,6-pyridine-carboxaldehyde bis (p-hydroxy phenylamine) LA, 2,6-pyridine-carboxaldehyde bis (o-hydroxy phenylamine) LB showed antibacterial activities. The obtained data replicate that the Schiff base ligand LA and LB show reasonable activity in comparison with S.aureus, E. coli, and are less active in assessment with Pseudomonas aeruginosa. LA shows good activity towards B. subtilis, while LB ligand is less active. The amazing activity of two Schiff base ligands might arise from the pyridyl-N and the hydroxyl group which may perform important role in the antibacterial activity as well as from the occurrence of two imine groups which enlightens the machinery of transformation reaction in the biological system [Santini *et al.* (2013)]. Tetra and hexa-coordinated metal chelate complexes of phosphate Schiff base ligands possess remarkable antibacterial properties but biological activities get improved in complexation with metal ions [MacLachlan *et al.* (1996), Neves *et al.* (2002)]. Tetradentate complexes of transition metal with Schiff base derived from 2-amino phenol or 2-amino thiophenol and 1-phenyl-2,3-dimethyl-4-(4-iminopentan-2-one)-pyrazol-5-one displayed antibacterial activity against *S. aureus, K. imeumoniac*, *B. subtilis*, *P. aeruginosa*, *S. typhi*, *A. niger*, *S. flexneri* and *T. viride*. Maximum complexes have advanced activity than free ligands. Complexes of transition metal with Schiff base derived from 2,3-dihydrazinoquinoxaline (DHQ) revealed antibacterial activity. Initial testing of the ligand and metal complexes for antimicrobial activity on the gram-positive *S. aureus* and gram-negative *E. coli* confirms that the ligand is active only against *S. aureus* and the activity is heightened by complexation. The metal complexes unveil more bacteriostatic activity against *E. coli*. The appearance of activity is due to synergistic mechanisms [Lemire *et al.* (2013), Potara *et al.* (2011)]. A tridentate Schiff base consequent of the condensation of S-benzyldithiocarabazate with salicylaldehyde and transition metal complexes exhibited substantial bioactivity against *B. circus* (gram-positive) and *P. aeruginosa* (gram-negative), while the uranium analogue was effective against *B. circus* and shown weak activity against Candida albicans fungi.

1.6.4.2 Antifungal properties

Fungal infections are typically not solitary to the contamination of surface tissues. Recently, a considerable increase in the frequency of systemic fungal infections are found, which are possibly life-threatening. Investigation and improvement of further effective antifungal agents is obligatory, and the individual Schiff bases are reflected to be capable antifungal medicines [Coelho & Casadevall (2016), Patil *et al.* (2018)]. The antifungal activity of many Schiff bases and their metal complexes was witnessed, and also, the activity is more noticeable in the case of complexes than ligands. As an example, antifungal activity of N-(2-hydroxy-1-nephthalidinephenyl) glycine and its transition metal complexes were inspected, and was found that, paralleled to free ligand, its metal complexes shown superior antifungal activity [Gudasi *et al.* (2006)], which could be described by the chelation theory. Semicarbazone and thiosemicarbazone complexes of Ni(II) possess antifungal activity against pathogenic fungi [Chandra & Gupta (2005)]. The complexes were soberly active against all pathogenic fungi but were found lower in activity when compared to standard fungicide Nystatin [Sheikh *et al.* (2008)]. Ni(II), Co(II) and Cu(II) complexes with Schiff base 3-3"-thiodipropionic acid bis(4-amino-5-ethylimino-2,3-dimethyl-1-phenyl-3-pyrazoline) have antifungal property against Aspergillus niger, Alternaria brassica and Fusarium oxy-sporum and results specify that the complexes demonstrate greater activity in contrast to free ligands [Parekh *et al.* (2006)]. Metal complexes of ligand hydrazine and carbothioamide illustrate antifungal activity against Helmintho sporiumgraminicum and Alternaria alternate. Mn and Mo complexes resist diseases caused by A. alternatainbrinjal crop [Sönmez *et al.* (2006)].

1.6.4.3 Biocidal properties

Schiff bases gained by the reaction of o-aminobenzoic acid and β-keto esters have found biocidal use against *S. epidermidis, B. cinerea, E. coli, and A. niger.* Distinctively, the Schiff bases of isatin derivatives are applied for the annihilation of protozoa and parasites [Pirrung *et al.* (2005)].

1.6.4.4 Antiviral properties

The usage of vaccines might be primed to the abolition of viral pathogens, such as polio, smallpox etc. However, virus-related and hepatitis C human immunodeficiency ailments are the drawback of vaccine approaches. Viral diseases are lethal for immunity suppresed patients, and rapid treatment is required to overcome this problem. Though many therapeutic routes are there for viral infections, currently existing antiviral agents are not yet fully operative, possibly due to the high frequency of virus mutation. There may also exist any of side effects. Salicylaldehyde Schiff bases of 1-amino-3-hydroxyguanidine tosylate are a worthy stage for the planning of some new antiviral agents. Infact, from set of diverse 1-amino-3- hydroxyguanidine tosylate-derived Schiff bases shown to be precisely effective against the mouse hepatitis virus (MHV), inhibiting development by 50% when applied at concentrations as low as 3.2 lM. Recently, Sriram and colleagues conveyed the synthesis and antiviral action of the abacavir-derived Schiff bases. These compounds are a innovative successions of abacavir prodrugs. Abacavir is a nucleoside analogue capable of impeding the activity of reverse transcriptase. It is applied to treat human immunodeficiency virus (HIV) and AIDS and is accessible with trade name Ziagen (GlaxoSmithKline). Compounds were considerably effective against the human immunodeficiency virus type 1 (HIV-1). The operative concentration (EC50) of these abacavir-derived Schiff bases confirmed to achieve 50% fortification of human leukemic cells (CEM) against the cytopathic outcome of HIV-1 was lower than 6 lM [Wang *et al.* (1990), Chang *et al.* (1998), Rauf *et al.* (2017)].

1.6.4.5 Antimalarial activity

Malaria is an ignored disease that still reasons severe public health issues. Approximately 500 million people are plagued by the disease every year of whom around 1–3 million decease, 90% of them are in sub-Sahara Africa are children. Malaria is presently found in about 100 countries throughout Africa, Asia and Latin America. Malaria is chiefly triggered by four species of Plasmodium (P. falciparum, P. vivax, P. ovale, and P. malariae). The female Anopheles mosquito is the vector of Plasmodium. Application in medicine and pharmacy, the consideration for new drugs, vaccines and insecticides to avert or treat this disease is obviously a precedence. Schiff bases are fascinating moieties for the design of antimalarial drugs [Le Thuy *et al.* (2012), Sharma *et al.* (2014)]. Ancistrocladidine is an inferior metabolite fashioned by plants. Ancistrocladaceae and Dioncophyllaceae that present an imine group in their molecular scaffold. It has been experientialised to be active against P. falciparum K1 and 3D7. The MIC values of ancistrocladidine obligatory to absolutely eradicate P. falciparum K1 and 3D7 growth were 0.3 and 1.9 l g/mL, respectively. Rathelot described the synthesis of Schiff base-functionalized 5-nitroisoquinolines and scrutinized the *in vitro* commotion of these compounds against an ACC Niger chloroquine resistant P. falciparum strain. Schiff base were found as most active antimalarial agent midst the synthesized 5-nitroisoquinoline derivatives. The concentration of compound compulsory to inhibit P. falciparum growth by 50% (IC50) was 0.7l g/mL. Under the identical experimental conditions, the IC50 value for chloroquine was 0.1 l g/mL.

Imine complexes have a comprehensive range of biological assets: Antitumor, antifungal, antiviral, antibacterial [Chang *et al.* (2008)]. They were also cast-off in the treatment of diabetes and AIDS. As biological models, they support in understanding the structure of biomolecules and biological progressions befalling in living organisms. They show contribution in photosynthesis as well as oxygen transport in organisms and are intricated in the management of cancer drug resistance [Prakash (2017)]. It could be used for the immobilization of enzymes also.

1.6.4.6 Therapeutic applications

Numerous Schiff bases were found to retain anti-inflammatory, analgesic, radical scavenging property and anti-oxidative activities [Dave & Bansal (2013), Jamil *et al.* (2015)]. Schiff bases derived by thiazole shown analgesic and anti-inflammatory property. Schiff bases from chitosan and carboxymethyl-chitosan have anti-oxidant property such as superoxide and hydroxyl scavenging. Furan semicarbazone metal complexes exhibit noteworthy analgesic and antihelminthic activities. Antitumor and cytotoxic properties were displayed by some of Schiff bases and their metal complexes [Katwal *et al*. (2013), Chohan *et al*. (2010)]. Salicylidieneanthranilic acid retains anti-ulcer activity, and complexation with Cu(II) expresses an increase in anti-ulcer activities. Some Schiff bases synthesized by salicylaldehyde, 2, 4-dihydroxy-benzaldehyde-glycine, and L-alanine and their metal complexes containing Cu, Zn, Ni and Co were established to have antitumor activity. The activity is maximum with Ni followed by Cu, Co, and Zn fluctuating with metal though

Schiff base is not altered. Amino Schiff bases derived by aromatic and heterocyclic amine show high activity against human tumor cell lines [Kumar *et al*. (2009), Sinha *et al*. (2008)].

1.6.4.7 Industrial applications

Schiff bases are testified to contribute to dyes and polymer industries. Chromium azomethane, cobalt complexes of Schiff base were reported to give colors to leather [Anis *et al.* (2013), Ispir, E. (2009)], textiles, food packages, and wools. Azo-group containing metal complexes were used for dyeing cellulose polyester textiles also. Cobalt complexes of salicylaldehyde with diamine devour excellent opposition to light, and storage ability does not reduce in acidic gases like CO_2 [Chen *et al.* (1989), Yuan *et al.* (2018)]. Novel tetradentate Schiff bases perform as a chromogenic reagent for resolution of Ni in ordinary food samples. ATNR (amine terminated liquid natural rubber) is produced by photochemical reduction of natural rubber in the incidence of ethylenediamine. ATNR upon treatment with glyoxal springs poly Schiff bases which advance resistance to ageing process. Organo cobalt complexes with tridentate Schiff bases turn to be an initiator towards emulsion polymerization and co-polymerization of dienyl and vinyl monomers [Oylumluoglu & Oner (2017), More *et al*. (2019)].

1.6.4.8 Agricultural applications

In agriculture, Schiff bases treasure their application as insecticides and also as plant growth regulators [Dudhat & Kulkarni (2018), Avaji *et al.* (2009)], certain Schiff bases display toxicity against insects. Such Schiff bases produced from sulfanethiodiazole and salicylaldehyde or thiophene-2-aldehyde and their metal complexes are strong examples of this application. When complexed with Mo(IV) these Schiff bases, show insecticidal activity against ball worm and indorse the survival rate of mung bean sprouts [ÇAKMAK *et al.* (2013)]. Insecticidal activity enhances upon fluorination of the aldehyde part. Schiff bases also show significant activity on plant growth hormones such as auxins and cytokinins. N-acylated compounds express growth inhibitory activity on seedlings of rye, wheat and barley. Schiff bases derived from thiodiazole have decent plant growth regulator action like auxins and cytokinins [Hu *et al.* (2014)].

1.6.4.9 Application as catalysts

Co(II), Fe(III) and Ru(III) complexes of Schiff bases obtained from hydroxy benzaldehyde are found to be used as catalysts in the oxidation of cyclohexane to cyclohexanol and cyclohexenone in the presence of peroxide [Al Zoubi & Ko (2016), Roy & Manassero (2010)]. Co(III) complexes of indoxyl thiosemicarbazone (ITSC) found one pair of well-defined reduction peaks at unalike potentials in the forward scan, which represent the reduction of Co(III) to Co(II) by one electron process and successive oxidation of Co(II). The quasi reversible nature of the Co(III) / Co(II) is due to the integral reducing affinity of thiosemicarbazone ligand. Ni(II) complexes with Bidentate (N-N) ligands developed as an effectual catalyst precursor for olefin oligomerization in the company of an activator [Mecking (2000), Speiser *et al.* (2005)]. A wide variety of Co(II) complexes are branded as reversible oxygen binder [Goedken *et al.* (1977)] and are, therefore, habitually studied as model natural oxygen carrier compounds [Chen *et al.* (1989), Fantucci & Valenti (1976)]. They are well used in O_2 storage, additionally as in organic synthesis owing to their catalytic properties under trivial environments.

1.6.4.10 Applications in analytical chemistry

The solicitation of Schiff bases in qualitative as well as quantitative analyses has been testified. A very huge number of Schiff base chelating agents are used for detection of metal ions and can be applied for their quantitative analysis [Marahel *et al.* (2011), Fathi & Yaftian (2009)]. In utmost cases, the procedures endure principally similar. The foremost footstep in the above application is the formation of complex, which depends chiefly on pH, cation size, temperature and the structure of the ligand. Augmentation of previsously discussed factors to augment the stability of the complexes leads us to the high selectivity of the established analytical technique.

1.6.4.11 Photometric method of analysis

Photometric methods have been extensively applied in the detection and quality determination of trace elements. They are based upon color formation chemistry resulting from reaction between Schiff bases and the ions. For example, o-[N-(o-hydroxyphenyl) forminidoyl]-phenol known as manganon forms with Mn(II) at pH 9.1 to 11.6 a brown complex, where the measured absorbance was found at 428nm. 2, 2‘‘(2,6-pyridiniyl BIS methylidynenitrito) phenol has been cast-off for the spectrophotometric determination of U(VI) [Bader (2009)]. Red color developed was measured at 500 nm, and absorptivity was 1.9 x 10^4 L mol^{-1} cm^{-1}. Very trace level of Pd (II) was determined by extraction of Pd(II)-biacetyl monoxime-2-pyridyl hydrazone (BMPH) from aqueous acidic solution into chloroform to form a purple reddish complex. The molar absorptivity of the Pd (II)-BMPH complex is about 7500 L mol^{-1} cm^{-1} at 560 nm in the extract of chloroform.

1.6.4.12 Fluorometry in analysis

Schiff bases obtained from salicylaldehyde and aniline shows fluorescence in alkaline medium [Cimerman *et al.* (1997)]. Therefore, they can be used as an acid-base indicator in titrations, O-[-(o-hydroxyphenyl)formidoyl] phenol applied for the quantitative determination of aluminium. The analytical importance of such indicators depends on the fact that they make conceivable acid-base titration [Brodowska *et al.* (2016)] in colored solutions where the application of conservative indicators are precluded. During analysis, there is continually the dependency of fluorescence on the pH very similar to that of acid-base fluorescence indicators [Derinkuyu *et al.* (2008), Amendola *et al.* (2002)]. It is very good method for the recognition and determination of inorganic ions.

1.6.4.13 Potentiometric sensors

Ganjali had prepared sensors for Dy (III) based on bis-pyrrolidene Schiff base [Ganjali *et al.* (2004), Shamsipur *et al.* (2000)]. This electrode has also been applied in the potentiometric determination for fluoride ions in mouthwash by titrating against Dy (III). They also organized a bromide sensor constructed by Fe (III)-salen. This sensor show high bromide selectivity over a wide range of organic and inorganic anions, especially iodide, chloride, and hydroxide ions. Salen show tetradentate –O-N-N-O- donor Schiff base synthesized from one equivalent diamine and two equivalent of salicylic aldehyde, and forms square planer metal complexes. [Jeong *et al.* (2005), Gholivand *et al.* (2007)]. The potentiometric sensors are based on the development of potential between molecular species under zero or very low current flow [Faridbod *et al.* (2008), Afkhami *et al.* (2012)]. The advantage of this kind of analysis is that it is cheap, highly sensitive, and specifically selective in the detection of ionic activities.

1.6.4.14 Schiff base as solvent extractant

Kim *et al.* deliberated the solvent extraction of Cu(II), Ni(II) and Co(II) using salophen and trace determination of above mentioned ions was finished in water samples. Macrocyclic Schiff bases encompassing thiophene or phenol subunits were created, and the outcome of ligand atoms on the liquid-liquid extraction of bi-valent transition metals was done [Abe *et al.* (1994), Vigato & Tamburini (2004)]. The phenolic groups in the macrocycle lead to an increase in the rate of extraction of transition metal ions. Likewise, the extractability of acyclic Schiff bases was established to be greater than of macrocyclic Schiff bases [Hadj *et al.* (2008), Zoubi (2013)].

1.6.4.15 Schiff bases and gels

For instance, a new mystifying region of supramolecular chemistry and materials sciences, supramolecular gels [Sangeetha & Maitra (2005)] are addressed to low molecular mass gelators (LMMGs) [Terech & Weiss (1997), Tu *et al.* (2011)]. Which have involved substantial contemplation during the last two decades with respect to their unique properties and their plentiful prospective applications in nanodevices, sensors, drug delivery and release, template synthesis, catalysis carriers, self-cleaning membranes, self-healing materials, and many more. In formation of supramolecular gels, the noncovalent intermolecular interactions are usually hydrogen bonding, van der Waals, $\pi - \pi$ stacking, electrostatic, dipole−dipole, or a combination of some of these. However, it was recently in the past decade that metal-ligand interactions have also been exploited to construct supramolecular gels [Foster & Steed (2010), Wang *et al.* (2015)], which were also baptized metallogels [Tam & Yam (2013)], and these metallogels have fascinated a rapid interest because the diversity of metal−ligand coordination could readily and delicately control the self-assembly progression and microstructures of gels and consequently influence the properties of gel. Furthermore, incorporation of metal centers could bequeath gels with some great fascinating properties [Wei *et al*. (2015)], such as photocatalysis [Zhou *et al*. (2019)], redox responsivity, gas adsorption, sensing, and so on.

Accordingly, metallogels would own multiple occupations that could not be obtained in gels prepared only by using organic small molecule gelators [Foster *et al.* (2010)]. It is eminent that the structures and coordination capabilities of ligands could yield a theatrical effect on topologies and functional properties of metal complexes. So, the design and selection of ligands are highly vital in preparing functional metallogels. Ligands with diverse structural features have been used in metallogels, for example, pyridyl-based compounds, porphyrin derivatives, carboxylic acids, azoles, and Schiff bases. In coordination chemistry, Schiff bases have enticed significant attentiveness not only because of their ability to construct metal−organic molecular architectures, but also their potential applications in the areas of magnetism, catalysis, analgesia, anti-inflammation antimicrobials, anti-biotics and especially anticancer activities.

Consequently, it is envisaged that using Schiff bases as ligands would mark metallogels with excellent belongings. However, very few reports are found on metallogels that utilize Schiff bases as organic ligands [Liu *et al.* (2009), Chen *et al.* (2015)]. Also, in all Schiff base ligand-based metallogels reported, the structures of Schiff base ligands include bigger blocks without any coordination ability such as long-chain alkyls and cholesterol

[Geiger *et al.* (1999)]. Schiff base ligands with simple structures till now have been largely used in crystal chemistry [Tarafder *et al.* (2002)] yet, and has been ignored in metallogels.

1.6.4.15.1 Definition and Classification of gels

As soon as any material seems to be wedged between liquid and solid-state, since it is not bowled away like fluid, but is more bendable than solid matter, this material could be designated as a gel or as jelly-like material. In the past century, scientists have made attempts to find a strong definition of the term gel. In 1926, Dorothy Jordon-Lloyd already accepted that "the colloidal condition, the gel, is one which is easier to recognize than to define." Almost about 50 years later, Paul John Flory offered a extra adaptive proposal to define a gel in his "Universal characteristics of a gel" which was widely accepted today. First and, almost universally recognized property, is the solid-like comportment that also can be perceived in rheological study [Terech *et al.* (2013)]. If a material's dynamical mechanical properties do not possess storage modulus, G', which is higher than G", the loss modulus, then the material can not be gel. As another requirement, at least for the full length of an experiment, the gel must own a constant structure with macroscopic dimensions [Wen & Tang (2015)].

Gel materials play an important role in day to day lives of people. Right from the beginning of human life, gels provide big convenience to each family like disposable diapers for the infants. Besides a polyethylene film and cotton, the most important ingredient is a super-absorbent polymer. When this super absorber catches contact with urine, a hydrogel is formed which keeps the baby dry [Singh *et al.* (2013)]. In agriculture also, the hydrogels have found an key role in water-saving practices [Sharma *et al.* (2014)]. Countries with arid and hot climate can get benefited from the fact that super absorbers impound water like a sponge with them. A further exceptional product that profit us from the hydrogels are contact lenses. In 1960 the Czech chemist Otto Wichterle first reported about hydrophilic gels for biological use. This was the very beginning of the expansion of soft hydrogel lenses, as they are widely used in day-today [Fonn *et al.* (2002)]. Hydrogels have also enabled revolutionary application in medicine by their ability to act in wound management systems [Gupta *et al.* (2002)]. Repithel®, for example, is a polyacrylate-based hydrogel with incorporated hydrosomes, these hydrogel dresses the wound without any need for gauzes and cotton and support a wet climate that provisions wound healing since it removes necrotic tissues. Additionally, the hydrosomes in the wound decompose into building blocks, which are then used for the regeneration of the damaged tissue. Also, organogels have found their applicability in the different fields since 1980 [Basak *et al.* (2012)], organogels have been applied for art conservation and provided a fresh approach for the cleaning of painted surfaces. This avoids the inevitability to put on organic solvents unswervingly to the work of art.

Furthermore, organogels may be used in medicine like Pluronic lecithin organogel, PLO as a drug delivery media in transdermal drug transport [Belgamwar *et al.* (2014)]. PLO enhances the skin permeation and fecilitate transport of the drug molecules into and across the skin at same time. The above-mentioned examples afford just a tiny facet of the extensive spectrum where gels find their solicitation, even when they only contain a small portion of the unalike classes of gels. All gels have one thing in common is that they consist of at least two parts, first part is called the gelator, which ensnares the solvent as the liquid. The gelator build up a 3D network that entraps the second part, the solvent [Gronwald *et al.* (2002)]. Most of the time, the liquid component offers the major part, and the gelator molecules immobilize up to 10^5 solvent molecules for each gelator molecule. The viscosity is highly scaled up by a factor of 10^{10} and can easily respond to diverse external stimuli. Not each molecule that lures to act as a good gelator, in first sight, will evolve the ability to gel a solvent since the gel state is an adequate balance amongst dissolution and crystallization. When a compound is dissolved applying heat where the concentration of the compound is higher than the solubility limit at RT, three potential circumstances can appear. When the molecules start to condense, an ordered aggregation could result in development of crystals. The second possibility is a haphazard aggregation that could offer amorphous precipitate. And the last alternate is an aggregation process that too between precipitation and crystallization, which finally leads to a gel material.

It is worthy to be mentioned here that the heating-cooling process is not the solitary way to obtain a gel [Lipińska *et al.* (2009), Yu *et al.* (2014)]. The major prerequisite for the gelation procedure is the pre-achievement of an isotropic solution of the gelator. In this concern, other non-thermal methods, such as pre-dissolution or sonication in a different solvent, can also be applied to encourage the gel formation.

1.6.4.15.2 Classification of gel

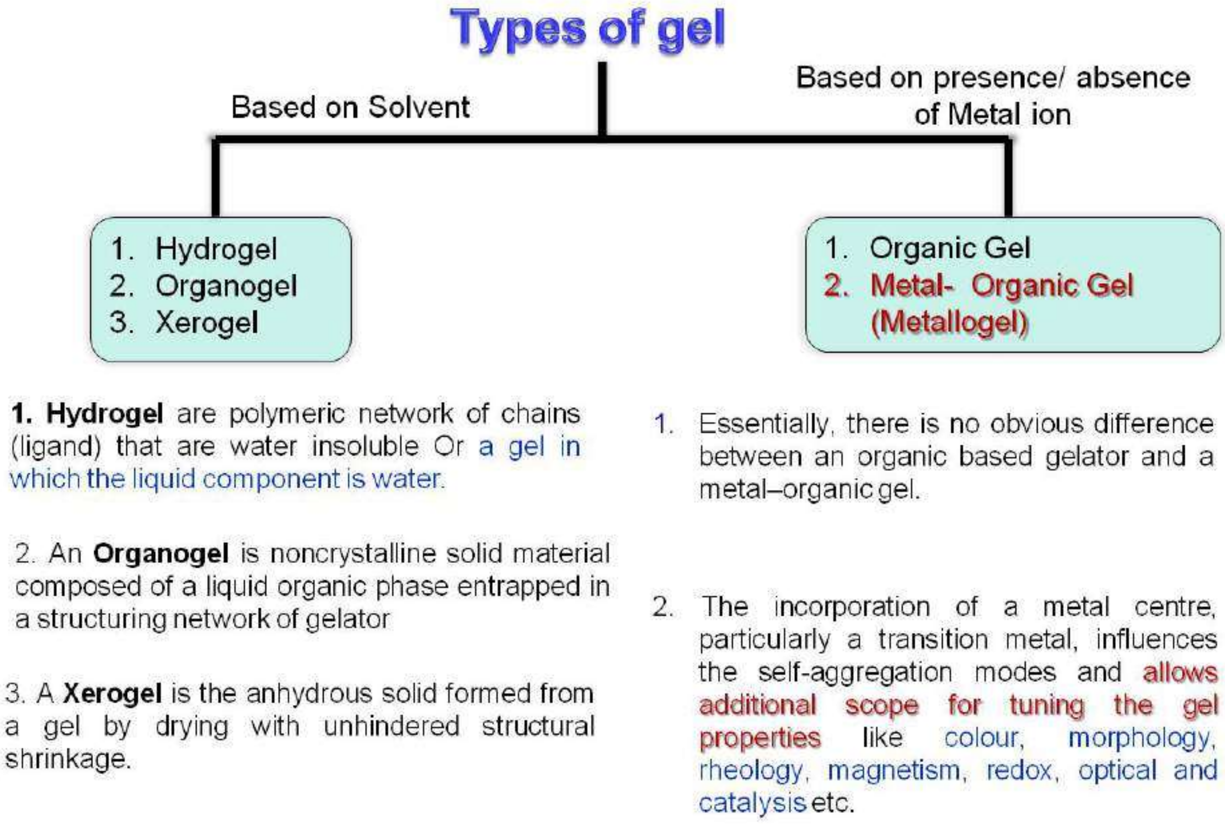
Gels can be categorized upon different criteria; one of the modest methods is to categorize them by identifying their solvent. If water is used as the solvent, it is termed hydrogel [Saito *et al.* (2007), Wu *et al*. (2016)]. If any organic solvent like ethanol, toluene or dichloromethane is used for preparation, it is called organogel in its place. Additionally, some unusual cases occur when the solvent is a mixture of organic solvent and water, for example, alcohol-water mixture. Aerogels are obtained when the solvent in the gel is substituted by gas without shrinking the original structure of gelator [Yang *et al.* (2015), Zhuang *et al.* (2014)]. Xerogels also show the same substitution of solvent by gas, but the change is that their gelator structure will suffer from attenuation [Luo & Lin (2007)].

Additionally, the gels can be illustrious by a natural or artificial origin of the gelator molecule. Like alginate, gelatin or chitosan, a huge number of natural gelators derived from flora and fauna exist [Zhang & Weiss (2016)]. Chitosan can be obtained from chitin, gelatin from skin and bones of animals, like fish, cattle or pork and alginate is extracted from seaweed. These materials are, therefore, inexpensive and practical as compared to artificial gelators which were synthesized in laboratories, where time-consuming synthesis and screening with expensive chemicals are mandatory. However, the artificial gelators can be fortified with certain building blocks that compromise various functionalities, for example, a photo-responsive azobenzene residue [Wang *et al.* (2010), Sun *et al.* (2014)]. The amalgamation of any functional group badges the gelator to form not only gel but also a smart material.

The third way of peculiarizing between gels is to scrutinize their motivating force for molecular aggregation. Naturally-derived gelators like the ones discoursed above are habitually macromolecular and use H-bonding and other physical cross-linking to form gels. Literature discriminates between two types of artificial gelator based gels i.e. chemical, and physical gels. Chemical gels are held unruffled by strong chemical bonds. They are attained by cross-linking macromolecular compounds [Imato *et al.* (2012), Kröger *et al.* (2008)], Physical gels are consequent from macromolecules or low molecular mass compounds, called supramolecular gels. Starting as of entangled Self-Assembled Fibrillar Networks (SAFINs), the small gelator molecules are capable to self-aggregate by one or in a combination of more than a few non-covalent, but intermolecular interactions [Ikkai & Shibayama (1999)]. van der Waals interactions, H-bonding, dipole-dipole interactions, π-π stacking, donor-acceptor interactions, metal coordination, hydrophobic or solvophobic forces are developing bonds which hold the structure of gelator together. Besides these, some systems include both types of connections.

The meekest way of expounding the difference between physical and chemical gels is to relate their distinct thermo reversibility [Westcott *et al.* (2009)]. Most of times chemical gels shows no re-dissolution due to the formation of chemical bonds. While weaker non-covalent interactions which Physical gels consist of, make them frequently thermally reversible. They could be easily liquefied upon heating up to their sol-to-gel transition temperature T_{gel} which causes the collapse of their 3D network and the re-formation of their 3 dimensional gelator structure upon re-cooling.

For both, chemical as well as physical gels, probable use in further fields of chemistry are conceivable, as both of them provide 3D networks, and they could easily act as reaction vessels and catalysts. Díaz Díaz and coworkers (2011), further classified gels as low molecular weight (LMW) and polymer gels, these polymer gels can build their gel network by non-covalent or covalent forces [Ahn *et al.* (2008)]. The polymeric gels were allocated into three groups: acrylamide- and PVA-based hydrogels, electroactive hydrogels, and biopolymer-based hydrogels. Where hydrogels, metallogels, and organogels [Tam *et al.* (2007)] form the three pillars for the low molecular weight gels (Figure 1.6).



1. Hydrogel
2. Organogel
3. Xerogel

1. Organic Gel
2. Metal- Organic Gel (Metallogel)

1. Hydrogel are polymeric network of chains (ligand) that are water insoluble Or a gel in which the liquid component is water.

2. An **Organogel** is noncrystalline solid material composed of a liquid organic phase entrapped in a structuring network of gelator

3. A **Xerogel** is the anhydrous solid formed from a gel by drying with unhindered structural shrinkage.

1. Essentially, there is no obvious difference between an organic based gelator and a metal–organic gel.

2. The incorporation of a metal centre, particularly a transition metal, influences the self-aggregation modes and allows additional scope for tuning the gel properties like colour, morphology, rheology, magnetism, redox, optical and catalysis etc.

Figure 1.6 Classification of LMW gels

1.6.4.15.3 Definition of supramolecular metallogels

Co-ordination polymeric gel or Supramolecular metallogels [Leong *et al.* (2008), Kim *et al*. (2005), Lee *et al.* (2011)] institute an imperative subcategory of solid-like metal ion and spanning organic ligand assemblies (similar to metal-organic frameworks) which custom three-dimensional networks by trapping the solvent as an outcome of non-covalent interactions. Though physical assets of these gels might be comparable to orthodox high molecular weight organic polymer gels, the coordination polymeric gels have often alienated themselves from the former. Being copiously rescindable in the occurrence of external stimuli (heat, shaking, sonication) to season a solution of solvated gelators. In contrast to gels subsequent from virginally organic self-assembled LMWG, metal ions being incorporated into the fibrillar networks bridging the bulk solvent can convey metallogels with surplus functionalities. The solid/liquid behavior of the gels permits external species to wander inside the gel system and intermingle with metals, ligands as well as solvent [Ajayaghosh & Praveen (2007)]. These dynamic structures, taking advantage from the coordination of metal ions, orientation of the organic polydentate ligands and functionality, or a blend of both properties display a prospective application in catalysis, chemosensing, fluorescence and drug-delivery.

Refinement of these systems through selection of metal ion and ligand via guiding self-assembly with external stimuli, the coherent synthesis of real-world systems can be visualized. Supramolecular interactions such as co-ordination bonding, hydrogen-bonds, π–π stacking, and hydrophobic interaction can easily formulate Metallogels. Kimizuka and co-workers provided a brilliant example of such metallogel by reporting the first thermally reversible gel networks in organic media. A lipophilic Co^{2+} complex of 4-(3-lauryloxy) propyl-1,2,4-triazole (LA) can be dissolved in chloroform to yield a blue colored gel (MG; MG=Metallogel) at room temperature., The gel turns into a pale pink solution upon cooling below 25 °C which is a result of profusely reversible thermochromic transition from tetrahedral geometry of Co^{2+} to octahedral.

1.6.4.16 Luminescent Studies

Luminescent materials with highly fundamental and technical repercussions epitomize a swiftly evolving area and have gained great academic and industrial interest [Zhou *et al*. (2014), Jüstel *et al.* (1998)]. Most of times the basic practices of luminescent materials are steered in solution state with substantial intermolecular connections between solvent molecules, but slight interactions amidst the dyes. However, in reality, the dyes are frequently exploited in the aggregated states through intimate contact amid themselves. For example, the hydrophobic luminogens meant for chemo-sensing and biological solicitations applied in aqueous media, while materials prepared for devices used in solid states [Hong *et al*. (2009), Hu *et al.* (2014)]. The study of emission in aggregated state of luminescent materials is therefore of boundless fundamental reputation. Highly significant with their numerous potential applications like fluorescent bio-imaging agent, chemo/biosensors, organic light-emitting diodes (OLEDs), as well as in optoelectronic devices [Sun *et al.* (2019), Han *et al.* (2018)].

1.6.4.16.1 Aggregation caused Quenching and Emission

The solution studies have made prodigious offerings at a molecular level to the basic considerate of luminescence processes. The assumptions are strained from the dilute solution analysis; still, cannot universally be protracted to the solutions with high concentration. Indeed, most of organic luminophores demonstrate different light-emitting behaviors in dilute and concentrated solutions [Zhao *et al.* (2013), Yuan *et al.* (2010)]. For example, luminescence is generally quenched or wekened at high concentrations, widely known as ‘‘concentration quenching’’ phenomenon. Core reason for the quenching process is associated mechanistically through the ‘‘formation of aggregates’’, which is perhaps why the concentration quenching effect has normally been called as ‘‘aggregation-caused quenching’’ (ACQ) [Yuan *et al.* (2010), Guo *et al.* (2016), Jiang *et al.* (2018)]. The dilute solution (10 mM) of N,N-dicyclohexyl-1,7-dibromo-3,4,9,10-perylenetetracarboxylic diimide (DDPD) in THF was found highly luminescent. Quenching in emission is observed upon water addition into THF since the immiscibility of DDPD in water increases the concentration of local luminophore and aggregate of DDPD molecules occur. With upto the 60 vol% increase in water content, the solvating ability of the THF/water mixture turns so poor that DDPD molecules become aggregated mostly. The light emission of DDPD is entirely quenched as an outcome of aggregate formation. The DDPD molecule comprehends a disc-like perylene core, where the perylene rings may observe strong π–π stacking interactions in the DDPD aggregates. This stimulate the establishment of such detrimental species as excimers, hence leads to the apparent ACQ effect. As Birks summarized in his classic book of photophysics, the ACQ effect is "most common to aromatic hydrocarbons and their derivatives". Typical containment of planar aromatic rings in conventional luminophores are the structural motivation for the ubiquity of the ACQ effect (e.g., perylene).

Since electronic conjugation are prime administrator of organic luminescence, merging more and more aromatic rings collectively is a widespread structural design scheme to escalate the extent of π-conjugation. The bigger discotic plates can result more efficient luminesce in the solutions, but concomitantly, with increase in chances of such huge luminophores to form excimers or exciplexes their ACQ effects also become pronounced. Inorganic luminophoric systems, such as quantum dots also possess the ACQ effect. From the lookout of real-world applications ACQ effect is normally measured disadvantageous. For example, luminophores have been applied as sensors to perceive biological molecules in physiological buffers and as probes to scrutinize ionic species present in river water. Although chromophoric unit are rendered hydrophilic by attaching polar functional groups, the subsequent water-miscible luminophores due to the unalterable hydrophobicity of their active components in π-conjugated aromatic rings are quiet prone to form aggregates in aqueous media. Towards assemblage of efficient organic light-emitting diodes (OLEDs), where the luminophores are used as thin solid films the ACQ effect is still a trouble [Lin *et al*. (2016)]. ACQ effect converts most unadorned in the solid-state since the luminophore concentration stretches its maxima due to the lack of solvent. Research groups have made abundant efforts to challenge the problem since ACQ effect is detrimental to real-world applications.

Using chemical reactions, physical approaches or engineering progressions are some collective maneuvers to obstruct the development of luminophoric aggregates. For example, in direction to hamper the luminophores from approaching each other colossal cyclic units that are affixed to transparent polymers are unified with chromophores. However, limitation of the conjugation span and a drop in the OLED efficiency opon practicing the electronically non-conjugated entities owe to the encouraged twist in the luminophore conformation and hurdle towards charge transport. An old concern is partly resolved, but countless new difficulties are fashioned and these tactics thus often terminated up in such an excruciating net outcome. Since luminophoric molecules have an inherent propensity to form aggregates in the solid-state or concentrated solutions, basic crux of the matter is that these efforts are running counter to a natural phenomenon. Since it is not ingenious to "sail against the current" our way of approach in undertaking the difficulty, needs to be changed profoundly. In 2001, an unusual luminogenic system was discovered, in which aggregation functioned in constructive manner, rather than the conventional structures where they act destructively. A series of silole derivatives in dilute solutions were recognized as non-emissive but as soon as their molecules remained aggregated in concentrated solutions or casted into solid films display high luminescence. Process was labeled as "aggregation-induced emission" (AIE) since the light emission was encouraged by aggregate formation [Luo *et al*. (2001), Mei *et al*.

(2015), Mei *et al.* (2014)]. Constructive AIE effect is exactly reverse to the infamous ACQ effect (Figure 1.7), which makes it promising for technologists to aggressively exploit the aggregation process, instead of unreceptively working in contradiction of it.

There has been an extensive investigation in dilute solutions for mechanism of photophysical processes. In distinction to it, there is much less study upon luminescence behaviors in the aggregated state. The capability of AIE process offers a platform to experts in order of investigating probable light emissions from luminogenic aggregates and provide intuitions into working mechanisms alongwith structure-property associations. Structural design for the advancement of efficient luminogens will obtain directives from such informations. The AIE studies moreover leads to formerly dreadful technological originations since this photophysical effect of the light emission befall in the practically beneficial solid-state. Many groups have drove on the designing and synthesis of new AIE luminogens being attracted to fascinating results, intonation and synthesis of their aggregate morphologies, and examination and operation of their luminescent properties. Organic, organometallic, and polymeric luminogens, alongwith unorthodox systems comprehending no chromophores in the old-styled fashion are few typical examples of AIE systems established by several scientific groups. In a struggle to abstract evidence on their structure-property interactions and derive structural-design approaches for crafting new AIE systems they also drove towards mechanistic and functioning principles of the AIE progressions.

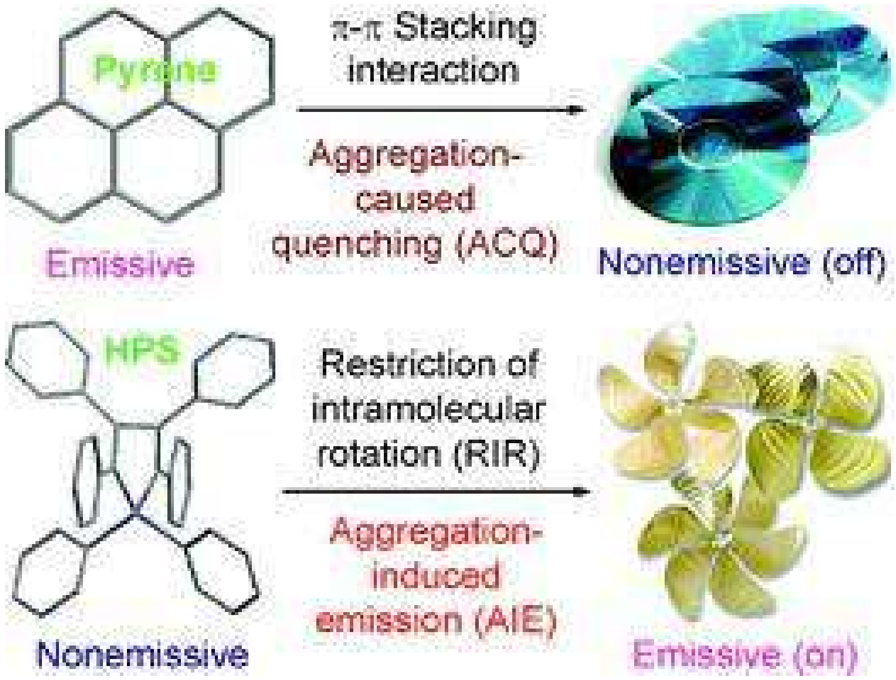


Figure 1.7 (A) Planar luminophoric molecules like perylene have a tendency to aggregate as pile up discs, owing to the strong π–π stacking interactions among the aromatic rings, which normally acts as turns "off" light emission. (B) whereas non-planar luminogenic molecules like hexaphenylsilole (HPS) with their turned "on" light emissions by aggregate formation perform oppositely, owed to restriction of the intramolecular rotation (RIR) of the multiple phenyl rotors against the silole stator in the aggregate state [Luo *et al*. (2001), Mei *et al*. (2015), Mei *et al.* (2014)]

1.7 Research Objectives

The main objective of this Ph.D. work was the development of new Schiff base ligands and their application towards the formation of metallogels and luminophores for bioimaging and their studies in terms of structure, functionalities, preparation techniques, gelation mechanism, and potential applications, Aggregation induced emission and Quenching mechanism.

The different components of this work have been partitioned into six sections. The results contribute to the overall goal of design and preparation of metallo-supramolecular gels, as well as the characterization of their stimuli-responsive properties, particularly focusing on the rheological properties. The sixth chapter will describe the Aggregation induced emission and quenching behavior of Pyrene derived luminophore and its application in bioimaging and cell imaging properties.

The purpose of the research reported herein was to develop a better understanding of the mechanism of gel formation in these materials and subsequently to elucidate in more detail the nature of their responsiveness to environmental stimuli, particularly mechanical, thermal and chemical. Also, the potential for controlling the gelation process and manipulating the gel properties in various ways, such as solvent composition, metal ion composition, monomer structure, and so on, will be explored.

From the extensive literature survey and the aforementioned information, the goal of this research work is to fabricate and explore easy and simple method to develop Schiff base derived fluorescent materials to exhibits gelation behaviour and AIE properties for the cell imaging application (Figure 1.8). This research work also aims to develop new materials with easy synthetic strategy and economic viability.

Thus the main objectives of the present research work are as follow:

- Design and Synthesis of Schiff base ligands for gelation and fluorescent properties.
- To study the effect of various stimuli and structural modification over gelation properties.
- Design and Synthesis of AIE active materials via a simple and easy method

- Tuning the size and optical properties of AIE active materials by varying the water fraction in the organic solvent

Characterization of these Schiff base gelators and fluorescent materials by various instrumental techniques like

a) ^{1}H- NMR and ^{13}C-NMR analysis

b) Mass spectroscopy

c) Fourier Transform Infrared Spectroscopy (FT-IR) analysis

d) UV-visible spectroscopy

e) Fluorescence lifetime measurement

f) Fluorescence Spectrometry

g) Scanning Electron Microscopy (SEM) Analysis

h) Transmission Electron Microscopy (TEM) Analysis

i) Rheology

j) Atomic Force Microscopy (AFM) Analysis

- Utilization of Schiff bases as plausible gelators for various mechano-responsive and stimuli responsive behaviour.

- Utilization of the synthesized AIE active material as a cell imaging agent

➢ Utilization of synthesized fluorescent Schiff base gelators in various applications.

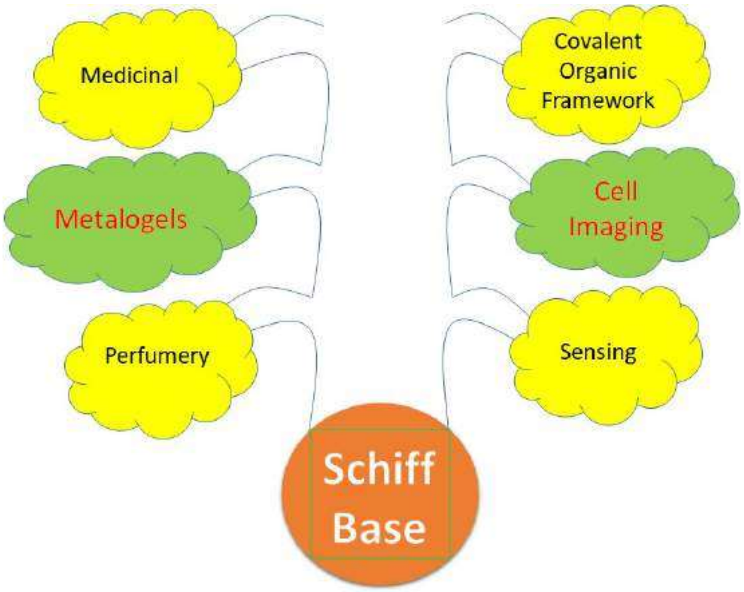


Figure 1.8 applications of Schiff bases in various fields