

Schiff Bases and Their Complexities: A Review

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ABSTRACT

Objective: H. Schiff of Germany made the first attempts at preparing the Schiff bases in 1864, first showing that primary aliphatic or aromatic amines could react with ketones or aldehydes to form condensed monoalkyl or monoaryl imines with little change in the stereochemistry of the carbonyl carbon. The identification of this led to a long history of development of Schiff base research, which prompted chemists to find novel analogues that have better biological and therapeutic properties. **Method:** When Schiff bases are complexed with metallic ions, they often form very stable complexes that have shown promising antibacterial, antifungal, and anticancer effects. They can play an important role in coordination chemistry, largely because the azomethine (C=N) functional group has a strong binding capacity and is able to interact with a large range of metal ions, especially transition metal ions. **Results:** Schiff bases have the azomethine motif (C=N-R₂) structurally and can be made highly reactive with the inclusion of heterocyclic compounds like pyrazole or imidazole. **Novelty:** A combination of these rings with the Schiff base skeleton frequently leads to the production of compounds which exhibit significant antifungal properties.

INTRODUCTION

The Schiff bases are organic compounds formed by the reaction of a primary amine with aldehydes or ketones, by linking the nitrogen atom in the amine group to the carbonyl group in or other aldehydes to form a group Azomethine C=N-R R₂, which is most commonly obtained by subliming a ketone or aldehyde with a primary amine, with the R group being either aryl or alkyl. [1]. Schiff bases with aryl substituents are more stable and faster to form than their alkyl-substituted counterparts, and Schiff bases form aliphatic aldehydes, which are unstable and ready to proceed to the polymerization process, and aromatic aldehydes, which contain active electron exchange, are more stable. The nature of the reaction that is needed to make a Schiff base is the condensation reaction of ketones or aldehydes, which is a reverse-type reaction. This reaction is carried out in an acidic or a basic catalyst medium or in the presence of a heating process, as is the case in the following diagram [2], [3].

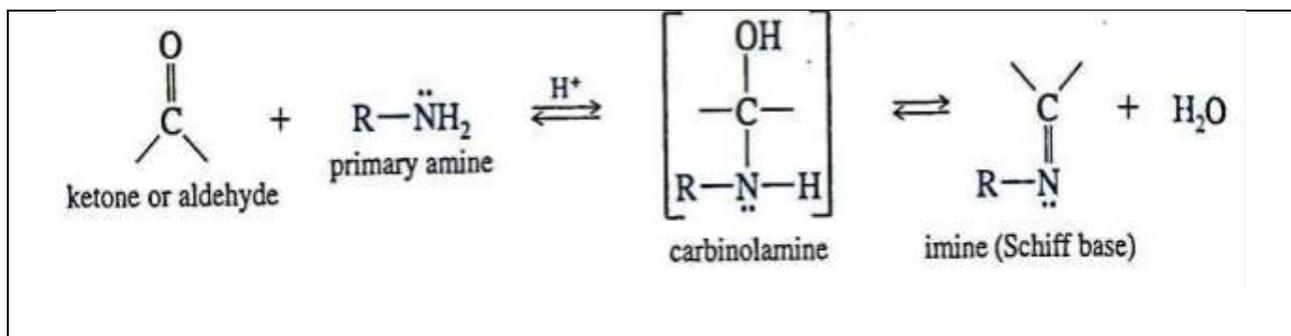


Figure 1. General representations of the Schiff bases.

This is because the ability to dissociate a water molecule from the unstable compound (carbinolamine) can be referred to as the step that dictates the reaction speed. This is reckoned the chief cause of allowing acids to excite the reaction, and this necessitates that the acid be unconcentrated, since the amine group here will be affected by the concentrated acid and therefore will separate and lose its property.

Hence, the reaction equilibrium moves to the left, and the intermediate product (carbinolamine) is not obtained [4]. Thus, the majority of the reaction in the preparation of Schiff bases takes place in a moderately acidic medium of pH. Schiff base reactions are included. Addition reacts with the azomethine functionality on the amine, to which the reagent is introduced on the polar and double bond. These nucleophilic reagents react with the carbon atom of the bond of the azomethine group. An example of such a reaction is the addition of alkyl halides, which form the quaternary amino salts, which in turn convert to the secondary amine group. The nitrogenous compounds are known as Schiff bases and resemble ketones or aldehydes in the event that their amino group is substituted with an azomethine amino group (C=N). It is a form of amine which is formed by a carbon atom that is connected to a nitrogen atom by a double bond and a group consisting of an aryl or alkyl group. Ready by the scientist Hugo chef [5].

1. The chemical properties of Schiff bases

The nature and location of substituents to the nitrogen in the azomethine structure greatly affect several properties of Schiff bases. The nitrogen electronegative groups tend to enhance the imine bond strength. It is exemplified by the fact that oximes, phenylhydrazones, semicarbazones, i.e., those in which the hydroxyl or NH groups are attached to the nitrogen, are far more resistant to hydrolysis than Schiff bases in which the corresponding alkyl or aryl groups are attached to the nitrogen group. In spite of the fact that the Schiff bases are stable in alkaline media, they are prone to hydrolysis in acidic conditions, which will result in the recovery of the parent amine and carbonyl group. Since the water is formed during their formation, the balance may reverse unless the reaction mixture is dried. Due to this reason, it is common to conduct the synthesis in solvents that are able to remove water azeotropically. With amines that are electronegative and have lone pairs, the reaction is typically a high-yield process, and the resulting Schiff bases can be isolated in high yield, as reflected in Figure 2. Schiff bases usually have their structures comprising tautomeric structures that can change with the solvent polarity and intramolecular hydrogen bonding. The same is supported by

quantum mechanical studies that have shown that a non-planar arrangement (Figure 3) is the most stable one.

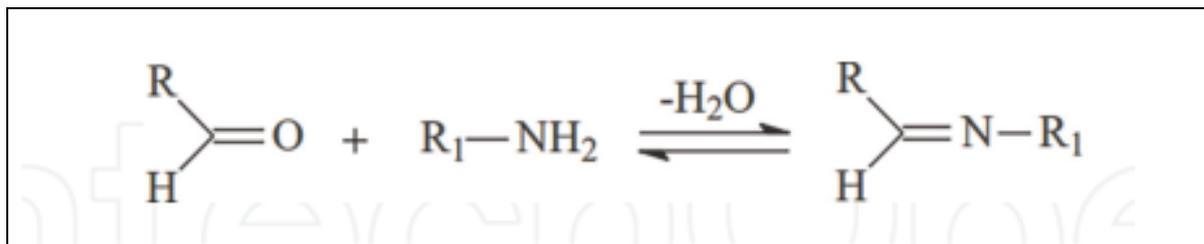


Figure 2. Reaction of Schiff base formation.

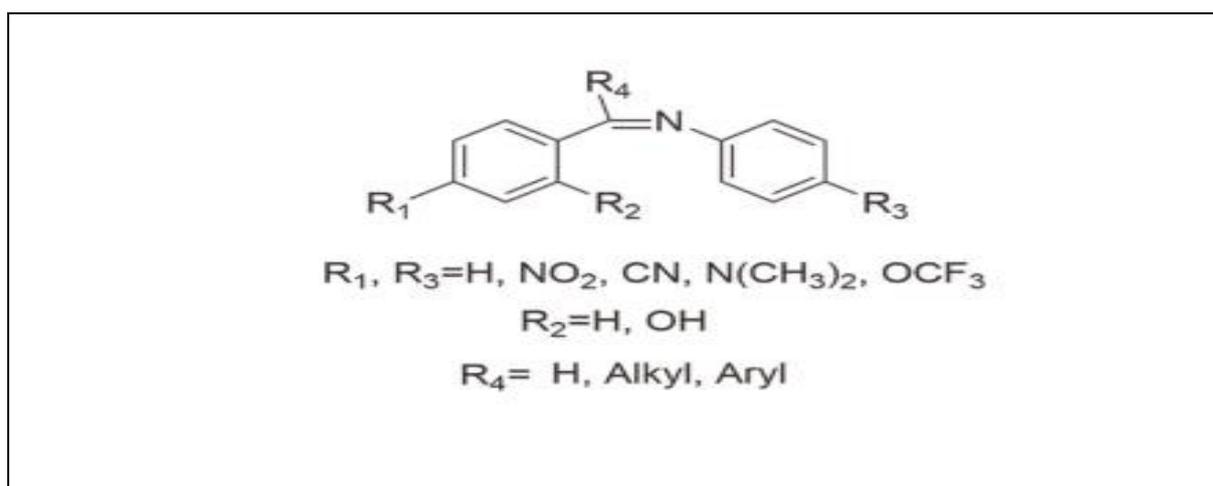


Figure 3. Schiff bases' preferred conformation.

2. Physical characteristics of Schiff bases

The appearance of the schiff bases depends on the form as crystalline or colored solids. They are applicable in the determination of carbonyl containing compounds and the concentration of metal ions because the C=N bond is comparatively active and is readily isomerized unlike a carbon-carbon double bond. The polarization of the bond between the two atoms in the azomethine linkage is caused by the relative electronegativity of nitrogen and carbon, which is greater in nitrogen than in carbon (Figure 4). The energy difference between the two isomeric species is very low making the separation of the stereoisomer of most of the Schiff bases to be very difficult. But in the case of an electronegative substituent that moves the nitrogen it enhances the rotational barrier around the C=N bond such that the isomers can be separated. Since these substituents cause the electron density to be pulled towards nitrogen, polarization reduces and this consequently enhances the double-bond nature of the azomethine group [7]. A compound with the azomethine moiety acts as a basic compound because of the free pair on the nitrogen atom as well as the electron giving disposition of C=N bond. They, however, are less basic than the analogous amines. This decrease is possible due to the fact that the nitrogen atom that was sp³ hybridized in the amines transforms to sp² in imines, thus, enhancing the s-character and decreasing the presence of the lone pair of electrons to protons [8].

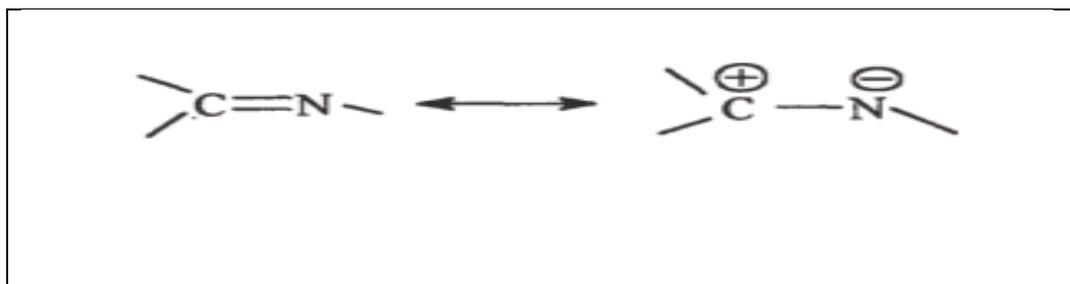


Figure 4. Azomethine bond polarization.

3. Synthesis procedures of Schiff Rules

3.1 Reaction of organometallic compounds with nitriles:

Nitriles are also able to react by addition reactions with Grignard reagents to give ketimines. Due to the ease with which the intermediary imine product can be hydrolyzed to its ketone counterpart, reaction under conditions where no water is allowed to enter is typically employed. To avoid this undesirable hydrolysis, dry hydrogen chloride or ammonia is usually added to the reaction mixture. This plan enables the potential isolation of the ketimine intermediates, usually with a yield of between 50 and 90 percent, as shown in Figure 5.

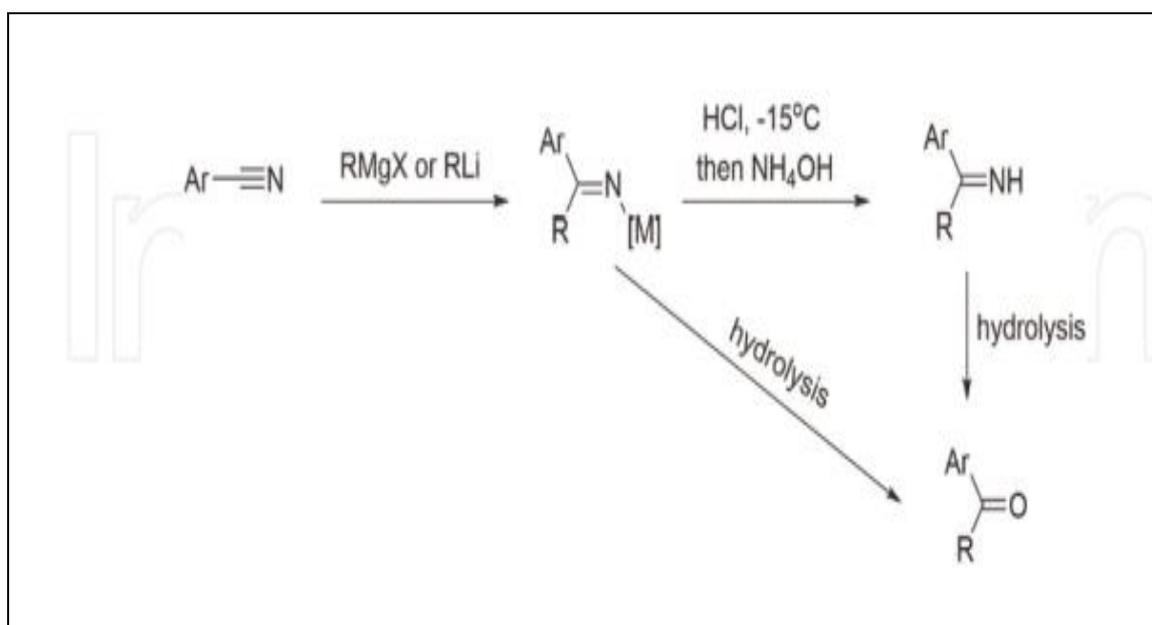


Figure 5. Reaction of organometallic to nitriles.

3.2 Reaction of aldehydes and ketones with primary amines:

Primary amines tend to react with the carbonyl groups via refluxing to form Schiff bases. Because this conversion is reversible, water generated in the process of condensation should be continuously eliminated to prevent the reversal of the reaction. The most popular methods of water-removal involve the utilization of a Dean-Stark device, or of dehydrating materials like molecular sieves or sodium sulfate. Also, the reaction can be fastened by acid-catalysis, which can be added. In different solvent

systems, catalysts including mineral acids (H_2SO_4 , HCl), organic acids (p-toluenesulfonic acid), acidic resins, or even Lewis acids ($ZnCl_2$, $TiCl_4$, $SnCl_4$, $BF_3 \cdot Et_2O$) are often used. Other dehydrating agents, such as tetramethylorthosilicate and trimethylorthoformate, have also been found to be effective.

3.3 Reaction of phenols, phenol ethers, and nitriles.

In acid catalysis, the alkyl or aryl nitriles undergo addition to both phenol and phenol ethers to form ketimines [15]. This is done by saturating a solution containing nitrile and phenol dissolved in ether with the HCl gas. With lower reactivity phenols, $ZnCl_2$ is recommended in the reaction (Figure 6).

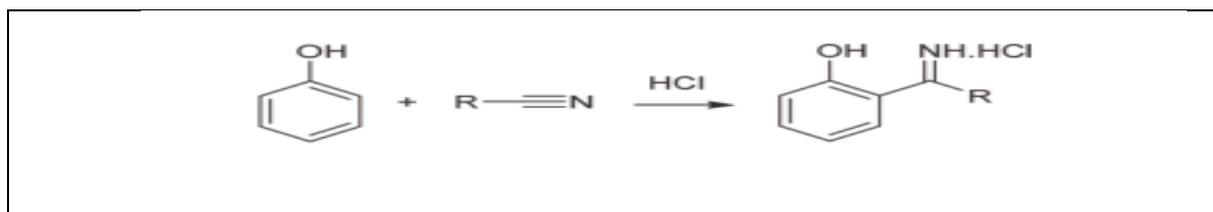


Figure 6. Mixed with nitriles and phenols: reaction.

3.4 Reaction of metal amides

Primary amines that are reduced to the alkali- or alkaline-earth-metal amide salts can be used to react with aromatic ketones to form Schiff bases. This metal amide reagent is a strong nucleophile, which reacts to form the imine bond. It is a simple synthetic pathway to the production of Schiff bases by aromatic ketones.

3.5 Aerobic oxidative synthesis procedure

The oxidation of alcohols to imines can also be used as a pathway to produce aldehydes and ketones, and with that, the primary and secondary amines can be oxidatively coupled to form imines (Figures 11 and 12). Based on this strategy, Huang and Largeron invented catalyst systems that are able to convert alcohols to imines using oxygen in the atmosphere as the oxidant, under mild conditions. These aerobic oxidation procedures provide cleaner and more efficient synthetic paths having less by-products and reaction conditions that are environmentally favorable.

4. New ways of synthesizing Schiff base

Interestingly, imine compounds are used in a different manner in medicine as well as industry. Therefore, chemists have wasted a lot of time demonstrating the best ways of preparing new materials with the imine group.

4.1 The use of glacial acetic acid and ethanol as a catalyst.

A synthetic procedure for Schiff bases via the condensation of aromatic aldehydes with 4-aminobenzenesulfonamide derivatives in the presence of glacial acetic acid at ~ 60 degC has been developed. The catalytic system effectively forms imine products, and a series of sulfonamide-based Schiff bases are obtained. The compounds so synthesized possess significant antimicrobials and antifungals at high concentrations against *Bacillus subtilis*, *Staphylococcus aureus*, *Escherichia coli*, *Salmonella typhi*, *Candida albicans*, and *Aspergillus niger*.

4.2 Schiff base synthesis by the method of microwave-assisted synthesis.

The microwave heating method has emerged in recent years as a useful method to activate a great number of chemical reactions. It was shown that the reaction of aniline derivatives with different aromatic aldehydes can be done in a quicker, purer, and solvent-free reaction with the help of aid of microwave irradiation. Purification of products in various appropriate solvents was done by the recrystallization method, and it demonstrated an excellent yield with high purity [21], [22]. Microwave technique was used to make different types of Schiff base compounds in a reaction extremely fast, one or two minutes instead of two hours without a microwave, and at room temperature (Figure 7) [23].

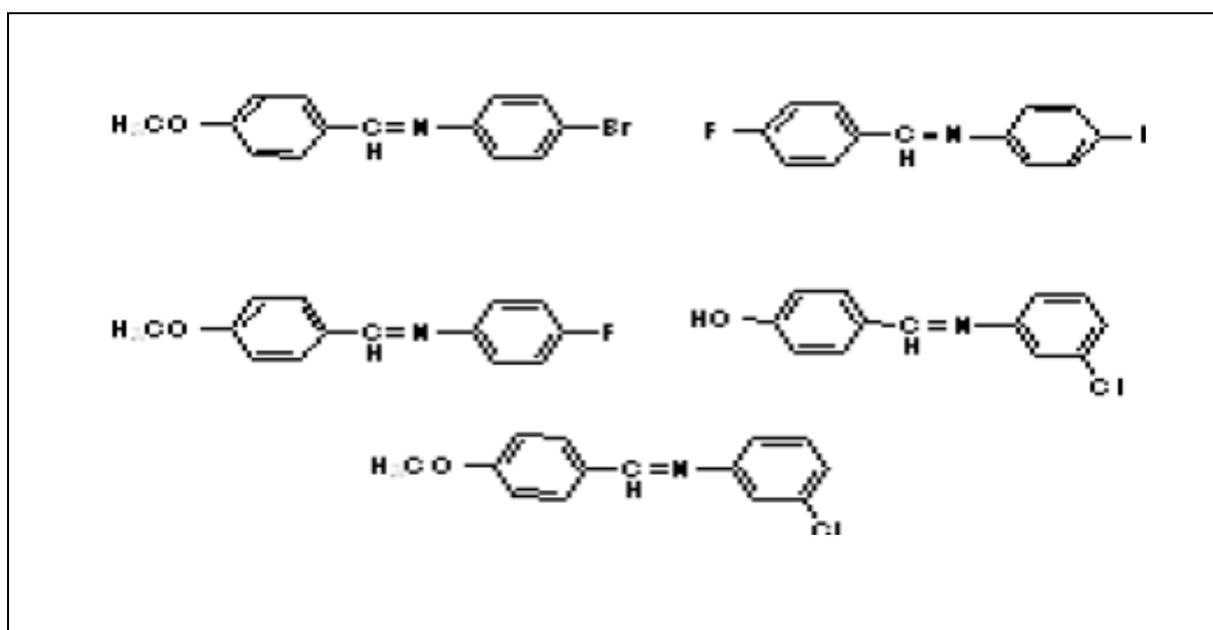


Figure 7. Schiff base compounds.

4.3 Synthesis of the Schiff base with the use of natural catalysts

Lemon juice is a natural acidic catalyst that can be used to prepare Schiff bases in an eco-friendly, solvent-free manner. Imine formation happens quickly without the use of organic solvents when an aromatic amine and an aromatic aldehyde are mixed at room temperature in the presence of a catalyst rich in citric acid. After straightforward purification, the reaction usually yields a high yield, frequently yielding crystalline products with efficiencies as high as 94%. This technique reduces toxic waste, cuts expenses, and speeds up reaction times.



Figure 8. Synthesis of Schiff base using natural acid (lemon juice) as a catalyst.

4.4 When synthesizing under UV Rays.

A mixture of p-toluidine and vanillin was shaken and put in the UV Chamber over a period of 15 min, as revealed in Figure 9. The resulting product was a pale yellow color, which shows that the reaction is complete. The crude product was purified using the shock cooling recrystallization method, and it yielded an excellent product of approximately 97% in the form of a beautiful crystal. Therefore, in the traditional process, it only provides 78 percent. Additionally, the duration taken by the conventional technique is higher, i.e., 1-1.5 hours, as compared to the reaction time of approximately 15 minutes when UV light was used [26], [27].

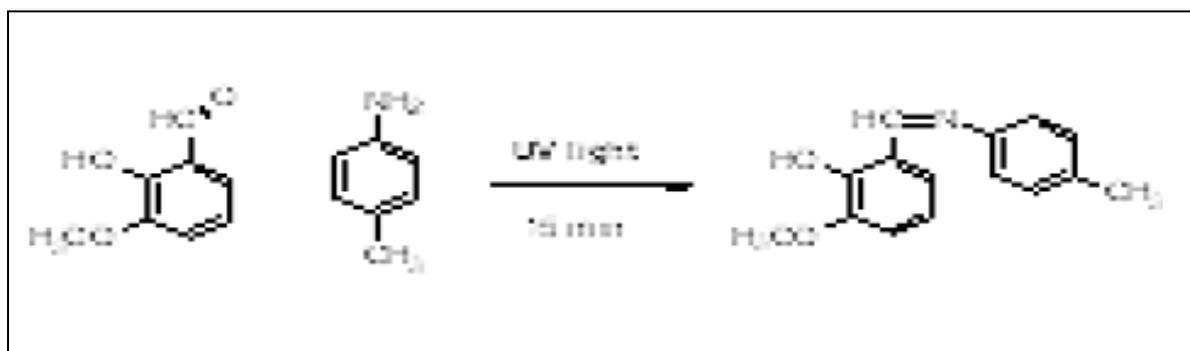


Figure 9. The preparation of the Schiff base compound under UV light.

4.5 Synthesis through application of a sonicator.

A- Without catalyst: Vanillin (0.05 mole) was dissolved in methanol (5 ML) in another container, and p-toluidine 0.05 mole was dissolved in the same solvent. Then, the two contents were combined in a beaker, which was put in a sonicator for approximately 15 minutes at 44 o C. The crude product was purified by the shock cooling recrystallization method, and a good yield of approximately 97 percent was obtained, as the product was an excellent crystal. Therefore, the classical procedure yields only 78%, [28], [29].

B- With a catalyst. The catalyst-assisted sonication method involves dissolving vanillin in methanol, mixing it with p-toluidine, and then adding a few drops of acetic acid. The mixture is exposed to ultrasonic radiation for nine to ten minutes at a temperature of about 45 degrees Celsius. Imine production is indicated by the formation of a pale yellow solid. The Schiff base is obtained in excellent yield – often above 98% – after purification by shock-cooling recrystallization, usually with ethanol. This process

minimizes by-product formation, requires milder conditions, and is quicker than classical methods.

5. Classification of Schiff bases

The number of azomethine groups ($C=N$) is the basis of the classification of the Schiff bases based on the number of groups and the number of sites that they can provide during the coordination.

5.1 Monodentate Schiff Bases

They have one $C=N$ bond and offer only one donor atom, which can be bound to a metal center. They are the simplest type of Schiff-base ligands, as their structure is simple (Fig. 10).

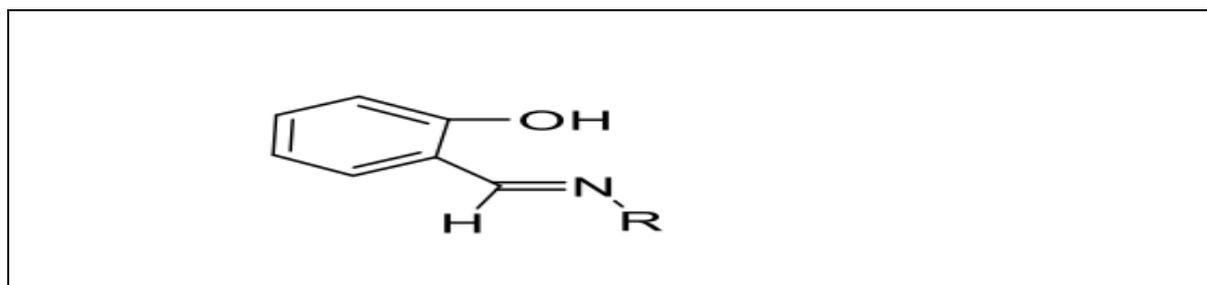


Figure 10. Monodentate Schiff base.

5.2 Bidentate Schiff Bases

Bidentate variants have two azomethine linkages or an azomethine bond conditioned with another donor group, thereby permitting them to bind using two coordination locations. This bi-valent binding makes the resultant complexes more stable (Fig. 11).

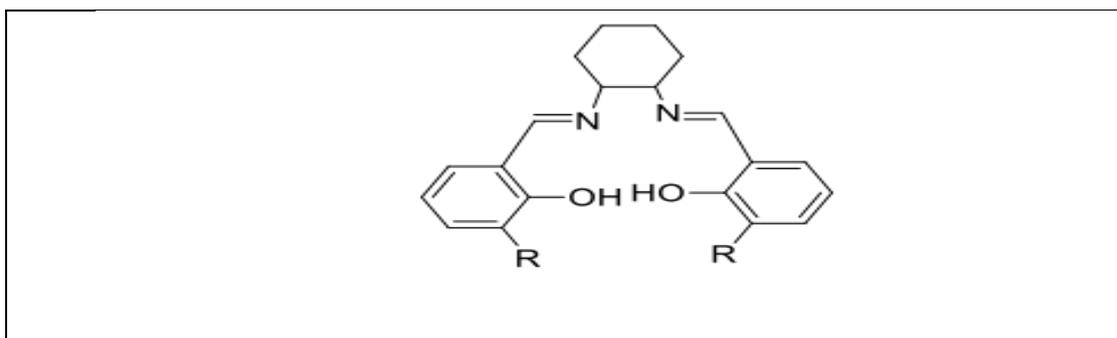


Figure 11. Bidentate Schiff base.

5.3 Polydentate Schiff Bases

These ligands have three or more donor atoms, normally due to a series of $C=N$ groups or auxiliary functional groups. They are multidentate, which gives them the ability to form large and stable chelate rings and more complex metal complexes (Fig. 12).

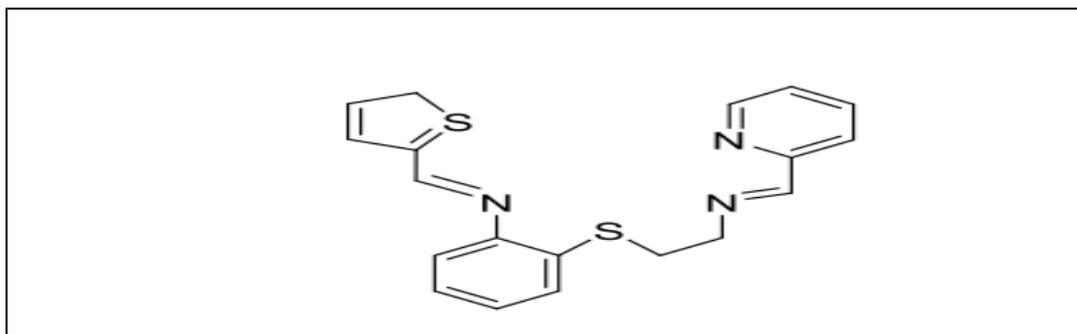


Figure 12. Polydentate Schiff base.

6. Reactions of Schiff bases

6.1 Reaction with HCN

Schiff bases easily add HCN to the equal part of the C=N bond to create derivatives of nitriles. Further hydrolysis of these intermediates yields α -amino acids; thus, this conversion is handy in synthetic organic chemistry (Fig. 13).

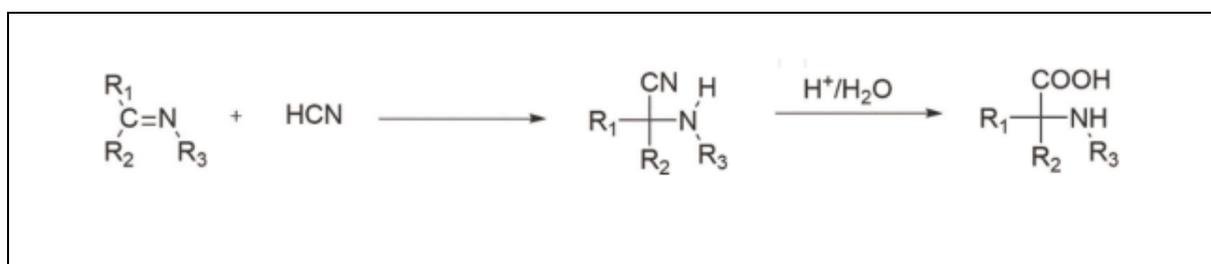


Figure 13. Reaction with HCN.

6.2 Reduction reactions:

Ordinary reducing agents, such as LiAlH_4 , NaBH_4 , and sodium in ethanol, transform the C=N bond in Schiff bases to secondary amines. The transformation is commonly applied to the synthesis of amine derivatives of imine intermediates (Fig. 14).

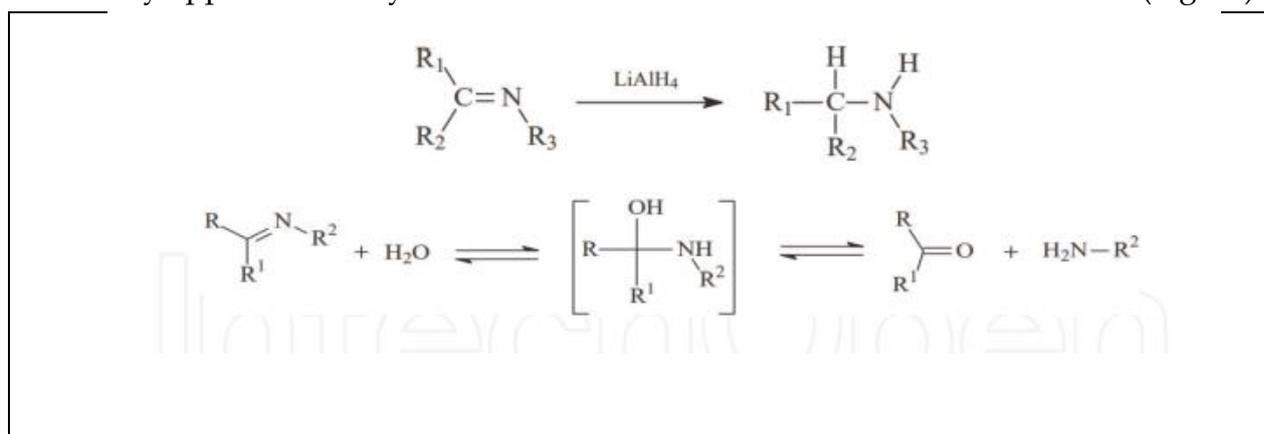


Figure 14. Reduction reactions.

6.3 Hydrolysis:

Since Schiff bases are condensed reversibly to yield the end products as amines and carbonyl compounds, they can be broken down under hydrolysis conditions into their

constituent molecules. Hydrolysis is normally catalyzed by a carbinolamine intermediate, and the rate of the reaction is much more active in acidic conditions.

6.4 Polymerization reaction:

Bifunctional aldehydes and amines found in the Schiff bases are capable of step-growth polymerizations to make poly(azomethine) or poly (Schiff base). These polymers have the following properties: liquid crystallinity, thermal stability, and electronic conductivity (Fig. 15).

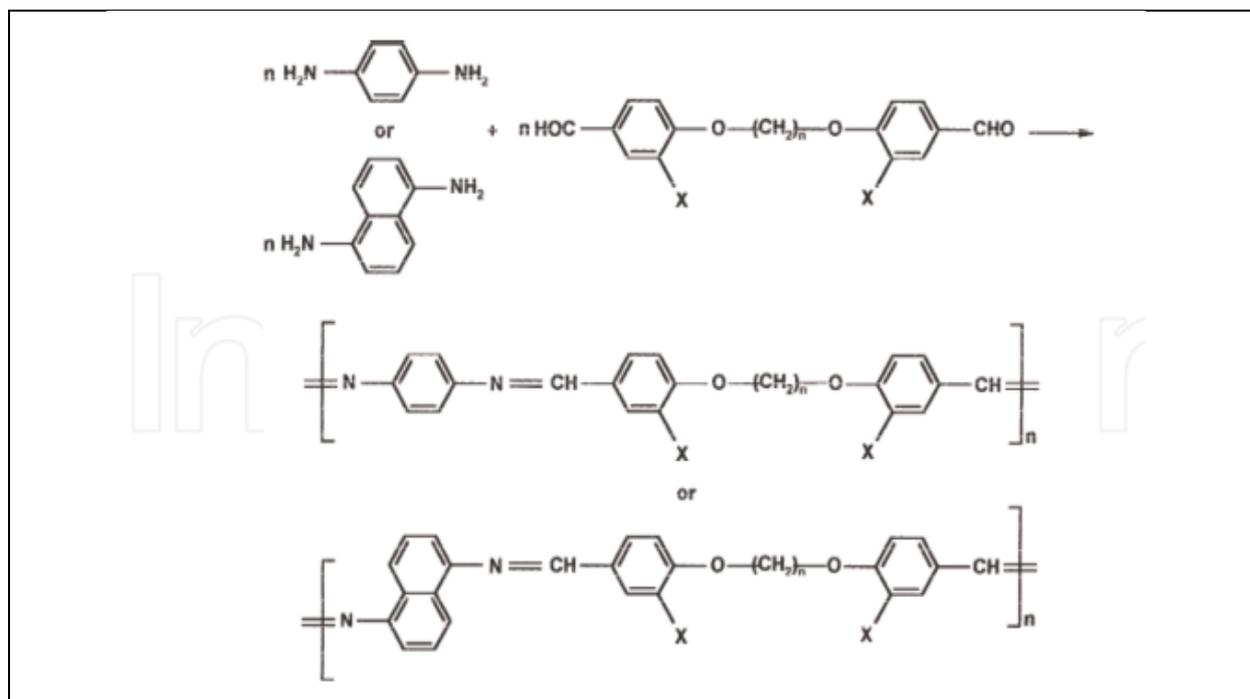


Figure 15. Polymer synthesis.

6.5 Zn and haloesters reaction:

Schiff bases reacted with haloesters and zinc at room temperature may produce β -lactam rings as a useful structural motif of medicinal chemistry. This can be dubbed the Schneiderman reaction (Fig. 16).

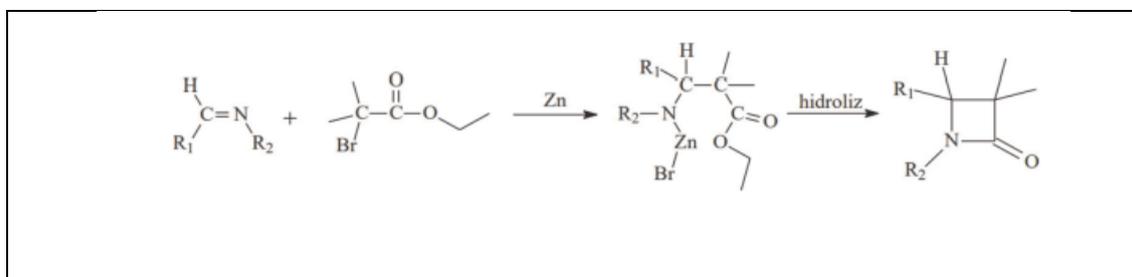


Figure 16. Zn and haloester reaction.

7. Schiff base metal complexes:

One of the most common systems of ligands used in coordination chemistry is the Schiff bases. The fact that they contain an imine nitrogen with a single electron pair gives them the capacity to act as Lewis bases and allows them to bind transition-metal ions

with high affinity. The azomethine nitrogen is the main site of coordination, although the carbon-nitrogen double bond may also take part in π -back bonding with metals, making the complexes formed thereby more stable. Schiff base ligands with extra donor groups, especially hydroxyl or thiol groups bound ortho to the imine bond, easily form stable six-membered chelate rings with metal ions, resulting in a wide assortment of structurally varied complexes.

7.1 Symmetrical and asymmetrical Schiff bases.

Schiff bases can either be symmetrical or asymmetrical, based on the availability of an internal symmetry element or not. Symmetrical ligands have a mirror plane or axis of rotation, but asymmetrical ligands do not. The asymmetrical Schiff bases have received more attention due to the fact that they are more similar to the binding environment of biological systems and can react with metal ions in a more specific manner. They also have structural variability, which enables them to build natural and synthetic coordination structures. Symmetrical and asymmetrical examples of salphen-type ligands are presented in Figure 17.

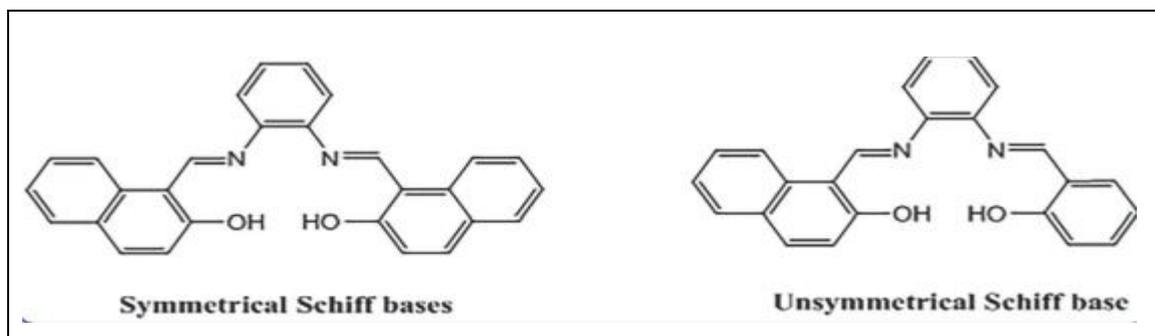


Figure 17. Symmetrical and asymmetrical salphen Schiff bases.

7.2 Homoleptic and heteroleptic metal complexes of Schiff bases

The major difference between homoleptic [46] and heteroleptic [47] complexes is that the homoleptic complexes have all the same ligands attached to a metal centre. In heteroleptic complexes, there is at least one different ligand attached to the metal centre in the complex (Figure 18).

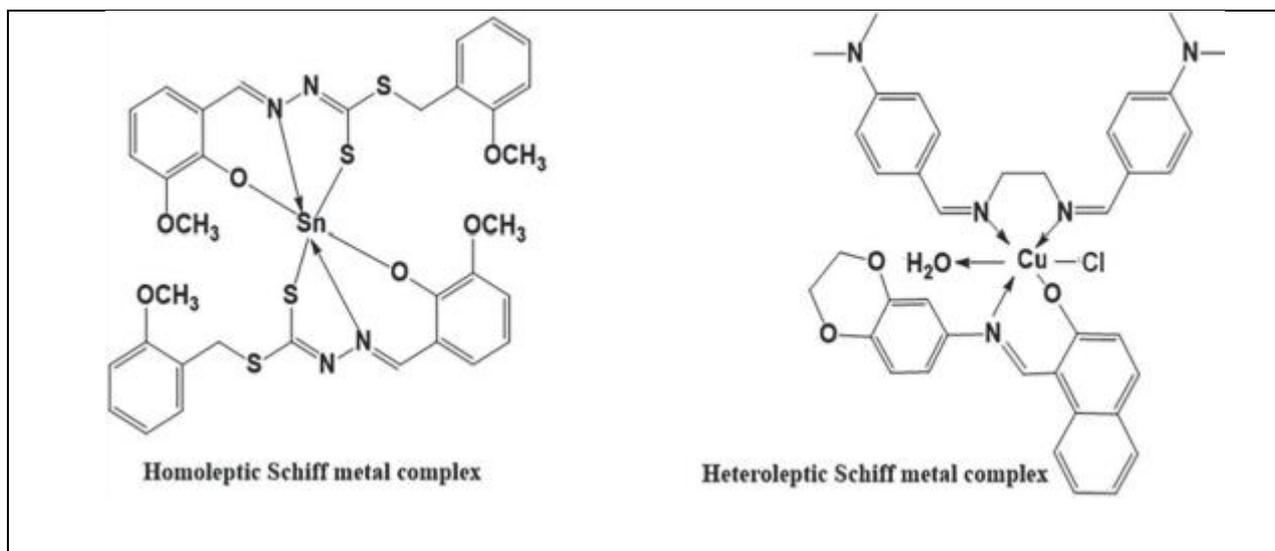


Figure 18. Metal complexes of Schiff bases, homoleptic and heteroleptic.

7.3 Mononuclear and polynuclear Schiff base metal complexes [48], [49].

The simplest form of Schiff base metal complex is a single metal atom or ion, which is encircled by monodentate ligands, bidentate ligands, tridentate ligands, and polydentate ligands. The presence of two or more coordinated metal, or ion, atoms within a mono-coordination sphere is what are referred to as a Polynuclear Schiff base metal complex. The two atoms can either be directly bonded by direct metal-metal bonds between ligands, or all these. Schiff bases are versatile ligands that form a variety of polynuclear metal complexes, both homonuclear and heteronuclear. These versatile ligands can be monodentate, bidentate, or polydentate, and can be designed to give mononuclear, dinuclear, or polynuclear metal-organic structures. Nuclearity of Schiff base complexes can be modified; that is, both mono- and dinuclear complexes could be synthesized with almost the same ligands and synthetic procedures to produce both forms of complexes (Figure 19)

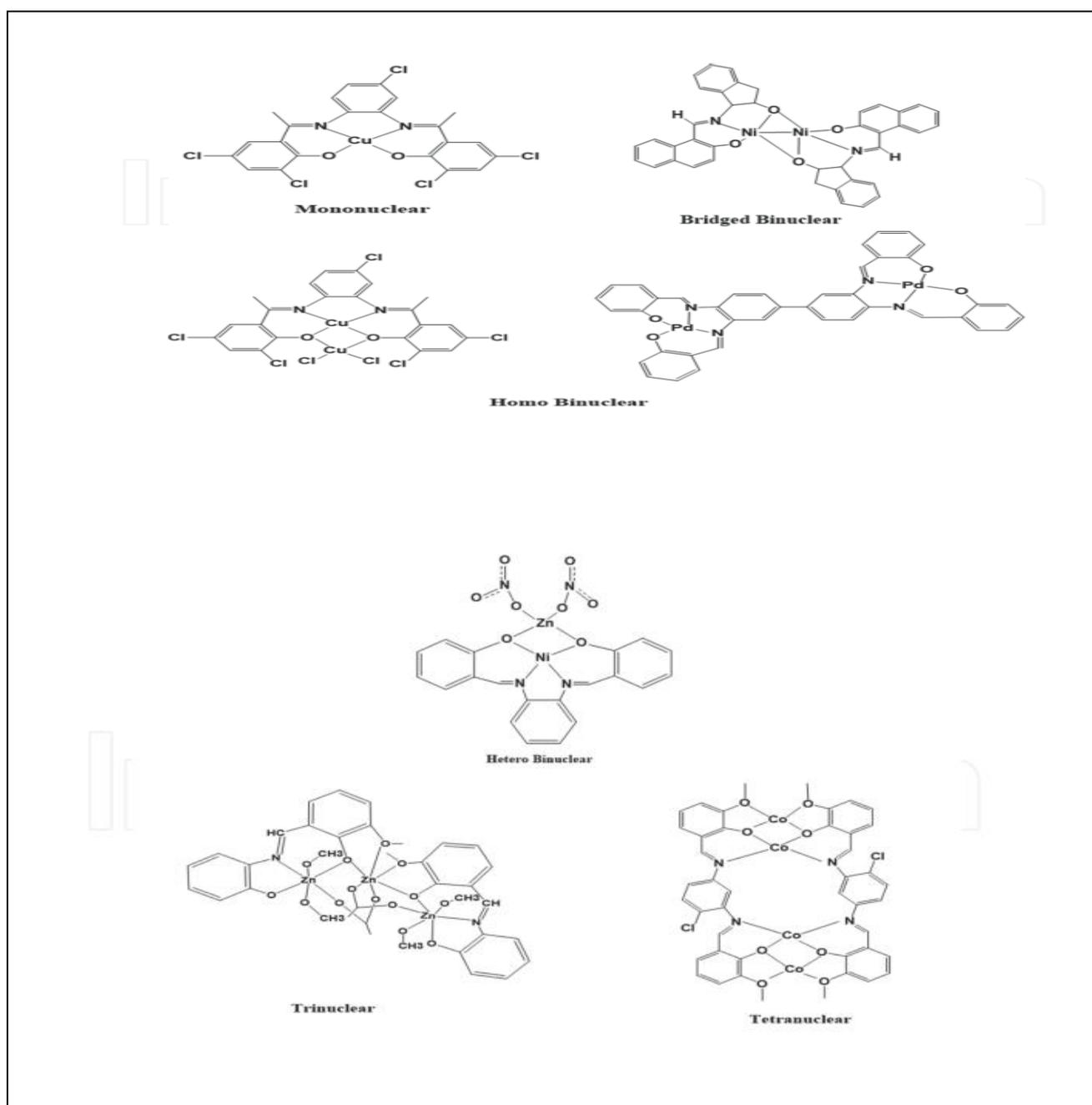


Figure 19. Mononuclear and polynuclear Schiff base metal complexes.

7.4 Achiral and chiral Schiff base metal complexes [50], [51].

A metal complex of chiral Schiff bases cannot be overlapped with its mirror at all since the two structures are not exactly the same in every aspect. The achiral Schiff base metal complex has a mirror image complex, which is the same as the complex. Optical activity phenomena have long been characterized by concepts of asymmetry and dissymmetry, but most recently, the concept of chirality has replaced the previous terms of asymmetry and dissymmetry. Chiral objects are two species that are chemically of the same constitution. The only difference that distinguishes them from the other is that they are the opposite arrangement of an object and the mirror reflection of that thing. The chemical compounds may be referred to as stereoisomers, provided that their chemical structures are identical, but their spatial orientations of atoms vary (Fig. 20). A chiral

molecule is the property of a molecule that cannot be coincident with mirror copies using rigid motions.

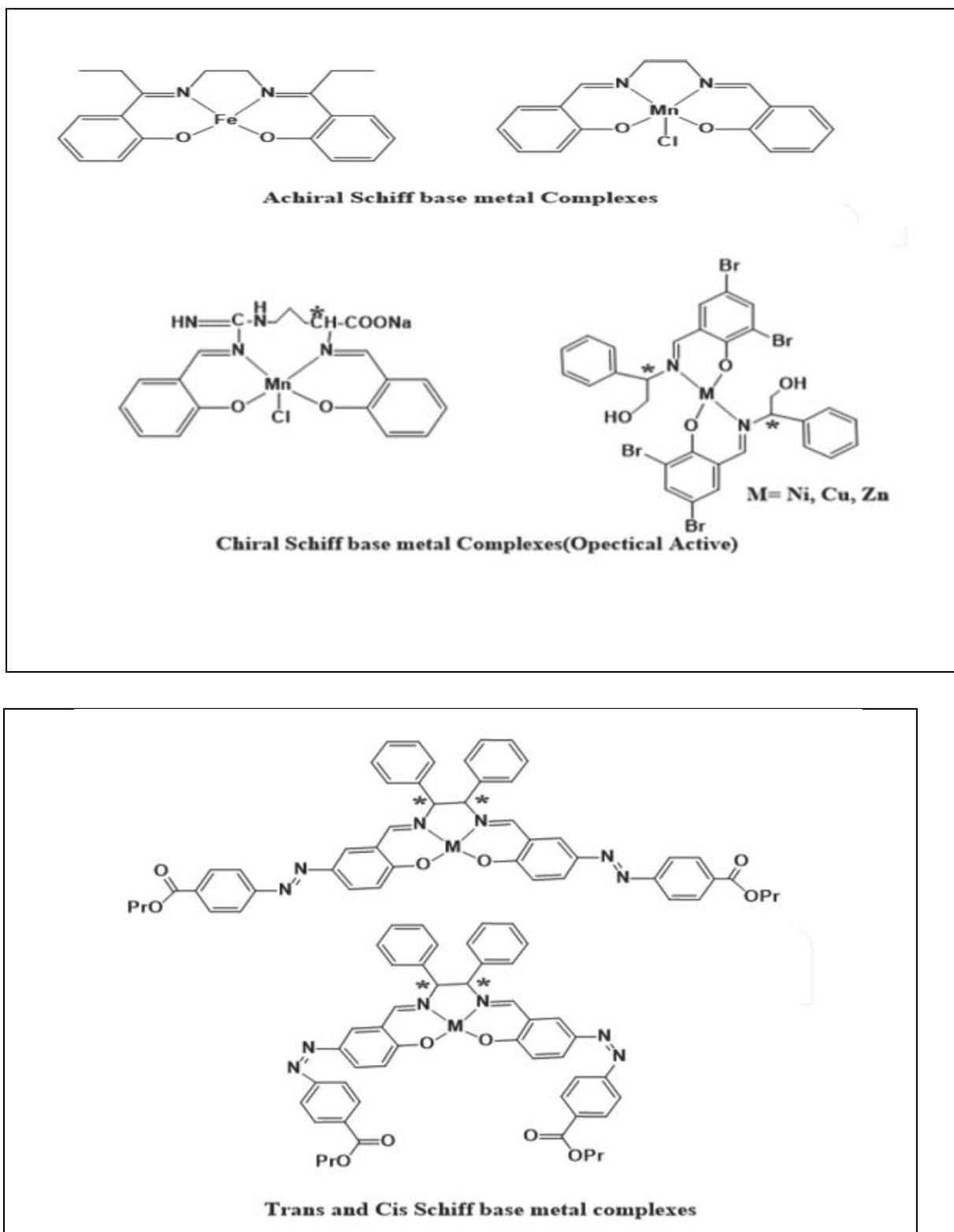


Figure 20. Achiral, chiral, Trans and cis Schiff base metal complexes.

8. Uses of Schiff Rules

8.1 Catalyst motivating factors:

The reaction was catalyzed with some of the following Schiff bases and their complexes: ruthenium complex - Schiff base. Another catalytic factor is the three-dentate Schiff base that is significant in organic-life reactions and binds the amino acids with the Schiff bases, thereby creating significant active sites [52].

8.2 Photochemical reactions:

In organometallic chemistry, Schiff rules and the complexes are significant and broad since they are readily made, and they can produce several stereoscopic or electronic effects in the products of the complexes [53]. The products can also be varied and serve as catalysts, particularly in case these rules are applied to the complexation of ruthenium [54].

8.3 In medicine and biotechnology, Bio-technology and NH [55].

8.4 Pharmaceutical and pharmaceutical industries. It ranks among the most significant drugs possessing anti-cancer, anti-fungal, and anti-bacterial effects [56].

8.5 Environmental Chemistry:

To estimate organic matter pollutants in water. The rules of Schiff are important in the area of analytical chemistry in voltammetric, potential, and reversal voltammetric experiments, in the determination of the value of kinetic coefficients, including the rate constant of the reaction, and the energy of activation of the reaction, and in the domain of chemistry. They have industrially been considered as stabilizers and plasticizers of polymers, initiators of the polymerization process, and these bases have been considered as antioxidants. There are also copper complexes with certain Schiff bases that have been employed in printing ink and dyes. It is also applied in the resistance to metal corrosion. They have been used in numerous other areas due to their high significance because it has been viewed that these bases are the foundation article in the manufacturing of most polymers whose molecular weight is high. These bases are also applicable in the construction of heterocyclic compounds and complexes of coordination of these rings [57].

9. Medical Uses of Schiff Rules

9.1 Antimicrobial activity of Schiff bases:

The more recent studies, such as those conducted by Hassan et al., have focused on the production of Schiff bases using the derivatives of 5-amine-pyrazole-4-carboxamide and have tested the antimicrobial activity of the compounds. The paper has discovered that some of these compounds showed high inhibitory activities towards multidrug-resistant bacteria. Certain Schiff base derivatives were more active than ciprofloxacin in the confrontation with *Staphylococcus epidermidis*, whereas several of them demonstrated an equivalent activity in the confrontation against *Enterococcus faecalis*, which is a predominant Gram-positive pathogen. In addition, the chosen compounds were active against the Gram-negative bacterium, *Acinetobacter baumannii*, with minimum inhibitory concentrations comparable to ciprofloxacin. Besides biological

assays, *in silico* ADMET profiling and molecular docking fully supported the idea that one of the molecules synthesized has a strong binding and inhibitory activity against key bacterial enzymes such as DNA gyrase and dihydrofolate reductase, which is one of the reasons why this molecule could be considered as a therapeutic candidate.

9.2 Schiff base as cancer therapeutic agents:

Cancer is a significant health issue in the world that is characterized by great morbidity and deadly outcomes and requires the creation of more efficient therapeutic agents. The lack of efficacy of current chemotherapeutic drugs is frequently due to resistance to them, so the discovery of novel compounds is necessary. Attention has been drawn to the Schiff bases and their metal complexes, since most of them inhibit vital biochemical pathways that are needed to keep cancer cells alive. Therapeutic intervention on cellular energy production is one of the significant methods. Some derivatives of Schiff bases may interfere with the mitochondrial complex I (NADH: ubiquinone oxidoreductase), which is an important enzyme in the electron transport chain. The inhibition of this enzyme lowers mitochondrial respiration, impairs proton-motive force, retards the tricarboxylic acid cycle, and ultimately leads to a reduction in ATP synthesis in the cell. Cancer cell proliferation is inhibited by such interference. It is because of these properties that Schiff bases form an attractive platform to develop selective, less toxic anticancer agents that are capable of inhibiting the metabolism of tumor cells as well as circumventing drug resistance mechanisms.

10. Utilization of Schiff bases and complexes

Metal complexes of Schiff bases are useful in a wide variety of fields of science and industry. Their capacity to coordinate metals, be biologically active, and have reversible chemical reactions renders them very useful in the fields of food technology, agrochemicals, analytical chemistry, catalysis, energy systems, sensing technology, nanoscience, and biomedical innovation.

10.1 Food industry:

Recent studies have paid much attention to the creation of new food-packaging materials that is eco-friendly. Movies that are made by chitosan, which is modified by forming Schiff bases, have exhibited great antimicrobial properties that can be used to improve the shelf life of the product and, at the same time, ensure that the movie maintains the required quality of flavors. Also, zirconium-based Schiff base composite polylactic acid (PLA) films have better barrier properties and antifungal properties. These materials can be used as good alternatives to traditional synthetic packaging, which, in most cases, causes environmental pollution.

10.2 Agrochemical industry:

The Schiff base ligands and the metal complex have also gained significant interest in agriculture, especially as pesticides, insect deterring agents, and nematocides. Other compounds that exhibit significant insecticidal properties with high application levels include glyoxal-salicylaldehyde derivatives. Coumarin-derived Schiff bases and complexed with rare-earth metals have also been demonstrated to be effective against

agricultural pests such as *Tribolium castaneum* and plant-damaging nematodes such as *Meloidogyne incognita*. These results indicate that they would be suitable as other environmentally-friendly anti-crop-protection agents.

10.3 Analytical applications:

Schiff bases have become popular as analytical reagents because of their great binding capacity to metal ions and their alteration of spectroscopic performances. They can be used as convenient probes to identify the primary amines, carbonyls, and metal ions. Their azomethine groups engage in the process of complex formation that results in quantifiable shifts in color, fluorescence, or absorbance. As an example, the successful applicability of *N,N*-bis(3-methylsalicylidene)-*o*-phenylenediamine has been done in the detection of nickel in food samples using spectrophotometry. Similarly, fluorescent sensors based on Schiff-base have been constructed to detect Cu^{2+} ions and other metals in solvents and at different PH conditions. Salicylaldehyde-based bases are used in the gravimetric and spectrophotometric analyses. Moreover, the same reagent was used in the recent past to detect Ni (II) at trace levels spectrophotometrically. The presence of Cu^{2+} ions has been determined with the fluorescent 4-(1-phenyl-1-methylcyclobutane-3-yl)-2-(2-hydroxy bromobenzylidene) - aminothiazole Schiff base. This is a chemical sensor that functions in the visible region, with a large dynamic range, and can be utilized in a broad pH range [68].

10.4 Energy storage:

Advanced storage technologies have become of interest due to the growing energy demand in the world and a shift towards renewable systems. Electroactive Organic oligomeric Schiff bases, as well as polymeric Schiff-base materials, have been promising as anode materials in sodium-ion batteries. In the same way, nitrogen-based porous carbon-based materials synthesized by Schiff-base chemistry have also been examined as a high-performance anode of a lithium-ion battery system. They have a tunable structure and are highly stable and good redoxers that qualify as the next generation energy devices.

10.5 Environmental Applications:

It has also been found in various water, soil, and plants. Cigarettes, beers, oils, and supplements are some of the products that require metals monitoring and quality control [72]. Metal corrosion has an enormous effect on the national economy and poses important safety and pollution problems despite the good-inhibitory properties of many of these compounds. They too cannot be used in environmental protection and sustainable development programs due to several reasons (because they are difficult to degrade, toxic, or have a high temperature). The future of inhibitors is to have stable, efficient, and ecologically friendly inhibitors. Most of the inhibitors, such as imidazolines, Mannich bases, and Schiff bases, include heteroatoms (N, S, O) or electron π -bond interactions. The heteroatoms of N, O, and S and the unsaturated $>\text{C}=\text{N}$ - bonds have the ability to form powerful and stable corrosion-inhibitory adsorption layers on metal surfaces, which prove excellent inhibitory properties. Simultaneously, Schiff base

compounds are appealing to researchers because of their low price, low cost of preparation and purification, high water solubility, as well as low toxicity [73].

10.6 Chemo-sensing applications:

Schiff base-based fluorescent probe structures have found extensive application in the detection of dangerous ions and molecules in chemical and biological settings. Their multi-donor nitrogen-oxygen structure allows them to bind to metal ions with a high affinity, resulting in quantifiable optical characteristics. Schiff-base sensors have been constructed in recent years to selectively detect ions, including Co^{2+} , Cu^{2+} , Zn^{2+} , Hg^{2+} , Ag^{+} , and Al^{3+} , and also reactive species, including ClO^- . These sensors can effectively be used in live-cell imaging and include large colorimetric shifts that can be used to follow in real time.

10.7 Bio-sensing applications:

Biomedical diagnostics have also been implemented using the Schiff-base-derived sensing systems. They have also been used in optical sensors to detect biomarkers such as hydrogen peroxide, glucose, and cancer-related antigen CA-125. Remarkable sensitivities of CA-125 in clinical samples can be achieved with gold nanoparticle-doped Schiff base sol-gel matrices, such as. Other researchers have shown Schiff base complexes of cerium (III)-isatin derivatives as potent spectrofluorometric assays for the measurement of creatinine with high selectivity and with extremely low detection limits.

10.8 Biomedical applications:

Schiff base metal complexes have a very wide range of biological and pharmacological actions. These are the antimicrobial, antiviral, anti-inflammatory, anti-convulsant, anti-oxidant, antimalarial, anticancer, and enzyme-inhibitory effects. The azomethine nitrogen is an important site for coordinating the necessary metal ions in the biological environment, which allows interaction with proteins, enzymes, and nucleic acids. Studies have indicated that Schiff base complexes have the ability to inhibit the growth of microbes, aid in the cleavage of DNA, aid in the process of drug-delivery, and aid in tissue regeneration. They remain versatile, and this has facilitated the continued production of new therapeutic agents.

CONCLUSION

Fundamental Finding : The primary discovery is that Schiff bases, with their highly versatile chemical and physical properties, are stable in various media, particularly under acidic conditions. The reaction mechanisms and synthesis routes have been optimized for higher yields, and Schiff bases' ability to bind with metal ions enhances their applicability across numerous fields such as catalysis, pharmaceuticals, and environmental science. The physical characteristics such as their stability, the ability to form isomers, and their reactivity in metal coordination further support their wide range of uses. **Implication :** The findings suggest that Schiff bases could be further explored in diverse applications, particularly in the development of new therapeutic agents, environmentally friendly materials, and effective analytical reagents. Their antimicrobial and anticancer properties are of particular importance for addressing ongoing global

health challenges, such as drug resistance and the need for more efficient cancer treatments. In industry, Schiff bases could be utilized to create more sustainable materials for food packaging, agricultural chemicals, and energy storage solutions. Additionally, the innovative synthesis methods, including green chemistry approaches using natural catalysts, align with growing demands for more eco-friendly chemical processes.

Limitation : Despite the promising results, Schiff bases' sensitivity to hydrolysis and the reversibility of their formation reactions pose challenges in their large-scale synthesis and stability under certain conditions. Further research is needed to refine the synthesis methods and overcome the issue of instability in certain media. Additionally, the challenge of isolating pure Schiff bases due to their tendency to form tautomers and the difficulty in separating isomers needs more focus, especially for industrial applications that demand high purity and consistency.

Future Research : Future studies should focus on optimizing the synthesis processes to enhance yields while maintaining the stability of Schiff bases under various conditions. Exploring the environmental impact and efficiency of green synthesis methods, such as using natural catalysts, should also be a priority. Furthermore, more in-depth research into the biocompatibility and toxicity of Schiff base derivatives will be crucial for their safe application in medical and pharmaceutical industries. Advancing the understanding of Schiff base-metal complexes, particularly their role in biomedical applications, holds great potential for the development of novel therapeutic agents. Finally, exploring the use of Schiff bases in emerging technologies like bio-sensing, energy storage, and environmental monitoring could unlock new avenues for their application in modern science and industry.

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